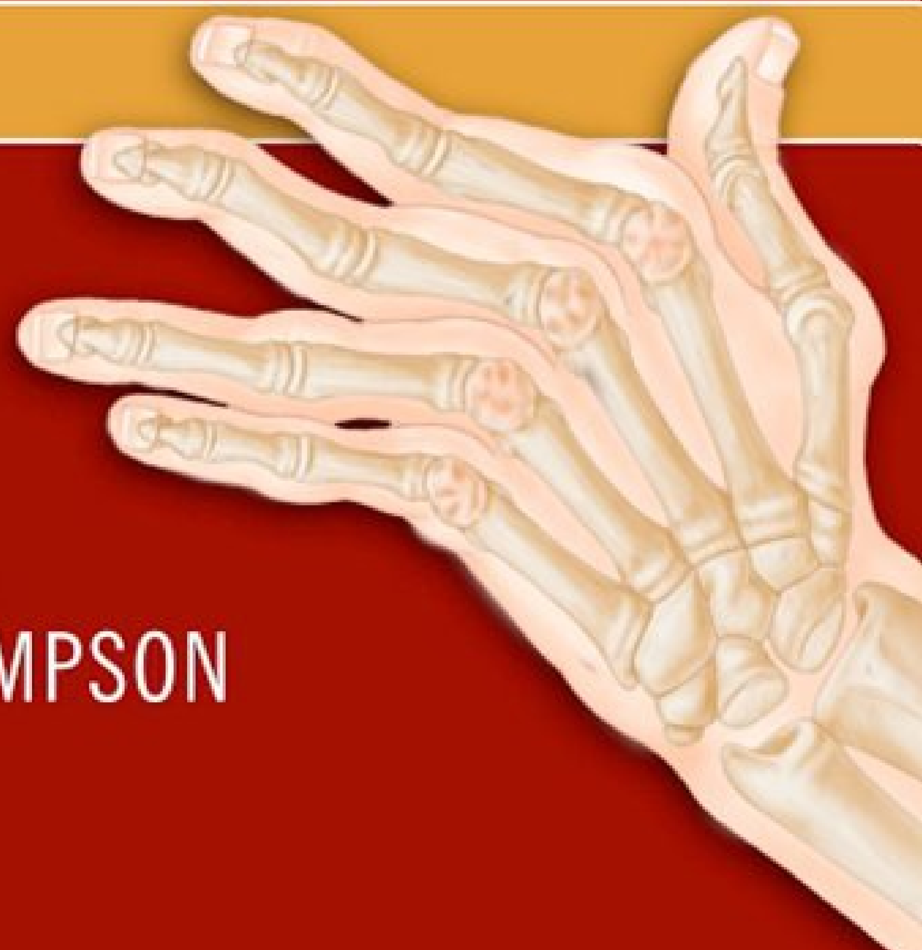
MILLER'S REVIEW OF
ORTHOPAEDICS

EIGHTH EDITION



MARK D. MILLER
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EIGHTH EDITION

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Dedication

To the generation of orthopaedic surgeons that I have had the honor to teach. For as long as I am able, I will continue to answer your questions, give my opinions, and share my experiences. The collective and collegial commitment to lifelong learning is both admirable and inspirational.

Mark D. Miller

For Linden, Harper, and Shannon. Because, Linden, you deserve to be first this time!

Stephen R. Thompson

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Preface

We are both humbled and honored to present the eighth edition of *Miller's Review of Orthopaedics*. Very few textbooks make it to an eighth edition, and for those that do, there are even fewer for which the senior editor is still contributing, or even still on this Earth. For that, and for the help of my friend and colleague, Steve Thompson, MD, I am very grateful.

So what is new for this edition of one of the most popular orthopaedic textbooks in history? The answer lies in the very concept of this book—we tried to get even closer to the bottom line. We completely reworked several chapters and put the unwieldy basic science chapter on a crash diet in furthering our efforts with each edition to find the most concise approach to content. We added several new composite figures that show multiple key testable concepts all in one image. We renewed our "war on typos" and hopefully advanced the battle lines at a very minimum. For those of you who have personally emailed us or stopped us at meetings all across the world, we are indebted to your contributions in this fight! We also began the "battle of the purge" across all the chapters, seeking to condense the material as much as is practical.

Thank you for purchasing this textbook. We are well aware of the millennial push to have everything digital and free. Nonetheless, we still see value in having an actual book to put on one's professional shelf and to circle, highlight, and reference as experiences and pursuit of knowledge dictates. And, for those who are going completely paperless, there is still an electronic version that will allow you to access the book in an interactive fashion.

As always, we remain indebted to our incredible team of authors, who have devoted a tremendous amount of time and effort in updating their respective chapters. We also want to acknowledge the efforts of the editorial and professional staff at Elsevier, including Laura Schmidt, Victoria Heim, and Kristine Jones.

Finally, this book would not be possible without you, the reader. Thank you for allowing us to help you prepare for your career in musculoskeletal medicine, whatever path it may travel!

Mark D. Miller

Stephen R. Thompson

CHAPTER 1

Basic Sciences

Jeremy K. Rush, Dustin Lybeck, Jessica Rivera, and Matthew R. Schmitz

Section 1 Orthopaedic Tissues

Bone

- **Histologic features of bone**
  - Types (Fig. 1.1; Table 1.1)
    - Normal bone: lamellar or mature
    - Immature and pathologic bone: woven, more random, more osteocytes, increased turnover, weaker
      - Lamellar bone is stress oriented; woven bone is not.
    - Cortical (compact) bone
      - Constitutes 80% of the skeleton
      - Consists of tightly packed osteons or haversian systems
        - Connected by haversian (or Volkmann) canals
        - Contains arterioles, venules, capillaries, nerves, possibly lymphatic channels
      - Interstitial lamellae: between osteons
        - Fibrils connect lamellae but do not cross cement lines.
        - Cement lines define the outer border of an osteon.
      - Nutrition provided by intraosseous circulation through canals and canaliculi (cell processes of osteocytes)
      - Characterized by slow turnover rate, higher Young's modulus of elasticity, more stiffness
    - Cancellous bone (spongy or trabecular bone)
      - Less dense, more remodeling according to lines of stress (Wolff's law)
      - Characterized by high turnover rate, smaller Young's modulus, more elasticity
  - Cellular biology (Fig. 1.2)
    - Osteoblasts
      - Appear as cuboid cells aligned in layers along immature osteoid
      - Are derived from undifferentiated mesenchymal stem cells
        - These stem cells line haversian canals, endosteum, and periosteum.

    - Become osteoblasts under conditions of low strain and increased oxygen tension
        - **Transcription factor RUNX2 and bone morphogenetic protein (BMP) direct mesenchymal cells to the osteoblast lineage.**
        - Core-binding factor α-1 and β-catenin also stimulate differentiation into osteoblast
    - Become cartilage under conditions of intermediate strain and low oxygen tension
    - Become fibrous tissue under conditions of high strain
- Have more endoplasmic reticulum, Golgi apparatus, and mitochondria than do other cells (for synthesis and secretion of matrix)
- Bone surfaces lined by more differentiated, metabolically active cells
- Entrapped cells: less active cells in resting regions; maintain the ionic milieu of bone
    - Disruption of the active lining cell layer activates entrapped cells.
- **Receptor-effector interactions in osteoblasts are summarized in Table 1.2**.
- Osteoblasts produce the following:
    - Alkaline phosphatase
    - **Osteocalcin** (stimulated by 1,25dihydroxyvitamin D [1,25$(OH)_2D_3$])
    - Type I collagen
    - Bone sialoprotein
    - Receptor activator of nuclear factor (NF)-κβ ligand (RANKL)
        - Osteoprotegerin—binds RANKL to limit its activity
- Osteoblast activity stimulated by intermittent

(pulsatile) exposure to parathyroid hormone (PTH)

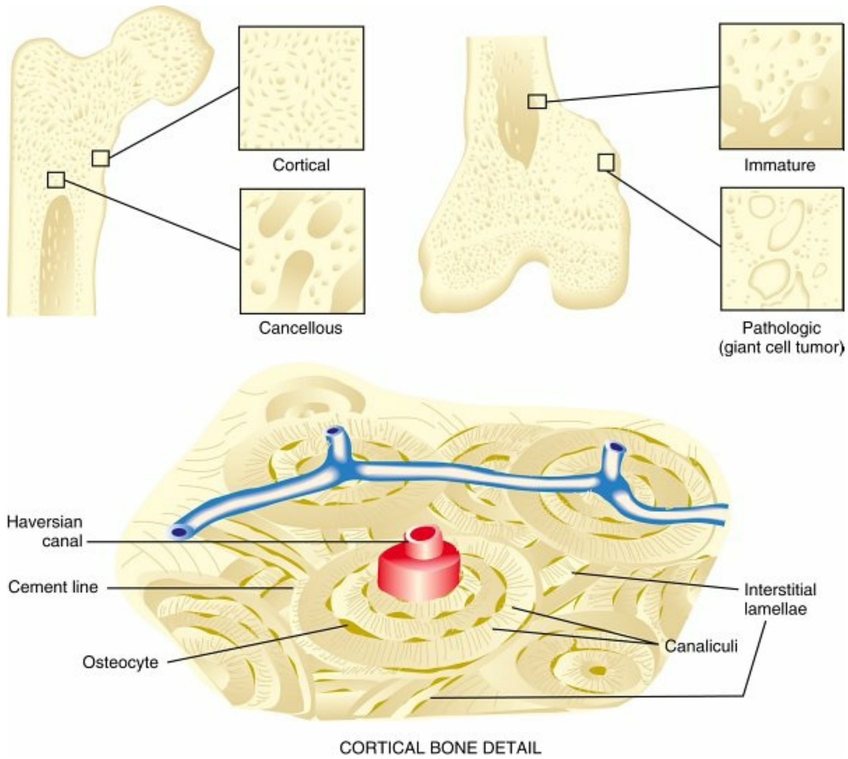


FIG. 1.1 Types of bone. Cortical bone consists of tightly packed osteons. Cancellous bone consists of a meshwork of trabeculae. In immature bone, unmineralized osteoid lines the immature trabeculae. Pathologic bone is characterized by atypical osteoblasts and architectural disorganization. Colorized from Brinker MR, Miller MD: *Fundamentals of orthopaedics,* Philadelphia, 1999, Saunders, p 2.

Table 1.1

Types of Bone

Microscopic Appearance	Subtypes	Characteristics	Examples
Lamellar	Cortical	Structure is oriented along lines of stress Strong	Femoral shaft
	Cancellous	More elastic than cortical bone	Distal femoral metaphysis
Woven	Immature	Not stress oriented	Embryonic skeleton Fracture callus
	Pathologic	Random organization Increased turnover Weak Flexible	Osteogenic sarcoma Fibrous dysplasia

Modified from Brinker MR, Miller MD: *Fundamentals of orthopaedics*, Philadelphia, 1999, Saunders, p 1.

- Osteoblast activity inhibited by TNF-α
- Wnts are proteins that promote osteoblast survival and proliferation.
  - Deficient Wnt causes osteopenia; excessive Wnt expression causes high bone mass.
  - **Wnts can be sequestered by other secreted molecules such as sclerostin (Scl) and Dickkopf-related protein 1 (Dkk-1)**.
    - Inhibiting sclerostin or Dkk-1 will lead to increased bone mass

- Osteocytes (see Fig. 1.1)
  - Maintain bone
  - Constitute 90% of the cells in the mature skeleton
  - Former osteoblasts surrounded by newly formed matrix
  - High nucleus/cytoplasm ratio
  - Long interconnecting cytoplasmic processes projecting through the canaliculi

- Less active in matrix production than osteoblasts
- Important for control of extracellular calcium and phosphorus concentration

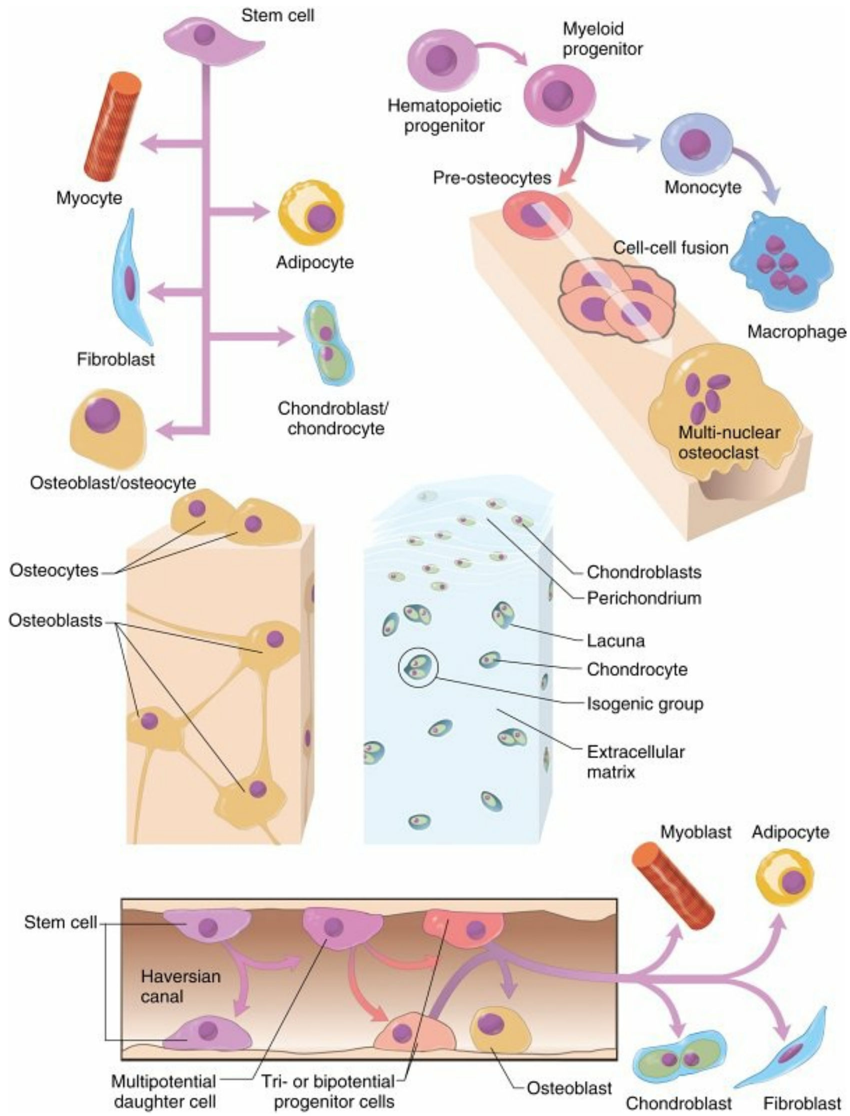


FIG. 1.2 Cellular origins of bone and cartilage cells.

Table 1.2

Bone Cell Types, Receptor Types, and Effects

Cell Type	Receptor	Effect
Osteoblast	PTH	Releases a secondary messenger (exact mechanism unknown) to stimulate osteoclastic activity Activates adenylyl cyclase
	$1,25(OH)_2$ vitamin D_3	Stimulates matrix and alkaline phosphatase synthesis and production of bone-specific proteins (e.g., osteocalcin)
	Glucocorticoids	Inhibits DNA synthesis, collagen production, and osteoblast protein synthesis
	Prostaglandins	Activates adenylyl cyclase and stimulates bone resorption
	Estrogen	Has anabolic (bone production) and anticatabolic (prevents bone resorption) properties Increases mRNA levels for alkaline phosphatase Inhibits activation of adenylyl cyclase
Osteoclast	Calcitonin	Inhibits osteoclast function (inhibits bone resorption)

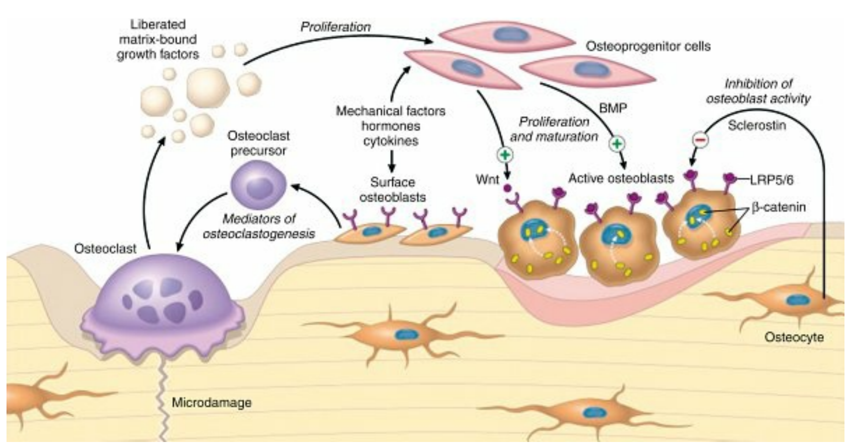


FIG. 1.3 Paracrine crosstalk between osteoblasts and osteoclasts.
From Kumar V et al, editors: Bones, joints, and soft tissue tumors. In *Robbins and Cotran pathologic basis of disease*, ed 9, Philadelphia, 2014, Saunders, Fig. 26-5.

- Directly stimulated by calcitonin, inhibited by PTH
- **Sclerostin secreted by osteocytes helps negative**

feedback on osteoblasts' bone deposition (Fig. 1.3).

- Differentially regulated according to mechanical loading, with decreased sclerostin in areas of concentrated strain
- Downregulation is associated with increased bone formation (via sclerostin antibody).
- Potential for use in fracture healing, bone loss, osseous integration of implants, and genetic bone diseases via upregulation of sclerostin

- Osteoclasts
  - Multinucleated irregular giant cells
  - **Derived from hematopoietic cells in macrophage lineage**
  - Monocyte progenitors form giant cells by fusion
  - Function
    - Bone resorption
      - **Bone formation and resorption are linked**
      - **Stimulated primarily by RANKL binding to RANK receptor on cell surface**
      - **Osteoblasts (and tumor cells) express RANKL (Fig. 1.4):**
        - **Binds to receptors on osteoclasts**
        - **Stimulates differentiation into mature osteoclasts**
        - **Inhibited by osteoprotegerin (OPG) binding to RANKL**
      - Occurs both normally and in certain conditions, including multiple myeloma and metastatic bone disease

- **Denosumab is a monoclonal antibody that targets and inhibits RANKL binding to the RANK receptor**

- Resorption mechanism
  - Osteoclasts possess a ruffled (brush) border and surrounding clear zone
    - Border consists of plasma membrane enfoldings that increase surface area
    - **Bind to bone surfaces through cell attachment (anchoring) proteins**
      - Integrin ($\alpha_v\beta_3$ or vitronectin receptor)
    - Bone resorption occurs in depressions: Howship lacunae.
      - Effectively seal the space below the osteoclast
      - Synthesize tartrate-resistant acid phosphate
      - Produce hydrogen ions through carbonic anhydrase
      - Lower pH
      - Increase solubility of hydroxyapatite crystals
    - Organic matrix then removed by proteolytic digestion through activity of the lysosomal enzyme **cathepsin K**
- Signaling
  - Have calcitonin receptors, which inhibit osteoclastic resorption
  - Interleukin-1 (IL-1): potent stimulator

of osteoclast differentiation and bone resorption

- Found in membranes surrounding loose total joint implants

- In contrast, IL-10 suppresses osteoclasts.

□ Matrix (Table 1.3)

- Organic components: 40% of dry weight of bone
  - Collagen (90% of organic components)
    - **Primarily type I (mnemonic: *bone* contains the word *one*)**
      - Type I collagen provides tensile strength of bone
    - Hole zones (gaps) exist within the collagen fibril between the ends of molecules.
    - Pores exist between the sides of parallel molecules.
    - Mineral deposition (calcification) occurs within the hole zones and pores.

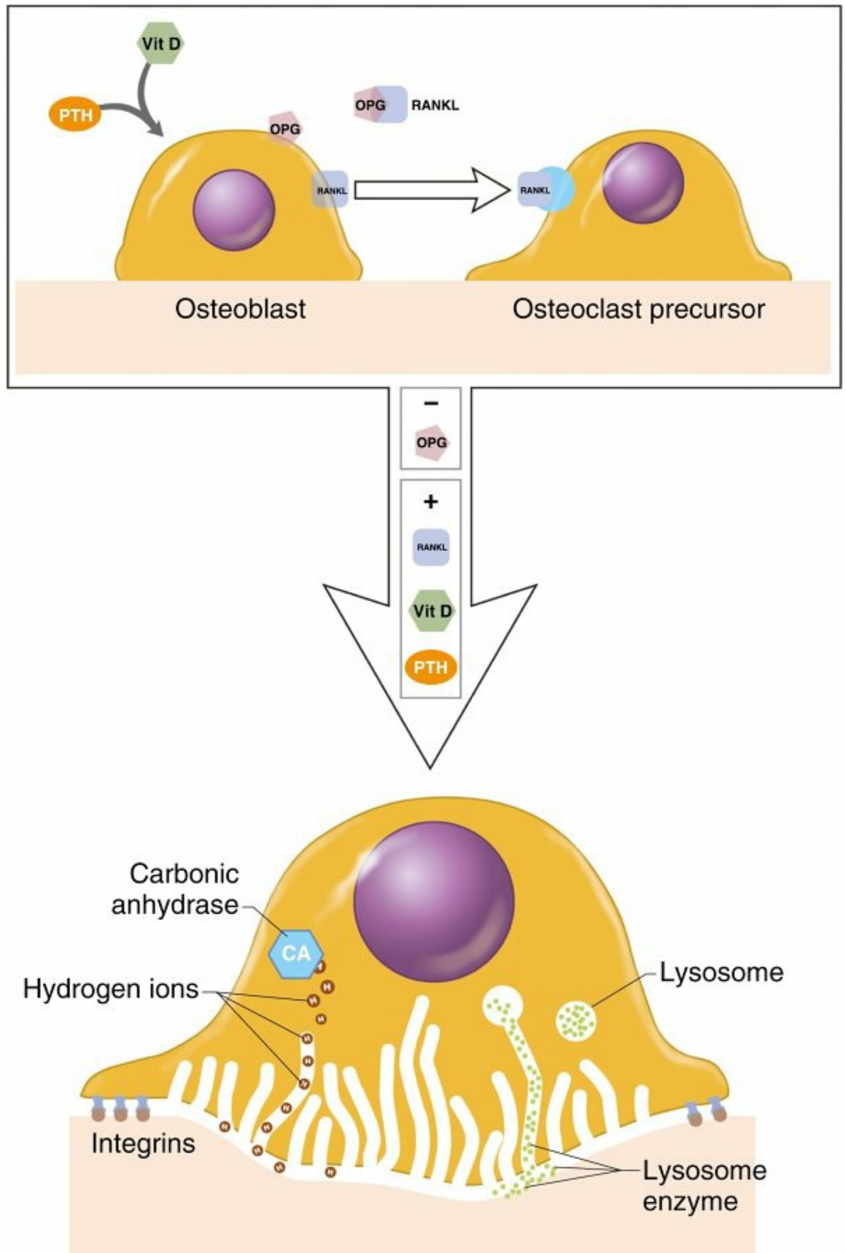


FIG. 1.4 Control and function of the osteoclast. *Vit,* vitamin.

- Cross-linking decreases collagen solubility and increases its tensile strength.
- Proteoglycans
- Matrix proteins (noncollagenous)
    - **Osteocalcin: most abundant noncollagenous protein in bone**
        - Inhibited by PTH and stimulated by $1,25(OH)_2D_3$
        - Can be measured in serum or urine as a marker of bone turnover
- Inorganic (mineral) components: 60%

of dry weight of bone

- **Calcium hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$]: provides compressive strength**
- Calcium phosphate (brushite)

□ Tissues surrounding bone

- Periosteum
  - Connective tissue membrane that covers bone
  - More highly developed in children
  - Inner periosteum, or cambium, is loose and vascular and contains cells capable of becoming osteoblasts.
    - These cells enlarge the diameter of bone during growth and form periosteal callus during fracture healing.
  - Outer (fibrous) periosteum is less cellular and is contiguous with joint capsules.
  - Bone marrow—source of progenitor cells; controls inner diameter of bone
    - Red marrow
      - Hematopoietic (40% water, 40% fat, 20% protein)
      - Slowly changes to yellow marrow with age, first in appendicular skeleton and later in axial skeleton
  - Yellow marrow
    - Inactive (15% water, 80% fat, 5% protein)

Table 1.3

Components of Bone Matrix

Type of Matrix	Function	Composition	Types	Notes
Organic Matrix				
Collagen	Provides tensile strength	Primarily type I collagen		Cor[illegible]

				Stru…
Proteoglycans	Partly responsible for compressive strength	Glycosaminoglycan-protein complexes		Inhibits…
Matrix proteins (noncollagenous)	Promote mineralization and bone formation		Osteocalcin (bone γ-carboxyglutamic acid–containing protein) Osteonectin (SPARC)	Attr… Secr…
			Osteopontin	Cell-bin… sim… inte…
Growth factors and cytokines	Aid in bone cell differentiation, activation, growth, and turnover		TGF-β IGF IL-1, IL-6 BMPs	Present… amo… mat…
Inorganic Matrix				
Calcium hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$]	Provides compressive strength			Most o… mat… min… colla… (hol… seco… min… peri…

Osteocalcium phosphate (brushite)				Makes rem inor

- Bone vascular supply
  - Bone receives 5%–10% of the cardiac output.
  - Bones with a tenuous blood supply include the scaphoid, talus, femoral head, and odontoid.
  - Hypoxia, hypercapnia, and sympathectomy increase flow.
  - Long bones receive blood from three sources (systems)
    - Nutrient artery system
      - Branch from systemic arteries, enter the diaphyseal cortex through the nutrient foramen, enter the medullary canal, and branch into ascending and descending arteries (Figs. 1.5 and 1.6)
      - Further branch into arterioles in the endosteal cortex, which enables blood supply to at least the inner two-thirds of the mature diaphyseal cortex via the haversian system (see Fig. 1.6)
      - BP in the nutrient artery system is high.
      - 60% of cortical bone vascularized by nutrient arteries

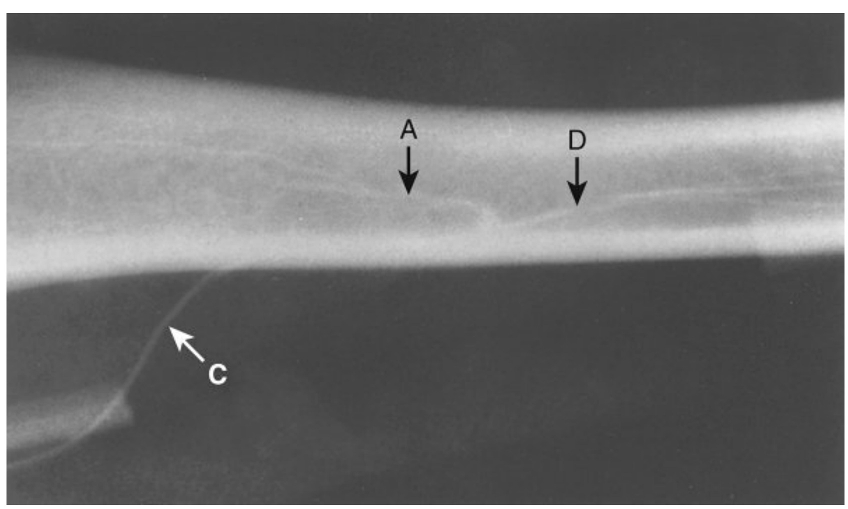


FIG. 1.5 Intraoperative arteriogram (canine tibia) demonstrating ascending *(A)* and descending *(D)* branches of the nutrient artery. *C*, Cannula.
From Brinker MR et al: Pharmacological regulation of the circulation of bone, *J Bone Joint Surg Am* 72:964–975, 1990.

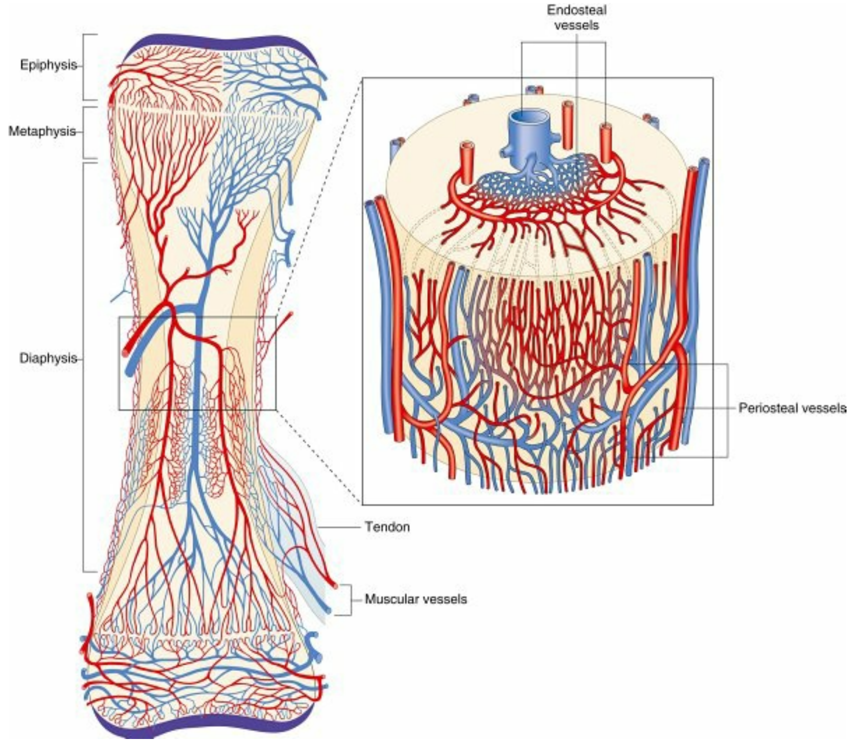


FIG. 1.6 Blood supply to bone.
From Standring S et al, editors: Functional anatomy of the musculoskeletal system. In *Gray's anatomy,* ed 40, London, 2008, Elsevier, Fig. 5-20.

- Metaphyseal-epiphyseal system
    - Arises from the periarticular vascular plexus (e.g., geniculate arteries)
- Periosteal system
    - Consists mostly of capillaries that supply the outer third (at most) of the mature diaphyseal cortex
    - BP in the periosteal system is low.
- Physiologic features
    - Direction of flow
        - Arterial flow in mature bone is centrifugal (inside to outside), which is the net effect of the high-pressure nutrient artery system and the low-pressure periosteal system.
        - When fracture disrupts the nutrient artery system, the periosteal system pressure predominates and blood flow is centripetal (outside to inside).
        - Flow in immature developing bone is centripetal because the highly vascularized periosteal system is the predominant component.
        - Venous flow in mature bone is

centripetal.
            - Cortical capillaries drain to venous sinusoids, which drain to the emissary venous system.
        - Regulation of bone blood flow
            - Influenced by metabolic, humoral, and autonomic inputs
            - Arterial system: great potential for vasoconstriction (from the resting state), less potential for vasodilation
            - Vessels within bone: have several vasoactive receptors (β-adrenergic, muscarinic, thromboxane/prostaglandin)
    - **Bone blood flow is the major determinant of how well a fracture heals**.
        - Initial response is a decrease in bone blood flow after vascular disruption at the fracture site.
        - Bone blood flow increases within hours to days (as part of the regional acceleratory phenomenon), peaks at approximately 2 weeks, and returns to normal in 3–5 months.
        - Unreamed intramedullary nails preserve endosteal blood supply.
        - Reaming devascularizes the inner 50%–80% of the cortex and delays revascularization of the endosteal blood supply.
- □ Types of bone formation (Table 1.4)
    - Enchondral
        - Examples:
            - Embryonic formation of long bones
            - Longitudinal growth (physis)
            - Fracture callus
        - Bone formed with demineralized bone matrix
        - Undifferentiated cells secrete cartilaginous matrix and differentiate into chondrocytes.
        - Matrix mineralizes and is invaded by vascular buds that bring osteoprogenitor cells.
        - Osteoclasts resorb calcified cartilage; osteoblasts form bone.
        - Bone replaces the cartilage model; cartilage is not converted to bone.
        - Embryonic formation of long bones (Figs. 1.7 and

1.8)

- These bones are formed from the mesenchymal anlage at 6 weeks' gestation.
- Vascular buds invade the mesenchymal model, bringing osteoprogenitor cells that differentiate into osteoblasts and form the primary ossification centers at 8 weeks.
- **Differentiation stimulated in part by binding of Wnt protein to the lipoprotein receptor–related protein 5 (LRP5) or LRP6 receptor**
- Marrow forms through resorption of the central cartilage anlage by invasion of myeloid precursor cells that are brought in by capillary buds.
- Secondary ossification centers develop at bone ends, forming the epiphyseal centers (growth plates) responsible for longitudinal growth.
- Arterial supply is rich during development, with an epiphyseal artery (terminates in the proliferative zone), metaphyseal arteries, nutrient arteries, and perichondrial arteries (Fig. 1.9).

- Physis
    - Two types of growth plates exist in immature long bones: (1) horizontal (the physis) and (2) spherical (growth of the epiphysis).
        - The spherical plate is less organized than the horizontal plate.
    - Perichondrial artery—major source of nutrition of growth plate
    - Delineation of physeal cartilage zones is based on growth (see Fig. 1.9) and function (Figs. 1.10 and 1.11).

Table 1.4

Types of Bone Formation

Type of Ossification	Mechanism	Examples of Norr Mechanisms
Enchondral	Bone replaces a cartilage model	Embryonic formation (long bones Longitudinal growth (physis) Fracture callus Bone formed with the us of demineraliz bone matri
Intramembranous	Aggregates of undifferentiated mesenchymal cells differentiate into osteoblasts, which form bone	Embryonic fla bone formation Bone formatio during distraction osteogenes Blastema bone
Appositional	Osteoblasts lay down new bone on existing bone	Periosteal bone enlargemer (width) The bone formation phase of bo remodeling

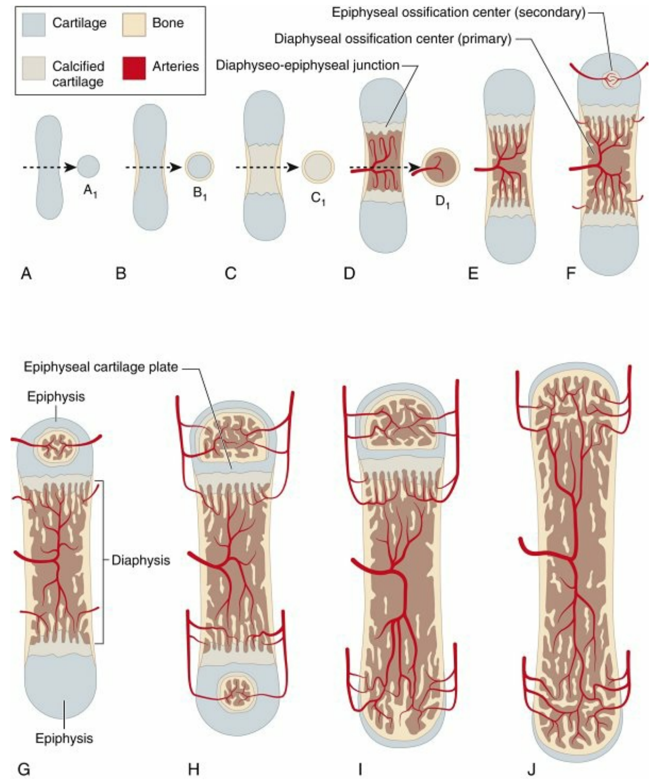


FIG. 1.7 Enchondral ossification of long bones. Note that phases F through J often occur after birth.
From Moore KL: *The developing human,* Philadelphia, 1982, Saunders, p 346.

- Reserve zone: cells store lipids, glycogen, and proteoglycan aggregates; decreased oxygen tension occurs in this zone.
    - Lysosomal storage diseases (e.g., Gaucher disease) can affect this zone.
- Proliferative zone: growth is longitudinal, with stacking of chondrocytes (the top cell is the dividing "mother" cell), cellular proliferation, and matrix production; increases in oxygen tension and proteoglycans inhibit calcification.
    - **Achondroplasia causes defects in this zone (see Fig. 1.11).**
    - **Growth hormone exerts its effect in the proliferative zone**.
- Hypertrophic zone:

- Divided into three zones: maturation, degeneration, and provisional calcification
- Normal matrix mineralization occurs in the lower hypertrophic zone: chondrocytes increase five times in size, accumulate calcium in their mitochondria, die, and release calcium from matrix vesicles.
- Chondrocyte maturation is regulated by systemic hormones and local growth factors (PTH-related peptide inhibits chondrocyte maturation; Indian hedgehog protein is produced by chondrocytes and regulates the expression of PTH-related peptide).
- Osteoblasts migrate from sinusoidal vessels and use cartilage as a scaffolding for bone formation.
- Low oxygen tension and decreased proteoglycan aggregates aid in this process.
- This zone widens in rickets (see Fig. 1.11), with little or no provisional calcification.

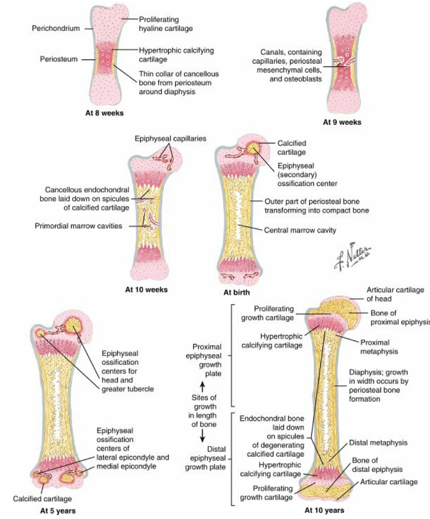


FIG. 1.8 Development of a typical long bone: formation of the growth plate and secondary centers of ossification. From Netter FH: *CIBA collection of medical illustrations,* vol 8: *Musculoskeletal system,* part I: *Anatomy, physiology and developmental disorders,* Basel, Switzerland, 1987, CIBA, p 136.

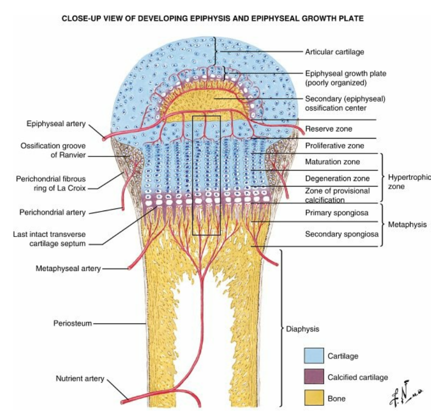


FIG. 1.9 Structure and blood supply of a typical growth plate. From Netter FH: *CIBA collection of medical illustrations,* vol 8*: Musculoskeletal system,* part I: *Anatomy, physiology and developmental disorders,* Basel, Switzerland, 1987, CIBA, p 166.

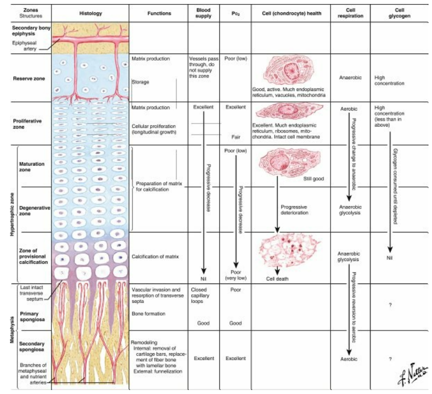


FIG. 1.10 Zone structure, function, and physiologic features of the growth plate. From Netter FH: *CIBA collection of medical illustrations,* vol 8*: Musculoskeletal system,* part I: *Anatomy, physiology and developmental disorders,* Basel, Switzerland, 1987, CIBA, p 164.

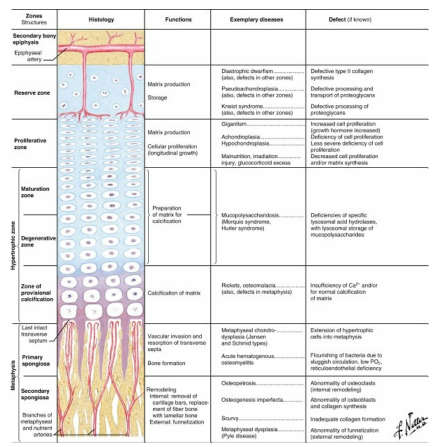


FIG. 1.11 Zone structure and pathologic defects of cellular metabolism. From Netter FH: *CIBA collection of medical illustrations,* vol 8*: Musculoskeletal system,* part I: *Anatomy, physiology and developmental disorders,* Basel, Switzerland, 1987, CIBA, p 165.

- Mucopolysaccharide diseases (see Fig. 1.11) affect this zone, leading to chondrocyte degeneration.
- **Physeal fractures**

probably traverse several zones, depending on the type of loading (Fig. 1.12).

- Slipped capital femoral epiphysis (SCFE) occurs here.
  - Except renal osteodystrophy (through metaphyseal spongiosa)

- Metaphysis
  - Adjacent to the physis and expands with skeletal growth
  - Osteoblasts from osteoprogenitor cells align on cartilage bars produced by physeal expansion.
  - Primary spongiosa (calcified cartilage bars) mineralizes to form woven bone and remodels to form secondary spongiosa and a "cutback zone" at the metaphysis.
  - **Groove of Ranvier**: supplies chondrocytes to the periphery for lateral growth (width)
  - Perichondrial ring of La Croix: dense fibrous tissue, primary membrane anchoring the periphery of the physis
- Intramembranous ossification
  - Occurs without a cartilage model
  - Undifferentiated mesenchymal cells aggregate into layers (or membranes), differentiate into osteoblasts, and deposit an organic matrix that mineralizes.
  - Examples:
    - Embryonic flat bone formation
    - Bone formation during distraction osteogenesis
    - Blastema bone (in young children with amputations)
- Appositional ossification
  - Osteoblasts align on the existing bone surface and

lay down new bone.
- Examples:
    - Periosteal bone enlargement (width)
    - Bone formation phase of bone remodeling

□ Bone remodeling
- General
    - Cortical bone and cancellous bone are continuously remodeled throughout life by osteoclastic and osteoblastic activity (Fig. 1.13).
    - **Wolff's law: remodeling occurs in response to mechanical stress**.
        - Increasing mechanical stress increases bone gain.
        - Removing external mechanical stress increases bone loss, which is reversible (to varying degrees) on remobilization.
        - Piezoelectric remodeling occurs in response to electric charge.
        - The compression side of bone is electronegative, stimulating osteoblasts (formation).
        - The tension side of bone is electropositive, stimulating osteoclasts (resorption).
    - **Hueter-Volkmann law**: remodeling occurs in small packets of cells known as *basic multicellular units (BMUs).*
        - Such remodeling is modulated by hormones and cytokines.

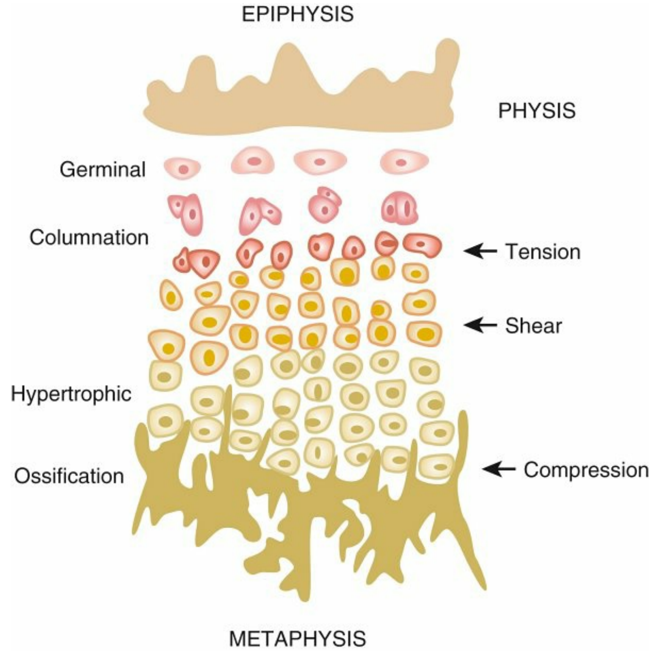


FIG. 1.12 Histologic zone of failure varies with the type of loading applied to a specimen.
From Moen CT, Pelker RR: Biomechanical and histological correlations in growth plate failure, *J Pediatr Orthop* 4:180–184, 1984.

- **Compressive forces inhibit growth; tension stimulates it**.
- Suggests that mechanical factors influence longitudinal growth, bone remodeling, and fracture repair
- May play a role in scoliosis and Blount disease

- Cortical bone remodeling
  - Osteoclastic tunneling (cutting cones; Fig. 1.14)
    - The head of the cutting cone is made up of osteoclasts followed by capillaries and osteoblasts.
    - Followed by layering of osteoblasts and successive deposition of layers of lamellae
- Cancellous bone remodeling
  - Osteoclastic resorption followed by deposition of

new bone by osteoblasts

- **Bone injury and repair**
  - Fracture repair (Table 1.5)
    - Stages of fracture repair
      - Inflammation
        - Fracture hematoma provides hematopoietic cells capable of secreting growth factors.
        - Subsequently, fibroblasts, mesenchymal cells, and osteoprogenitor cells form granulation tissue around the fracture ends.
        - Osteoblasts (from surrounding osteogenic precursor cells) and fibroblasts proliferate.
      - Repair
        - Primary callus response within 2 weeks
        - For bone ends not in continuity, bridging (soft) callus occurs.
          - Soft callus is later replaced through enchondral ossification by woven bone (hard callus).
          - Medullary callus supplements the bridging callus, forming more slowly and later.
        - Fracture healing varies with treatment method (Table 1.6).
          - In an unstable fracture, type II collagen is expressed early, followed by type I collagen.
          - Amount of callus is inversely proportional to extent of immobilization.
        - Progenitor cell differentiation
          - **High strain promotes**

            development of fibrous tissue.
         - **Low strain and high oxygen tension promote development of woven bone**.
         - **Intermediate strain and low oxygen tension promote development of cartilage**.
  - Remodeling
    - Remodeling begins in middle of repair phase and continues long after clinical healing (up to 7 years).
    - Allows bone to assume its normal configuration and shape according to stress exposure (Wolff's law)
    - Throughout, woven bone is replaced with lamellar bone.
    - Fracture healing is complete when the marrow space is repopulated.
- Biochemistry of fracture healing (Table 1.7)
  - Growth factors of bone (Table 1.8)
    - **BMP-2: acute open tibial fractures**
    - **BMP-3: no osteogenic activity**
    - **BMP-4: associated with fibrodysplasia ossificans progressiva**
    - **BMP-7: tibial nonunions**
    - BMPs activate intracellular signal molecules called SMADs to cause osteoblastic differentiation
  - Endocrine effects on fracture healing (Table 1.9)
    - Head injury
      - Can increase the osteogenic response to fracture
    - Nicotine (smoking)
      - Increases time to fracture healing
      - Increases risk of nonunion (particularly in the tibia)
      - Decreases strength of

fracture callus
  - Increases risk of pseudarthrosis after lumbar fusion by up to 500%
- Nonsteroidal antiinflammatory drugs
  - Have adverse effects on fracture healing and healing of lumbar spinal fusions
  - **Cyclooxygenase-2 (COX-2) activity is required for normal enchondral ossification during fracture healing.**
- Quinolone antibiotics
  - **Toxic to chondrocytes and inhibit fracture healing**
- Ultrasound and fracture healing
  - **Low-intensity pulsed ultrasound (30 mW/cm^2) accelerates fracture healing and increases the mechanical strength of callus**
  - A cellular response to the mechanical energy of ultrasound has been postulated.
- Effect of radiation on bone
  - High-dose irradiation causes long-term changes within the haversian system and decreases cellularity.
- Diet and fracture healing
- Protein malnutrition results in negative effects on fracture healing:
- Decreased periosteal and external callus
- Decreased callus strength and stiffness

- Increased fibrous tissue within callus
- **In experimental models, oral supplementation with essential amino acids improves bone mineral density in fracture callus**.

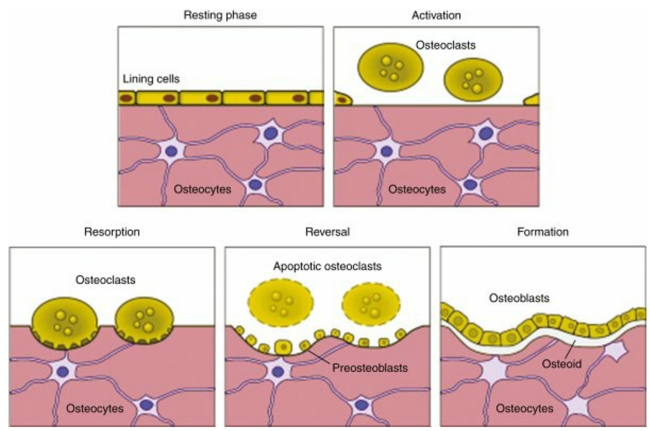


FIG. 1.13 Bone remodeling. Osteoclasts dissolve the mineral from the bone matrix. Osteoblasts produce new bone (osteoid) that fills in the resorption pit. Some osteoblasts are left within the bone matrix as osteocytes.
From Firestein GS et al, editors: *Kelley's textbook of rheumatology*, ed 8, Philadelphia, 2008, Saunders.

- Electricity and fracture healing
  - Definitions
    - Stress-generated potentials
      - Piezoelectric effect: tissue charges are displaced secondary to mechanical forces.
      - Streaming potentials: occur when electrically charged fluid is forced over a cell membrane that has a fixed charge

- Transmembrane potentials: generated by cellular metabolism

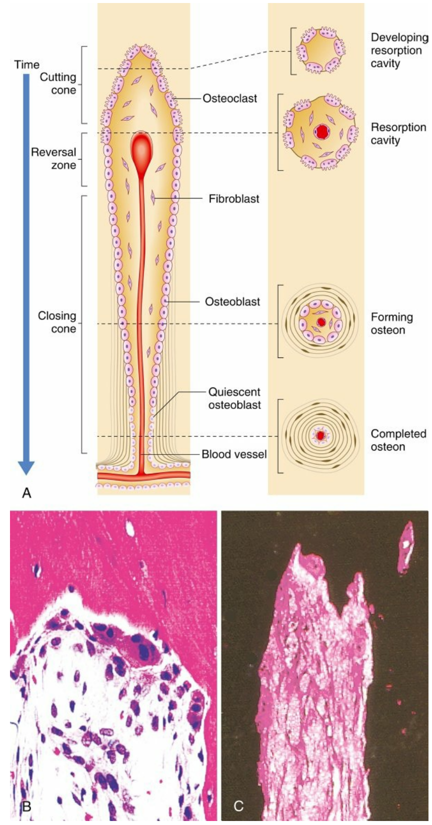


FIG. 1.14 Cortical bone remodeling. (A) Longitudinal and cross sections of a time line illustrating formation of an osteon. Osteoclasts cut a cylindrical channel through bone. Osteoblasts follow, laying down bone on the surface of the channel until matrix surrounds the central blood vessel of the newly formed osteon (closing cone of a new osteon). (B) Photomicrograph of a cutting cone. (C) Higher-magnification photomicrograph; osteoclastic resorption can be more clearly appreciated.

A from Standring S et al, editors: Functional anatomy of the musculoskeletal system. In *Gray's anatomy,* ed 40, London, 2008, Elsevier, Fig. 5-19.

Table 1.5

Biologic and Mechanical Factors Influencing Fracture Healing

Biologic factors	Patient age Comorbid medical conditions Functional level Nutritional status Nerve function Vascular injury Hormones Growth factors Health of the soft tissue envelope Sterility (in open fractures) Cigarette smoke Local pathologic conditions Level of energy imparted Type of bone affected Extent of bone loss
Mechanical factors	Soft tissue attachments to bone Stability (extent of immobilization) Anatomic location Level of energy imparted Extent of bone loss

Table 1.6

Type of Fracture Healing Based on Type of Stabilization

Type of Stabilization	Predominant Type of Healing
Cast (closed treatment)	**Periosteal bridging callus and interfragmentary enchondral ossification**
Compression plate	Primary cortical healin (cutting-cone type

	haversian remodeling)
Intramedullary nail	Early: periosteal bridging callus; enchondral ossification Late: medullary callus and intramembrano ossification
External fixator	Dependent on extent o rigidity: Less rigid: periosteal bridging callus; enchondral ossification More rigid: primary cortical healing; intramembranous ossification
Inadequate immobilization with adequate blood supply	Hypertrophic nonunio (failed enchondral ossification); type I collagen predominates
Inadequate immobilization without adequate blood supply	**Atrophic nonunion**
Inadequate reduction with displacement at the fracture site	Oligotrophic nonunion

- Types of electrical stimulation
    - Direct current: stimulates an inflammatory-like response, resulting in decreased oxygen concentrations and

increase in tissue pH (similar to effects of an implantable bone stimulator).
- Alternating current: “capacity-coupled generators”; affects cyclic AMP (cAMP) synthesis, collagen synthesis, and calcification during repair stage
- Pulsed electromagnetic fields (PEMFs): initiate calcification of fibrocartilage (but not fibrous tissue)

▪ **Bone grafting (** Table 1.10)
- ▫ Graft properties
  - **Osteoconductive matrix**: acts as a scaffold or framework for bone growth
  - **Osteoinductive factors**: growth factors (BMP) that stimulate bone formation
  - **Osteogenic cells:** primitive mesenchymal cells, osteoblasts, and osteocytes
  - Structural integrity
- ▫ Specific bone graft types
  - Cortical bone graft
    - Slower incorporation: remodels existing haversian systems through resorption (weakens the graft) and then deposits new bone (restores strength)
    - Resorption confined to osteon borders; interstitial lamellae are preserved.
    - Used for structural defects
    - Insufficiency fracture eventually occurs in 25% of massive grafts.
  - Cancellous graft
    - Useful for grafting nonunion and cavitary defects
    - Revascularizes and incorporates quickly

- Osteoblasts lay down new bone on old trabeculae, which are later remodeled (“creeping substitution”).

Table 1.7

Biochemical Steps of Fracture Healing

Step	Collagen Type
Mesenchymal	I, II, III, V
Chondroid	II, IX
Chondroid-osteoid	I, II, X
Osteogenic	I

Table 1.8

Growth Factors of Bone

Growth Factor	Action	Notes
Bone morphogenetic protein	Osteoinductive; stimulates bone formation Induces metaplasia of mesenchymal cells into osteoblasts	Target cells of BMP are the undifferentiated perivascular mesenchymal cells; signals through serine-threonine kinase receptors Intracellular molecules called SMADs serve as signaling mediators for BMPs
Transforming growth factor–β	Induces mesenchymal cells to produce type II collagen and proteoglycans Induces osteoblasts to synthesize collagen	Found in fracture hematomas; believed to regulate cartilage and bone formation in fracture callus; signals through serine/threonine kinase receptors Coating porous implants with TGF-β enhances bone ingrowth
IGF-2	Stimulates type I collagen, cellular proliferation, cartilage matrix synthesis, and bone formation	Signals through tyrosine kinase receptors
Platelet-derived growth factor	Attracts inflammatory cells to the fracture site (chemotactic)	Released from platelets; signals through tyrosine kinase receptors

- Vascularized bone graft

        - Although technically difficult to implant, allows more rapid union and cell preservation; best for irradiated tissues or large tissue defects (morbidity may occur at donor site [e.g., fibula])
        - Nonvascular bone grafts are more common
    - Allograft bone
        - Types
            - Fresh: increased immunogenicity
            - Fresh frozen: less immunogenic than fresh; BMP preserved
            - Freeze dried (lyophilized "croutons"): loses structural integrity and depletes BMP, is least immunogenic, is purely osteoconductive, has lowest risk of viral transmission
            - Bone matrix gelatin (a digested source of BMP): demineralized bone matrix is osteoconductive and osteoinductive.
            - Osteoarticular (osteochondral) allograft
                - Immunogenic (cartilage is vulnerable to inflammatory mediators of immune response)
                - Articular cartilage preserved with glycerol or DMSO
                - Cryogenically preserved grafts (leave few viable chondrocytes)
                - Tissue-matched (syngeneic) osteochondral grafts (produce minimal immunogenic effects and incorporate well)
        - Antigenicity
            - Allograft bone possesses a spectrum of potential antigens, primarily from cell surface glycoproteins.
            - Classes I and II cellular antigens in allograft are recognized by T

lymphocytes in the host.

Table 1.9

Endocrine Effects on Fracture Healing

Hormone	Effect	Mechanism
Cortisone	−	Decreased callus proliferation
Calcitonin	+?	Unknown
Thyroid hormone, PTH	+	Bone remodeling
Growth hormone	+	Increased callus volume

- Primary mechanism of rejection is cellular rather than humoral.
- Incorporation related to cellularity and MHC incompatibility.
- Cellular components that contribute to antigenicity are marrow origin, endothelium, and retinacular activating cells.
  - Marrow cells incite the greatest immunogenic response.
- Extracellular matrix components that contribute to antigenicity are as follows:
  - Type I collagen (organic matrix): stimulates cell-mediated and humoral responses
  - Noncollagenous matrix (proteoglycans, osteopontin, osteocalcin, other glycoproteins)
- Hydroxyapatite does not elicit immune response.

- Demineralized bone matrix
  - Acidic extraction of bone matrix from allograft
  - Osteoconductive without structural support
  - Minimally osteoinductive despite preservation of

osteoinductive molecules

- Synthetic bone grafts: calcium, silicon, or aluminum
    - Calcium phosphate–based grafts: capable of osseoconduction and osseointegration
        - Biodegrade very slowly
        - Highest compressive strength of any graft material
        - Many prepared as ceramics (heated apatite crystals fused into crystals [sintered])
    - Tricalcium phosphate
    - Hydroxyapatite; purified bovine dermal fibrillar collagen plus ceramic hydroxyapatite granules and tricalcium phosphate granules
    - Calcium sulfate: osteoconductive
        - Rapidly resorbed
    - Calcium carbonate (chemically unaltered marine coral): resorbed and replaced by bone (osteoconductive)
    - Coralline hydroxyapatite: calcium carbonate skeleton is converted to calcium phosphate through a thermoexchange process.
    - Silicate-based: incorporate silicon as silicate (silicon dioxide); bioactive glasses and glass-ionomer cement

Table 1.10

Types of Bone Grafts and Bone Graft Properties

Graft	Properties			
	Osteoconduction	**Osteoinduction**	**Osteogenic Cells**	**Struc Integ**
Autograft				
Cancellous	Excellent	Good	Excellent	Poor
Cortical	Fair	Fair	Fair	Excel
Allograft	Fair	Fair	None	Gooc
Ceramics	Fair	None	None	Fair
Demineralized bone matrix	Good	Fair	None	Poor
Bone marrow	Poor	Poor	Good	Poor

Modified from Brinker MR, Miller MD: *Fundamentals of orthopaedics*, Philadelphia, 1999, Saunders, p 7.

- Aluminum oxide: alumina ceramic bonds to bone in response to stress and strain between implant and bone

□ Five stages of graft healing (Urist) are listed in Table 1.11.

□ Distraction osteogenesis

- Definition: distraction-stimulated formation of bone
- Clinical applications:
  - Limb lengthening
  - Deformity correction (via differential lengthening)
  - Segmental bone loss (via bone transport)
- Biologic features:

- Under optimal stability, intramembranous ossification occurs.
- Under instability, bone forms through enchondral ossification.
  - Under extreme instability, pseudarthrosis may occur.

- Three histologic phases:
  - Latency phase (5–7 days)
  - Distraction phase (1 mm/day [≈1 inch/mo])
  - Consolidation phase (typically twice as long as distraction phase)
- Optimal conditions during distraction osteogenesis:
  - Low-energy corticotomy/osteotomy
  - Minimal soft tissue stripping at corticotomy site (preserves blood supply)
  - Stable external fixation and elimination of torsion, shear, and bending moments
  - Latency period (no lengthening) 5–7 days
  - Distraction: 0.25 mm three or four times per day (0.75–1.0 mm/day)
  - Neutral fixation interval (no distraction) during consolidation
  - Normal physiologic use of the extremity, including weight bearing

□ Heterotopic ossification

- Ectopic bone forms in soft tissues.
  - Most commonly in response to injury or surgical dissection
  - Myositis ossificans: heterotopic ossification in muscle
- Increased risk with traumatic brain injury
  - Recurrence after resection is likely if neurologic compromise is severe.
  - Timing of surgery for heterotopic ossification after traumatic brain injury is important:
    - Time since injury (3–6 months)
    - Evidence of bone maturation on radiographs (sharp demarcation, trabecular pattern)
- Heterotopic ossification may be resected after total hip arthroplasty (THA).
  - Resection should be delayed for 6 months or longer after THA.

- Adjuvant radiation therapy may prevent recurrence of heterotopic ossification.

Table 1.11

Stages of Graft Healing

Stage	Activity
Inflammation	Chemotaxis stimulated by necrotic debris
Osteoblast differentiation	From precursors
Osteoinduction	Osteoblast and osteoclast function
Osteoconduction	New bone forming over scaffold
Remodeling	Process continues for years

- Optimal therapy: single preoperative or postoperative dose of 600–800 rad/cGy (6-8 Gy)
- Prevents proliferation and differentiation of primordial mesenchymal cells into osteoprogenitor cells
- Preoperative radiation (600–800 rad/cGy) may be given in a single fraction up to 24 hours prior to surgery.
    - Helps prevent heterotopic ossification after THA in patients at high risk for this development
    - Incidence of heterotopic ossification after THA among patients with Paget disease is approximately 50%.

- **Normal bone metabolism**
    - Calcium
        - Important in muscle and nerve function, clotting, and many other areas
        - More than 99% of the body's calcium is stored in bones.
            - Plasma calcium is about equally free and bound (usually to albumin).
            - Approximately 400 mg of calcium is released from bone daily.
        - Absorbed in the duodenum by active transport
            - Requires ATP and calcium-binding protein
            - Regulated by $1,25(OH)_2D_3$
        - Absorbed in the jejunum by passive diffusion
        - Kidney reabsorbs 98% of calcium (60% in proximal tubule)
            - Calcium may be excreted in stool.

- **Primary homeostatic regulators of serum calcium are PTH and 1,25(OH) $_2$ D $_3$**
- **Dietary requirement for elemental calcium:**
    - Approximately 600 mg/day for children
    - Approximately 1300 mg/day for adolescents and young adults (ages 10–25 years)
    - 750 mg/day for adults ages 25–50 years
    - 1200–1500 for adults over age 50 years
    - 1500 mg/day for pregnant women
    - 2000 mg/day for lactating women
    - 1500 mg/day for postmenopausal women and for the patient with a healing fracture in a long bone
- Calcium balance is usually positive in the first three decades of life and negative after the fourth decade.

□ Phosphate

- A key component of bone mineral
    - Approximately 85% of the body's phosphate stores are in bone.
    - Plasma phosphate is mostly unbound.
- Also important in enzyme systems and molecular interactions as a metabolite and buffer
- Dietary intake of phosphate is usually adequate.
- Daily requirement is 1000–1500 mg.

□ Reabsorbed by the kidney (proximal tubule)

□ Phosphate may be excreted in urine.

□ Parathyroid hormone

- An 84–amino acid peptide
- Synthesized in and secreted from chief cells of the (four) parathyroid glands
- N-terminal fragment 1-34 is the active portion.
- **Teriparatide, the synthetic form of recombinant human PTH, contains this active sequence.**
    - Used to treat some forms of osteoporosis
    - Increased risk of osteosarcoma
- **Effect of PTH mediated by the cAMP second-messenger mechanism downstream in osteocytes**

Table 1.12

Regulation of Calcium and Phosphate Metabolism

Parameter	PTH (Peptide)	1,25(OH)2D (Steroid)	Calcitonin (Peptide)
Origin	Chief cells of parathyroid	Proximal tubule	Parafollicular cells

	glands	of kidney	of thyroid gland
Factors stimulating production	Decreased serum Ca^{2+}	Elevated PTH level Decreased serum Ca^{2+} level Decreased serum Pi	Elevated serum Ca^{2+} level
Factors inhibiting production	Elevated serum Ca^{2+} Elevated $1,25(OH)_2D$	Decreased PTH Elevated serum Ca^{2+} Elevated serum P_i	Decreased serum Ca^{2+}
Effect on end-organs for hormone action:			
Intestine	No direct effect Acts indirectly on bowel by stimulating production of $1,25(OH)_2D$ in kidney	Strongly stimulates intestinal absorption of Ca^{2+} and P_i	?
Kidney	Stimulates 25(OH)D 1α-hydroxylase in mitochondria of proximal tubular cells to convert 25(OH)D to $1,25(OH)_2D$ Increases fractional resorption of filtered Ca^{2+} Promotes urinary excretion of P_i	?	?
Bone	Stimulates osteoclastic resorption of bone Stimulates recruitment of preosteoclasts	Strongly stimulates osteoclastic resorption of bone	Inhibits osteoclastic resorption of bone ? Role in normal human physiology
Net effect on Ca^{2+}	Increased serum Ca^{2+}	Increased	Decreased serum

and P_i concentrations in extracellular fluid and serum	level Decreased serum P_i level	serum Ca^{2+} level Increased serum P_i level	Ca^{2+} level (transient)

Adapted from Netter FH: *CIBA collection of medical illustrations, vol 8: Musculoskeletal system, part I: Anatomy, physiology and developmental disorders*, Basel, Switzerland, 1987, CIBA, p 179.

        - PTH helps regulate plasma calcium.
            - Decreased calcium levels in extracellular fluid stimulate β_2 adrenoreceptors to release PTH, which acts at the intestines, kidneys, and bones (Table 1.12).
    - PTH directly activates osteoblasts.
    - PTH modulates renal phosphate filtration.
    - PTH may accentuate bone loss in elderly persons.
    - PTH-related protein and its receptor have been implicated in metaphyseal dysplasia.

□ Vitamin D
- Naturally occurring steroid
- Activated by ultraviolet radiation from sunlight or utilized from dietary intake (Fig. 1.15)
- Hydroxylated to $25(OH)D_3$ in the liver and hydroxylated a second time in the kidney to one of the following:
    - $1,25(OH)_2D_3$, the active hormone
    - $24,25(OH)_2D_3$, the inactive form (Fig. 1.16)
- $1,25(OH)_2D_3$ works at the intestines, kidneys, and bones (see Table 1.12).
- Phenytoin (Dilantin) impairs metabolism of vitamin D.

□ Calcitonin
- A 32–amino acid peptide hormone produced by clear cells in the parafollicles of the thyroid gland
- Limited role in calcium regulation (see Table 1.12)
- Increased extracellular calcium levels cause secretion of calcitonin.
    - Controlled by a β_2 receptor
- Inhibits osteoclastic bone resorption
    - Osteoclasts have calcitonin receptors.
    - Calcitonin decreases osteoclast number and activity.

- Decreases serum calcium level
  - May also have a role in fracture healing and in reducing vertebral compression fractures in high-turnover osteoporosis

□ Other hormones affecting bone metabolism

- Estrogen
  - Prevents bone loss by inhibiting bone resorption
    - Decrease in urinary pyridinoline cross-links
  - Because bone formation and resorption are coupled, estrogen therapy also decreases bone formation.
  - Supplementation is helpful in postmenopausal women only if started within 5–10 years after onset of menopause.
    - Risk of endometrial cancer is reduced when estrogen therapy is combined with cyclic progestin therapy.
  - Certain regimens of hormone replacement therapy may increase risks of heart disease and breast cancer.
  - Other postmenopausal pharmacologic interventions (alendronate, raloxifene) should be strongly considered.
- Corticosteroids
  - Increase bone loss
    - Decrease gut absorption of calcium by decreasing binding proteins
    - Decrease bone formation (cancellous more than cortical) by inhibiting collagen synthesis and osteoblast productivity

- Do not affect mineralization
- Alternate-day therapy may reduce the effects.

- Thyroid hormones
  - Affect bone resorption more than bone formation
    - Large (thyroid-suppressive) doses of thyroxine can lead to osteoporosis.
  - Regulates skeletal growth at the physis
    - Stimulates chondrocyte growth, type X collagen synthesis, and alkaline phosphatase activity
- Growth hormone
  - Causes positive calcium balance by increasing gut absorption of calcium more than it increases urinary excretion

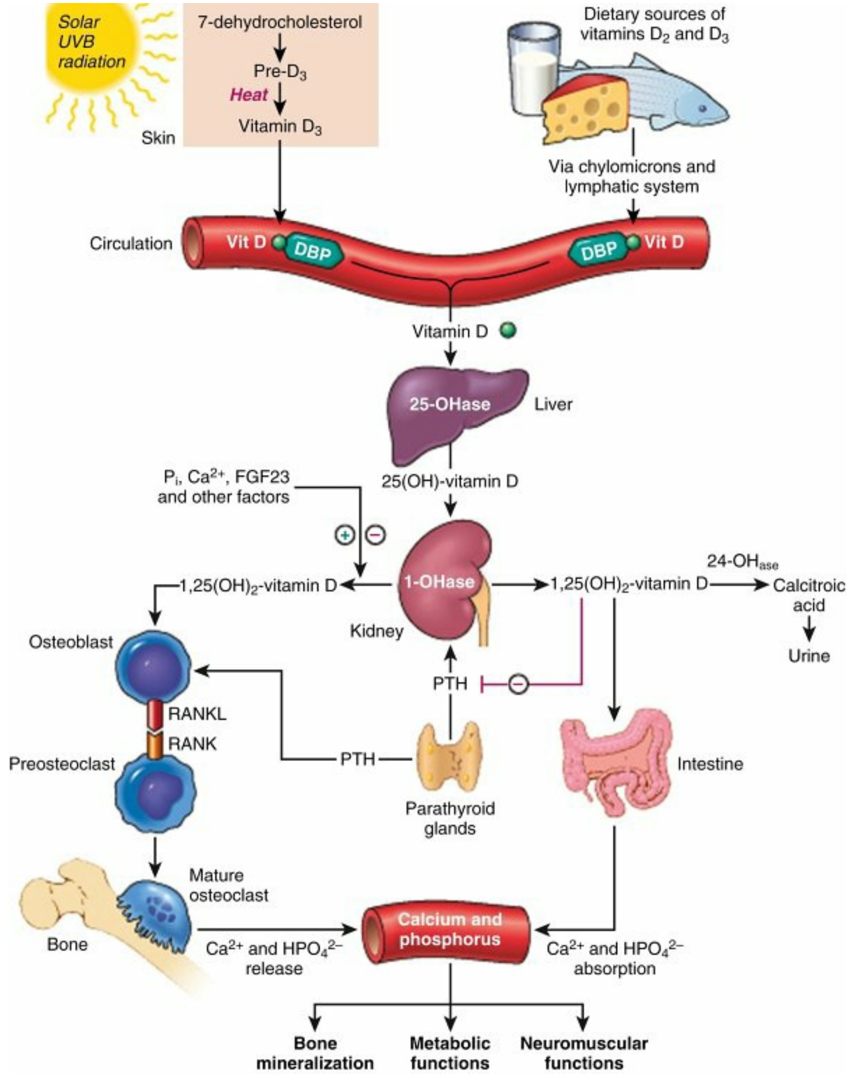


FIG. 1.15 Vitamin D metabolism. *DBP,* vitamin D–binding protein; *OHase,* 1α-hydroxylase; *Pi,* inorganic phosphate.

From Kumar V et al, editors: *Robbins and Cotran pathologic basis of disease*, Philadelphia, 2010, Saunders.

- Insulin and somatomedins participate in this effect.
- Growth factors
  - Transforming growth factor β (TGF-β), platelet-derived growth factor (PDGF), monokines, and lymphokines have roles in bone and cartilage repair.

□ Peak bone mass

- Believed to occur between 16 and 25 years of age
- Higher in men and in African Americans
- After peak, bone loss occurs at a rate of 0.3%–0.5% per year
- Rate of bone loss is 2%–3% per year in untreated women during the sixth through tenth years after menopause.
  - **Affects trabecular more than cortical bone**
    - Increase in trabecular rods results in increased anisotropy.

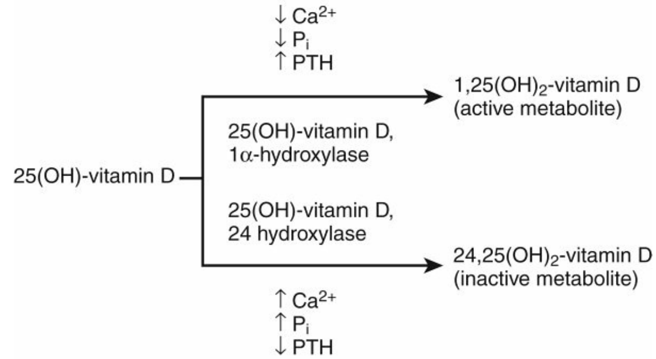


FIG. 1.16 Vitamin D metabolism in the renal tubular cell.

From Simon SR, editor: *Orthopaedic basic science,* Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 165.

- Cortical bone becomes thinner and intracortical porosities increase.
- Cortical bone becomes more brittle, less strong, and less stiff.
- **Long bones have greater inner and outer diameters**.

□ Bone loss

- Occurs at the onset of menopause when both bone formation and resorption are accelerated
  - A net negative change in calcium balance: menopause decreases intestinal absorption and increases urinary excretion of calcium.
- **Both urinary hydroxyproline and pyridinoline cross-links are elevated when bone resorption occurs.**
- **Serum alkaline phosphatase level is elevated when bone formation is increased**.

▪ **Conditions of bone mineralization (**Tables 1.13 through 1.17)

□ Hypercalcemia

- Can manifest in a number of ways
  - Polyuria, polydipsia, and nephrolithiasis
  - Excessive bony resorption with or without fibrotic tissue replacement (osteitis fibrosa cystica)
  - CNS effects (confusion, stupor, weakness)
  - GI effects (constipation)
- Can also cause anorexia, nausea, vomiting, dehydration, and muscle weakness
- Primary hyperparathyroidism
  - Overproduction of PTH usually a result of a parathyroid adenoma (surgical parathyroidectomy is curative)
    - Generally affects only one

parathyroid gland

- Reflected in a net increase in plasma calcium and a decrease in plasma phosphate (as a result of enhanced urinary excretion)
- **Increased osteoclastic resorption** and failure of repair attempts (poor mineralization as a result of low phosphate level)
- Diagnosis:
    - Laboratory findings
        - Increased serum calcium, PTH, and urinary phosphate
        - Decreased serum phosphate
    - Bony changes
        - Osteopenia
        - Osteitis fibrosa cystica (fibrous replacement of marrow)
        - Brown tumors: increased giant cells, extravasation of RBCs, hemosiderin staining, fibrous tissue hemosiderin
        - Chondrocalcinosis
    - Radiographic findings
        - Deformed, osteopenic bones
        - Fractures
        - Shaggy trabeculae
        - Radiolucent areas (phalanges, distal clavicle, skull)
        - Destructive metaphyseal lesions
        - Calcification of soft tissues
    - Histologic changes
        - Osteoblasts and osteoclasts active on both sides of the trabeculae (as in Paget

disease)
- Areas of destruction
- Wide osteoid seams

- Other causes of hypercalcemia
    - Familial syndromes
        - Pituitary adenomas associated with multiple endocrine neoplasia (MEN) types I and II

Table 1.13

Overview of Clinical and Radiographic Aspects of Metabol

Disease	**Cause**	**Clinical Fi**
Hypercalcemia		
Hyperparathyroidism	PTH overproduction: adenoma	Kidney sto hyperr
Familial syndromes	PTH overproduction: MEN/renal	Endocrine abnorm
Hypocalcemia		
Hypoparathyroidism	PTH underproduction: idiopathic	Neuromus irritabil
PHP/Albright syndrome	PTH receptor abnormality	Short MC/
Renal osteodystrophy	Chronic renal failure: ↓ phosphate excretion	Renal abn
Rickets (osteomalacia)		
Vitamin D–deficiency rickets	↓ Vitamin D diet; malabsorption	Bone defo hypoto
Vitamin D–dependent (types I and II) rickets	See Table 1.16	Total baldn
	↓ Renal tubular phosphate	Bone defo hypoto

Vitamin D–resistant (hypophosphatemic) rickets	resorption	
Hypophosphatasia	↓ Alkaline phosphatase	Bone defor hypoto
Osteopenia		
Osteoporosis	↓ Estrogen: ↓ bone mass	Kyphosis,
Scurvy	Vitamin C deficiency: defective collagen	Fatigue, bl effusior
Osteodensity		
Paget disease of bone	Osteoclastic abnormality: ↑ bone turnover	Deformitie fractur
Osteopetrosis	Osteoclastic abnormality: unclear	Hepatosple anemia

↓, Decreased; ↑, increased.

Table 1.14

Laboratory Findings and Clinical Data Regarding Patients

Disorder	Changes in Level or Concentra		
	Serum Calcium	Serum Phosphatase	Alkalin Phosph
Primary hyperparathyroidism	↑	None or ↓	None o

Malignancy with bony metastases	↑	None or ↑	None or
Hyperthyroidism	↑	None	None
Vitamin D intoxication	↑	None or ↑	None or

↓, Decreased; ↑, increased.

Table 1.15

Laboratory Findings and Clinical Data Regarding Patients W

Changes in Level or Concentration			
Disorder	**Serum Calcium**	**Serum Phosphastase**	**Alka Phos**
Hypopara-thyroidism	↓	↑	None
Pseudohypopara-thyroidism	↓	↑	None
Renal osteodystrophy (high-turnover bone disease resulting from renal disease [secondary hyperparathyroidism])	↓ or none	↑↑↑	↑

Renal osteodystrophy (low-turnover bone disease due to renal disease [aluminum toxicity])	↑ or none	None or ↑	↑

↓, Decreased; ↑, increased.

Table 1.16

**Laboratory Findings and Clinical Data Regarding Patients **

Changes in Level or Concentration				
Disorder	**Serum Calcium**	**Serum Phos**	**Alkaline phos**	**PTH**
Nutritional rickets: vitamin D deficiency	↓ or none	↓	↑	↑

Nutritional rickets: calcium deficiency	↓ or none	↓	↑	↑
Nutritional rickets: phosphate deficiency	None	↓	↑	None
Hereditary vitamin D–dependent rickets type I (pseudo–vitamin D deficiency)	↓	↓	↑	↑
Hereditary vitamin D–dependent rickets type II [hereditary resistance to 1,25(OH)$_2$D]	↓	↓	↑	↑
Hypophosphatemic rickets (also known as vitamin D–resistant rickets and phosphate diabetes; Albright syndrome is an example of a	None	↓↓↓	↑	None

hypophosphatemic syndrome)				
Hypophosphatasia	↑	↑	↓↓↓	None

↓, Decreased; ↑, increased; *phos,* phosphatase.

Table 1.17

Differential Diagnosis of Metabolic Bone Diseases Based

Calcium Level	
Increased	**Decreased**
Primary hyperparathyroidism	Hypoparathyroidism
Hyperthyroidism	Pseudohypoparathyro
Vitamin D intoxication	Renal osteodystrophy (high-turnover bo disease)
Malignancy without bony metastasis	Nutritional rickets: vi D deficiency
Malignancy with bony metastasis	Nutritional rickets: ca deficiency
Multiple myeloma	Hereditary vitamin D- dependent rickets (types I and II)
Lymphoma	Malignancy with bon metastasis
Sarcoidosis	Malignancy without b metastasis
Milk-alkali syndrome	Multiple myeloma
Severe generalized immobilization	Lymphoma
Multiple endocrine neoplasias	Hyperthyroidism
Addison disease	Vitamin D intoxicatio
Steroid administration	Sarcoidosis
Peptic ulcer disease	Milk-alkali syndrome
Hypophosphatasia	Severe generalized immobilization
Pseudohypoparathyroidism	
Renal osteodystrophy	
Nutritional rickets: vitamin D deficiency	
Nutritional rickets: calcium deficiency	
Hereditary vitamin D–dependent rickets (types I and II)	

- Familial hypocalciuric hypercalcemia
    - Poor renal clearance of calcium
- Malignancy (most common)
    - Can be life threatening; commonly associated with muscle weakness
    - Initial treatment should include hydration with normal saline (reverses dehydration).
    - Can occur in the absence of extensive bone metastasis

            - Most commonly results from release of systemic growth factors and cytokines that stimulate osteoclastic bone resorption at bony sites not involved in the tumor process (RANKL pathway)
            - PTH-related protein secretion (lung carcinoma)
            - Lytic bone metastases and lesions (e.g., multiple myeloma)
        - Hyperthyroidism
        - Vitamin D intoxication
        - Prolonged immobilization
        - Addison disease
        - Steroid administration
        - Peptic ulcer disease (milk-alkali syndrome)
        - Kidney disease
        - Sarcoidosis
        - Hypophosphatasia
    - Treatment of hypercalcemia
        - Hydration (saline diuresis)
        - Loop diuretics
        - Dialysis (for severe cases)
        - Mobilization (prevents further bone resorption)
        - Specific drugs (bisphosphonates, mithramycin, calcitonin, and gallium nitrate)
- □ Hypocalcemia (Fig. 1.17)
    - Findings
        - Low plasma calcium
        - Results from low levels of PTH or vitamin D_3
        - Neuromuscular irritability (tetany, seizures, Chvostek sign), cataracts, fungal nail infections, ECG changes (prolonged QT interval), and other signs and symptoms
    - □ Hypoparathyroidism
        - Reduced PTH level causes decrease in plasma calcium level and increase in plasma phosphate level
            - Urinary excretion not enhanced because of the lack of PTH
        - Common findings:
            - Fungal nail infections
            - Hair loss

      - Blotchy skin (pigment loss, vitiligo)
    - Skull radiographs may show basal ganglia calcification.
    - Iatrogenic hypoparathyroidism most commonly follows thyroidectomy.
- □ Pseudohypoparathyroidism (PHP)
    - A rare genetic disorder caused by lack of effect of PTH on the target cells
    - PTH is normal or high.
    - PTH action is blocked by an abnormality at the receptor, by the cAMP system, or by a lack of required cofactors (e.g., Mg^{2+})
    - Defect in *GNAS* gene from mother
    - Albright hereditary osteodystrophy, a form of PHP
        - Short first, fourth, and fifth metacarpals (MCs) and metatarsals (MTs)
        - Brachydactyly

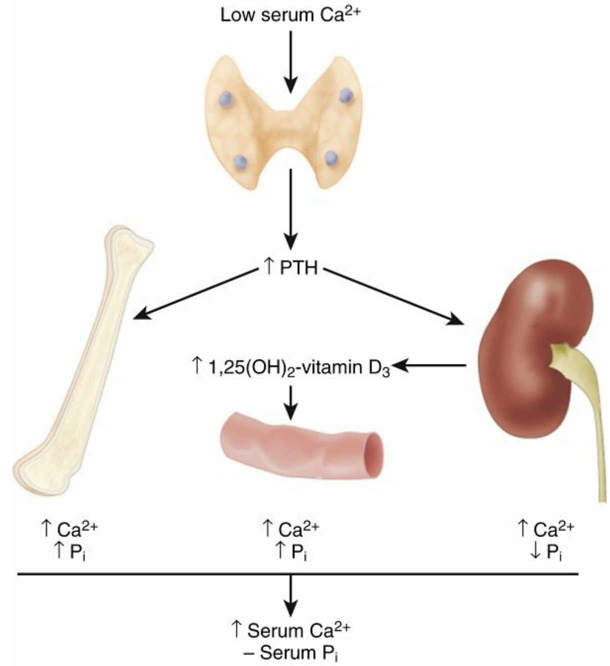


FIG. 1.17 Body's reaction to hypocalcemia, with consequent resorption of bone. When calcium level falls, PTH is secreted, which releases calcium and Pi from bone. PTH increases renal reabsorption of calcium while inhibiting phosphate reabsorption. These actions in combination restore calcium concentration. If hypocalcemia persists, PTH stimulates renal production of $1,25(OH)_2D_3$, which increases intestinal calcium absorption.
From Goldman L, Ausiello D, editors: *Cecil medicine,* ed 23, Philadelphia, 2008, Saunders Elsevier.

- Exostoses
- Obesity
- Diminished intelligence

□ Pseudo-pseudohypoparathyroidism (pseudo-PHP)

- Normocalcemic disorder that is phenotypically similar to PHP
- However, response to PTH is normal.

- Renal osteodystrophy (Fig. 1.18)
  - A spectrum of bone mineral metabolism disorders in chronic renal disease.
  - Due to impaired excretion, which compromises mineral homeostasis
  - Leads to abnormalities in bone mineral metabolism

- High-turnover renal bone disease
  - Chronically elevated serum PTH level leads to **secondary hyperparathyroidism** (hyperplasia of parathyroid gland chief cells).
  - Factors contributing to sustained **PTH increase** and secondary hyperparathyroidism include:
    - **Diminished renal phosphorus excretion; phosphorus retention promotes PTH secretion by three mechanisms:**
      - **Hyperphosphatemia lowers serum calcium, stimulating PTH**.
      - **Phosphorus impairs renal 1α-hydroxylase activity, impairing production of 1,25(OH) $_2$ D $_3$** .
      - **Phosphorus retention may directly increase the synthesis of PTH**.
      - Hypocalcemia
      - Impaired renal calcitriol [1,25(OH)$_2$D$_3$]
      - Alterations in the control of *PTH* gene transcription secretion
      - Skeletal resistance to the actions of PTH
- Low-turnover renal bone disease (adynamic lesion of bone and osteomalacia)

- Secondary hyperparathyroidism is not characteristic with this condition.
    - Serum PTH level is normal or mildly elevated.
- Bone formation and turnover are reduced.
- Excess deposition of aluminum into bone (aluminum toxicity) negatively affects bone mineral metabolism.
    - Impairs differentiation of precursor cells to osteoblasts
    - Impairs proliferation of osteoblasts
    - Impairs PTH release from the parathyroid gland
    - Disrupts the mineralization process
    - Adynamic lesion: accounts for the majority of cases of low-turnover bone disease in patients with chronic renal failure
    - Osteomalacia: defects in mineralization of newly formed bone
- Radiographs may demonstrate a rugger jersey spine (vertebral bodies appear to have increased density in the upper and lower zones in a striated appearance, like that in childhood osteopetrosis) and soft tissue calcification.
- β_2-Microglobulin may accumulate with long-term dialysis, leading to amyloidosis.
    - Amyloidosis may be associated with carpal tunnel syndrome, arthropathy, and

pathologic fractures.

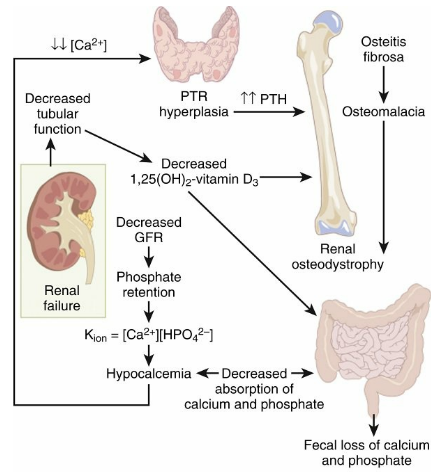


FIG. 1.18 Pathogenesis of bony changes in renal osteodystrophy. *PTR*, proximal tubule reabsorption.
From McPherson RA, Pincus MR, editors: *Henry's clinical diagnosis and management by laboratory methods*, ed 21, Philadelphia, 2007, Saunders Elsevier.

- In amyloidosis, Congo red stain causes tissue material to turn pink.
- Laboratory findings:
  - Abnormal glomerular filtration rate (GFR)
  - Increased alkaline phosphatase, blood urea nitrogen (BUN), and creatinine levels
  - Decreased venous bicarbonate level
- Treatment directed at relieving the urologic obstruction or kidney disease
- Rickets (osteomalacia in adults; Box 1.1)
  - Failure of mineralization leading to changes in the physis in the zone of provisional calcification (increased width and disorientation) and bone (cortical thinning, bowing)

Box 1.1 Causes of Rickets and Osteomalacia

Nutritional Deficiency

- Vitamin D deficiency
- Dietary chelators (rare) of calcium
- Phytates
- Oxalates (spinach)

Phosphorus Deficiency (Unusual)

- Abuse of antacids (which contain aluminum), which leads to severe dietary phosphate binding

Gastrointestinal Absorption Defects

- Postgastrectomy (rare today)
- Biliary disease (interference with absorption of fat-soluble vitamin D)
- Enteric absorption defects
- Short bowel syndrome
- Rapid transit (gluten-sensitive enteropathy) syndromes
- Inflammatory bowel disease
  - Crohn disease
  - Celiac disease

Renal Tubular Defects (Renal Phosphate Leak)

- X-linked dominant hypophosphatemic vitamin D–resistant rickets or osteomalacia
- Classic Albright syndrome or Fanconi syndrome type I
- Fanconi syndrome type II
- Phosphaturia and glycosuria
- Fanconi syndrome type III
- Phosphaturia, glycosuria, aminoaciduria
- Vitamin D–dependent rickets (or osteomalacia) type I—a genetic or acquired deficiency of renal tubular 25(OH)D 1α-hydroxylase enzyme that prevents conversion of 25(OH)D to the active polar metabolite 1,25$(OH)_2$D
- Vitamin D–dependent rickets (or osteomalacia) type II—which

represents enteric end-organ insensitivity to 1,25(OH)D and is probably caused by an abnormality in the 1,25$(OH)_2$D nuclear receptor)

- Renal tubular acidosis
- Acquired: associated with many systemic diseases
- Genetic
    - Debré–De Toni–Fanconi syndrome
    - Lignac-Fanconi syndrome (cystinosis)
    - Lowe syndrome

Renal Osteodystrophy: Miscellaneous Causes

Soft tissue tumors secreting putative factors
Fibrous dysplasia
Neurofibromatosis
Other soft tissue and vascular mesenchymal tumors
Anticonvulsant medication (induction of the hepatic P450 microsomal enzyme system by some anticonvulsants—e.g., phenytoin, phenobarbital, and primidone [Mysoline]—causes increased degradation of vitamin D metabolites)
Heavy metal intoxication
Hypophosphatasia
High-dose diphosphonates
Sodium fluoride

Adapted from Simon SR, editor: *Orthopaedic basic science,* ed 2, Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 169.

- Nutritional rickets (see Table 1.16)
    - Vitamin D–deficiency rickets
        - Rare after addition of vitamin D to milk, except in the following populations:
            - Asian immigrants

    - Patients with dietary peculiarities
    - Premature infants
    - Patients with malabsorption (celiac sprue)
    - Patients receiving long-term parenteral nutrition
- Decreased intestinal absorption of calcium and phosphate leads to secondary hyperparathyroidism.
- Laboratory findings
    - **Low-normal calcium level** (maintained by high PTH level)
    - **Low phosphate level** (excreted because of the effect of PTH)
    - **Increased alkaline phosphatase level**
    - **Low vitamin D level**
    - **Increased PTH** level leads to higher bone absorption
- Physical examination
    - Enlargement of the costochondral junction (rachitic rosary)
    - Bowing of the knees
    - Muscle hypotonia
    - Dental disease
    - Pathologic fractures (Looser zones: pseudofractures on the compression sides of bones)

- Milkman's fracture
- Waddling gait
- Radiographic findings
  - **Physeal widening and cupping**
  - Coxa vara
  - Codfish vertebrae
  - Retarded bone growth (defect in the hypertrophic zone, widened osteoid seams)
- In affected children, height is commonly below the fifth percentile for age.
- Treatment with vitamin D (1000–6000 IU daily based on weight) resolves most deformities.
- Calcium-deficiency rickets (Fig. 1.19)
- Phosphate-deficiency rickets
- Hereditary vitamin D–dependent rickets
  - Rare disorders with features similar to those of vitamin D–deficiency (nutritional) rickets, except that symptoms may be worse and patients may have total baldness
    - **Type I: defect in renal 25(OH)D 1α-hydroxylase, inhibiting conversion of inactive vitamin D to its active form**
      - Autosomal recessive inheritance
      - Gene on chromosome 12q14
    - Type II: defect in an intracellular receptor for $1,25(OH)_2D_3$

- Familial hypophosphatemic rickets (vitamin D–resistant rickets or phosphate diabetes)
- Most commonly encountered form of rickets
    - X-linked dominant inheritance

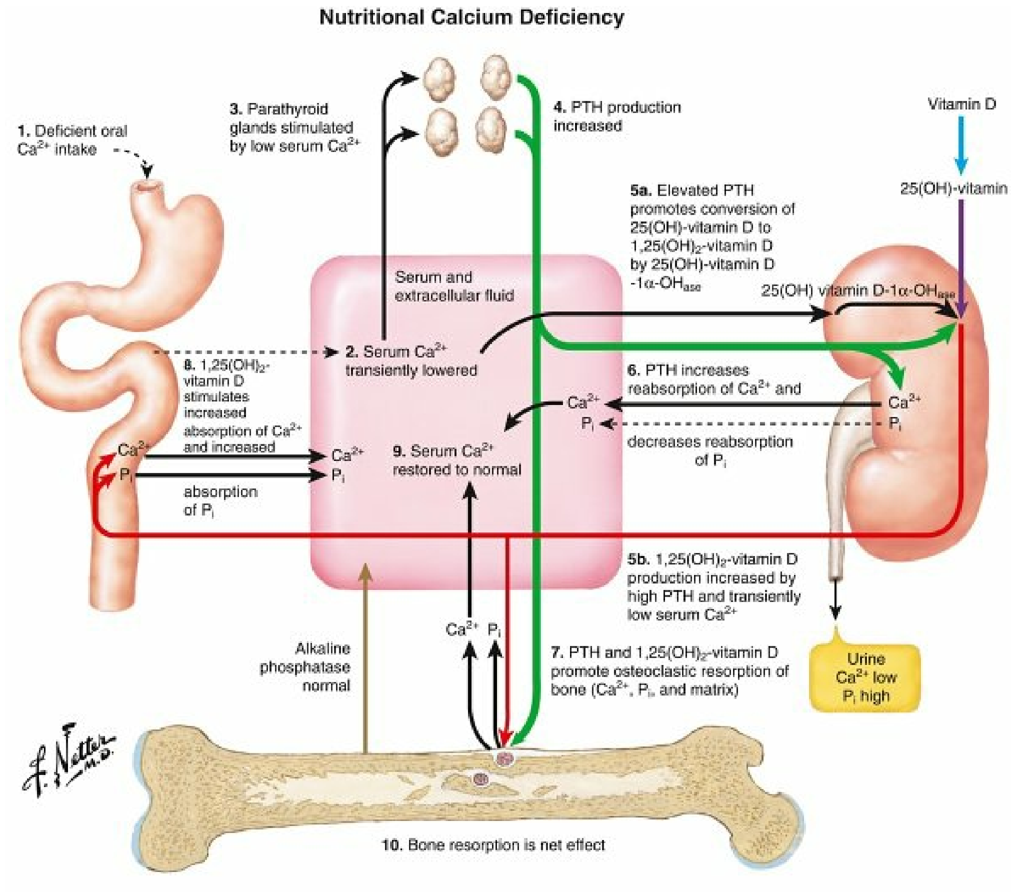


FIG. 1.19 Nutritional calcium deficiency.
From Netter FH: *CIBA collection of medical illustrations*, vol 8: *Musculoskeletal system*, part I: *Anatomy, physiology and developmental disorders*, Basel, Switzerland, 1987, CIBA, p 184.

- Impaired renal tubular reabsorption of phosphate
- Normal GFR with an impaired vitamin D_3 response
- Normal serum calcium, low serum phosphorus and 1, $(OH)_2D_3$, and high serum alkaline phosphatase levels
- Treatment:
- First line treatment with burosumab (anti-FGF23 monoclonal antibody)
- Second line elemental phosphate (1–2 g/day plus vitamin D 0.5–1 μg/day)
- Hypophosphatasia
    - Autosomal recessive
    - Error in the tissue-nonspecific isoenzyme of alkaline phosphatase
        - Leads to low levels of alkaline phosphatase, which is required for

            synthesis of inorganic phosphate (Pi) and important in bone matrix formation
        - Features are similar to those of rickets.
        - Increased urinary phosphoethanolamine is diagnostic.
        - Treatment may include phosphate therapy.

- **Conditions of bone mineral density**
    - Bone mass is regulated by rates of deposition and withdrawal (Fig. 1.20).
    - Osteoporosis
        - Age-related decrease in bone mass
            - Usually associated with estrogen loss in postmenopausal women (Fig. 1.21)
        - A quantitative, not qualitative, defect
            - Mineralization remains normal
        - World Health Organization's definition
            - Lumbar (L2–L4) density is **2.5 or more standard deviations less than mean peak bone mass of a healthy 25-year-old (T-score).**
            - Osteopenia: bone density is **1.0–2.5 standard deviations less than the mean peak bone mass of a healthy 25-year-old.**
        - Responsible for more than 1 million fractures per year
            - Fractures of the vertebral body are most common.
            - History of osteoporotic vertebral compression fractures are strongly predictive of subsequent vertebral fracture.
                - After initial vertebral fracture, the risk for a second vertebral fracture is 20%.
            - Vertebral compression fracture is associated with increased mortality rate.
                - Incidence of vertebral compression fractures is higher among men than women.
            - Lifetime risk of fracture in white women after 50 years of age: 75%
            - The risk for hip fracture is 15%–20%.
        - Risk factors (Box 1.2)
        - Cancellous bone is most affected.
        - Clinical features
            - Kyphosis and vertebral fractures

            - Compression fractures of T11–L1 that create anterior wedge-shaped defects or centrally depressed codfish vertebrae
        - Hip fractures
        - Distal radius fractures
- **Type I osteoporosis (postmenopausal)**
    - Primarily affects trabecular bone
    - Vertebral and distal radius fractures common
- Type II osteoporosis (age-related)
    - Patients older than 75 years
    - Affects both trabecular and cortical bone
    - Related to poor calcium absorption
    - Hip and pelvic fractures are common.
- Laboratory studies
    - Obtained to rule out secondary causes of low bone mass:
        - Vitamin D deficiency, hyperthyroidism, hyperparathyroidism, Cushing syndrome, hematologic disorders, malignancy
    - **Complete blood cell count; measurements of serum calcium, phosphorus, 25(OH)D, alkaline phosphatase, liver enzymes, creatinine, and total protein and albumin levels; and measurement of 24-hour urinary calcium excretion**
    - Results of these studies are usually unremarkable in osteoporosis.
- Plain radiographs not helpful unless bone loss exceeds 30%
- Special studies
    - Single-photon (appendicular) absorptiometry
    - Double-photon (axial) absorptiometry
    - Quantitative computed tomography (CT)
    - Dual-energy x-ray absorptiometry **(DEXA)**
        - **Most accurate with less radiation**
- Biopsy
    - After tetracycline labeling
    - To evaluate the severity of osteoporosis and identify osteomalacia
- Histologic changes
    - Thinning trabeculae
    - Decreased osteon size

- Enlarged haversian and marrow spaces
- Treatment (Fig. 1.22)
    - Physical activity
    - Supplements: **1000–1500 mg calcium plus 400–800 IU of vitamin D per day**
        - More effective in type II (age-related) osteoporosis
    - Bisphosphonates
        - Inhibit osteoclastic bone resorption—direct anabolic effect on bone
        - Categorized into two classes on the basis of presence or absence of a nitrogen side group:
            - **Nitrogen-containing bisphosphonates—up to 1000-fold more potent in their antiresorptive activity**
                - Zoledronic acid (Zometa) and alendronate (Fosamax)
                - **Inhibit protein prenylation within the mevalonate pathway, blocking farnesyl pyrophosphate synthase**
                - **Results in a loss of GTPase formation, which is needed for ruffled border formation and cell survival**
            - Non–nitrogen-containing bisphosphonates
                - Metabolized into a nonfunctional ATP analogue, inducing apoptosis
                - Decreases skeletal

events in multiple myeloma
    - **Associated with osteonecrosis of the jaw**
- Orthopaedic implications of bisphosphonate use
    - Spine—**reduced rate of spinal fusion in animal model**; withholding bisphosphonate is recommended after surgery.
    - Hip and knee—safe for use in cementless hip arthroplasty and cemented knee arthroplasty; may decrease rate of acetabular component subsidence

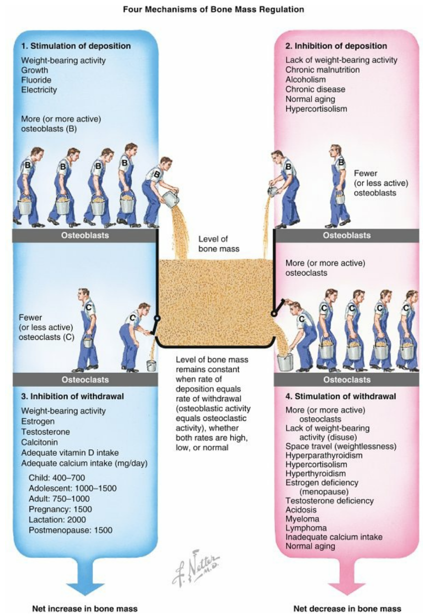


FIG. 1.20 Four mechanisms of bone mass regulation. From Netter FH: *CIBA collection of medical illustrations*, vol 8: *Musculoskeletal system*, part I: *Anatomy, physiology and developmental disorders*, Basel, Switzerland, 1987, CIBA, p 181.

- Fracture healing—no good data to recommend for or against use; will decrease future fracture risk
- Denosumab is a monoclonal antibody that targets and inhibits RANKL binding to the RANK receptor, which is found on osteoclasts.
- Other drugs (e.g., intramuscular calcitonin) may be helpful.
  - Expensive and may cause hypersensitivity reactions
- Efficacy of bone augmentation with PTH, growth factors, prostaglandin inhibitors, and other therapies remains to be determined.
- Prophylaxis for patients at risk for osteoporosis
  - Diet with adequate calcium intake
  - Weight-bearing exercise program

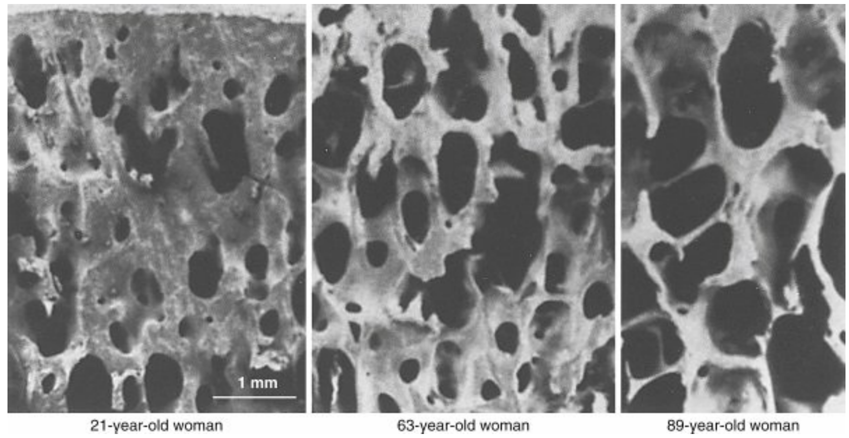


FIG. 1.21 Age-related changes in density and architecture of human trabecular bone from the lumbar spine. With progressive age, there is a quantitative decrease in bone, but the mineralization (qualitative) remains the same.

Box 1.2 Risk Factors for the Development of Osteoporosis

- White race, female gender, northern European descent (fair skin and hair)
- Sedentary lifestyle
- Thinness
- Smoking
- Heavy drinking
- Phenytoin (impairs vitamin D metabolism)
- Diet low in calcium and vitamin D
- History of breastfeeding
- Positive family history of osteoporosis
- Premature menopause

From Keaveney TM, Hayes WC: Mechanical properties of cortical and trabecular bone, *Bone* 7:285–344, 1993.

        - Estrogen therapy evaluation at menopause
- □ Other causes of decreased mineral density
    - Idiopathic transient osteoporosis of the hip
        - Uncommon; diagnosis of exclusion
        - Most common during third trimester of pregnancy in women but can occur in men
        - Groin pain, limited ROM, and localized osteopenia without a history of trauma
        - Treatment: analgesics and limited weight bearing
        - Generally self-limiting and tends to resolve spontaneously after 6–8 months
        - Stress fractures may occur.
        - Joint space remains preserved on radiographs.

- Osteomalacia
    - Femoral neck fractures are common.
    - Qualitative defect
    - **Defect of mineralization** results in a large amount of unmineralized osteoid.
    - Causes:
        - Vitamin D–deficient diet
        - GI disorders
        - Renal osteodystrophy
        - Certain drugs
            - Aluminum-containing phosphate-binding antacids; aluminum deposition in bone prevents mineralization
            - Phenytoin (Dilantin)

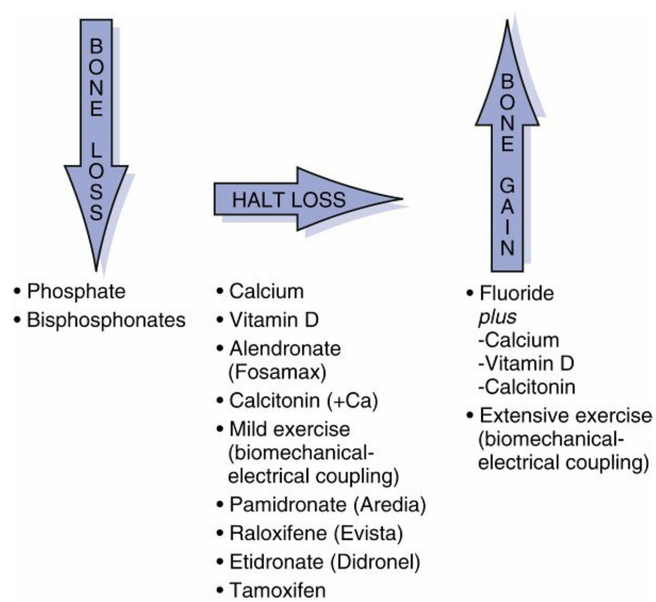


FIG. 1.22 Treatment options for osteoporosis.
Adapted from Simon SR, editor: *Orthopaedic basic science,* Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 174.

-
    -
        - Alcoholism
    - Radiographic findings
        - Looser zones (microscopic stress fractures)
        - Other fractures
        - Biconcave vertebral bodies
        - Trefoil pelvis
    - Biopsy (transiliac) required for diagnosis
        - Widened osteoid seams are histologic

findings.

  - Treatment: usually includes large doses of vitamin D
- Osteoporosis and osteomalacia are compared in Fig. 1.23.
- Scurvy
  - Vitamin C (ascorbic acid) deficiency
  - Produces a decrease in chondroitin sulfate synthesis
    - Leads to defective collagen growth and repair

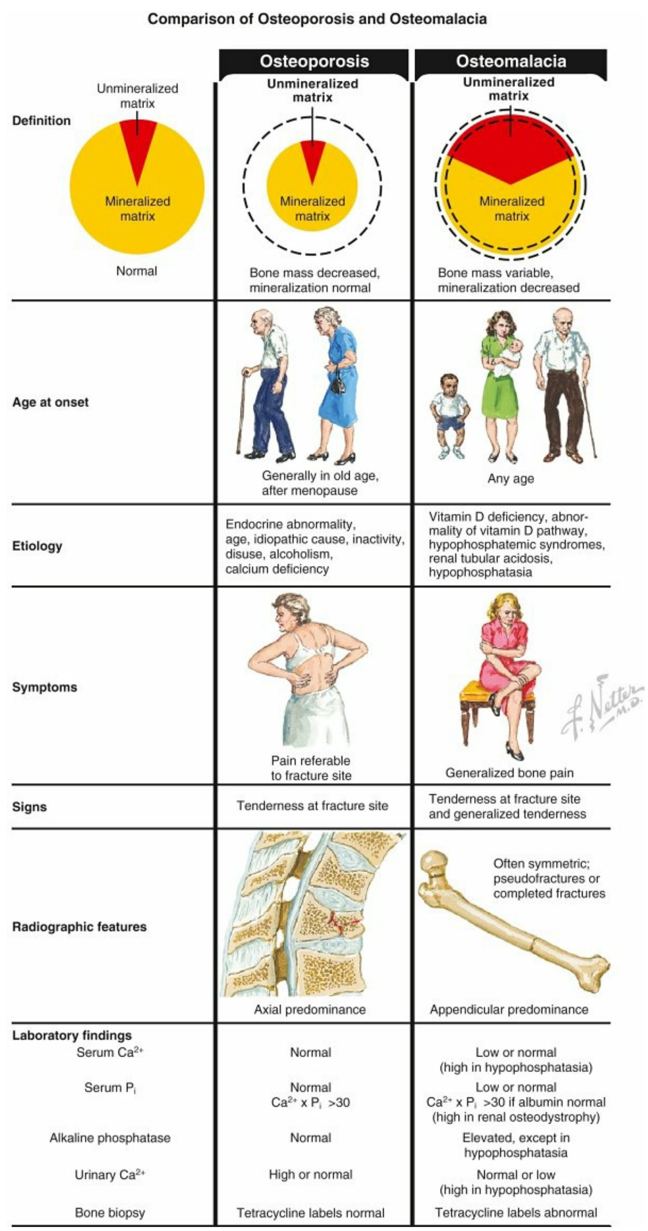


FIG. 1.23 Comparison of osteoporosis and osteomalacia.
From Netter FH: *CIBA collection of medical illustrations,* vol 8: *Musculoskeletal system*, part I: *Anatomy, physiology and developmental disorders,* Basel, Switzerland, 1987, CIBA, p 228.

            - Also leads to impaired intracellular hydroxylation of collagen peptides
        - Clinical features:
            - Fatigue
            - Gum bleeding
            - Ecchymosis
            - Joint effusions
            - Iron deficiency
        - Radiographic findings:
            - May include thin cortices and trabeculae and metaphyseal clefts (corner sign)
        - Laboratory studies: normal results
        - Histologic features
            - Primary trabeculae replaced with granulation tissue
            - Areas of hemorrhage
            - **Widening of the zone of provisional calcification in the physis**
                - Greatest effect on bone formation in the metaphysis
    - Marrow packing disorders
        - Myeloma, leukemia, and other such disorders can cause osteopenia.
    - Lead poisoning
        - Results in short stature and reduced bone density
        - Lead alters the chondrocyte response to PTH-related protein and TGF-β.
- □ Increased osteodensity
    - Osteopetrosis (marble bone disease)
        - Result of decreased osteoclast (and chondroclast) function: failure of bone resorption
    - Osteopoikilosis (spotted bone disease)
        - Islands of deep cortical bone appear within the medullary cavity and the cancellous bone of the long bones
            - Especially in the hands and feet
            - These areas are usually asymptomatic
        - This disease is accompanied by no known incidence of malignant degeneration.
    - Paget disease of bone (osteitis deformans)
        - Elevated serum alkaline phosphatase and urinary

hydroxyproline levels
- **Virus-like inclusion bodies in osteoclasts**—abnormal function of osteoclasts
- Both decreased and increased osteodensities may be present.
  - Depends on phase of disease
    - Active phase
      - Lytic phase: intense osteoclastic bone resorption
    - Mixed phase
      - Sclerotic phase: osteoblastic bone formation
    - Inactive phase

- **Conditions of bone viability**
  - Osteonecrosis
    - Death of bony tissue from causes other than infection
      - Usually adjacent to a joint surface
    - Caused by loss of blood supply as a result of trauma or another event (e.g., SCFE)
    - Idiopathic osteonecrosis of the femoral head and Legg-Calvé-Perthes disease may occur in patients with coagulation abnormalities.
      - Deficiency of antithrombin factors protein C and protein S
      - Increased levels of lipoprotein(a)
    - Commonly affects the hip joint
      - Leads to collapse and flattening of the femoral head, most frequently the anterolateral region
    - **Associated with the following conditions:**
      - Steroids
      - Heavy alcohol use
      - Blood dyscrasias (e.g., sickle cell disease)
      - Dysbarism (caisson disease)
      - Excessive radiation therapy
      - Gaucher disease
    - Cause
      - Osteonecrosis may be related to enlargement of space-occupying marrow fat cells, which lead to ischemia of adjacent tissues.
      - Vascular insults and other factors may also be significant.

- Idiopathic (or spontaneous) osteonecrosis is diagnosed when no other cause can be identified.
- Chandler disease: osteonecrosis of the femoral head in adults
- Medial femoral condyle osteonecrosis: most common in women older than 60 years
    - Idiopathic, alcohol, and dysbaric forms of osteonecrosis are associated with multiple insults.
    - These may be secondary to a hemoglobinopathy (e.g., sickle cell disease) or marrow disorder (e.g., hemochromatosis).
- Cyclosporine has reduced the incidence of osteonecrosis of the femoral head among renal transplant recipients.
- Pathologic changes
    - Grossly necrotic bone, fibrous tissue, and subchondral collapse (Figs. 1.24 and 1.25)
- Histologic findings
    - Early changes (14–21 days) involve autolysis of osteocytes and necrotic marrow.
    - Followed by inflammation with invasion of buds of primitive mesenchymal tissue and capillaries
    - Newly woven bone is laid down on top of dead trabecular bone.

FIG. 1.24 Fine-grain micrograph demonstrating space between articular surface and subchondral bone: crescent sign of osteonecrosis.
From Steinberg ME: *The hip and its disorders,* Philadelphia, 1991, Saunders, p 630.

- Followed by resorption of dead trabeculae and remodeling through creeping substitution
    - The bone is weakest during resorption and remodeling.
    - Collapse (crescent sign on radiographs) and fragmentation can occur.
- Evaluation
    - A careful history (to discern risk factors) and physical examination (e.g., to discern decreased ROM, limp) should precede additional studies.
    - Other joints (especially the contralateral hip) should be evaluated to identify the disease process early.
    - The process is bilateral in the hip in 50% of cases of idiopathic osteonecrosis and up to 80% of cases of steroid-induced osteonecrosis.

- MRI and bone scanning are helpful for early diagnosis.
  - **MRI: earliest study to yield positive results; highest sensitivity and specificity**
- Treatment
  - Resurfacing arthroplasty of the hip is associated with increased risk of implant loosening and failure.
  - Total hip arthroplasty is indicated in Ficat stage III or IV.
  - Nontraumatic osteonecrosis of the distal femoral condyle and proximal humerus may improve spontaneously without surgery.
  - Precise role of core decompression remains unresolved.
    - Results are best when core decompression is performed in early hip disease (Ficat stage I).
- Osteochondrosis (Table 1.18)
  - Can occur at traction apophyses in children
  - May or may not be associated with trauma, joint capsule inflammation, vascular insult, or secondary thrombosis

Cartilage and Joint

- **Hyaline cartilage characteristics**
  - □ Articular bearing surface

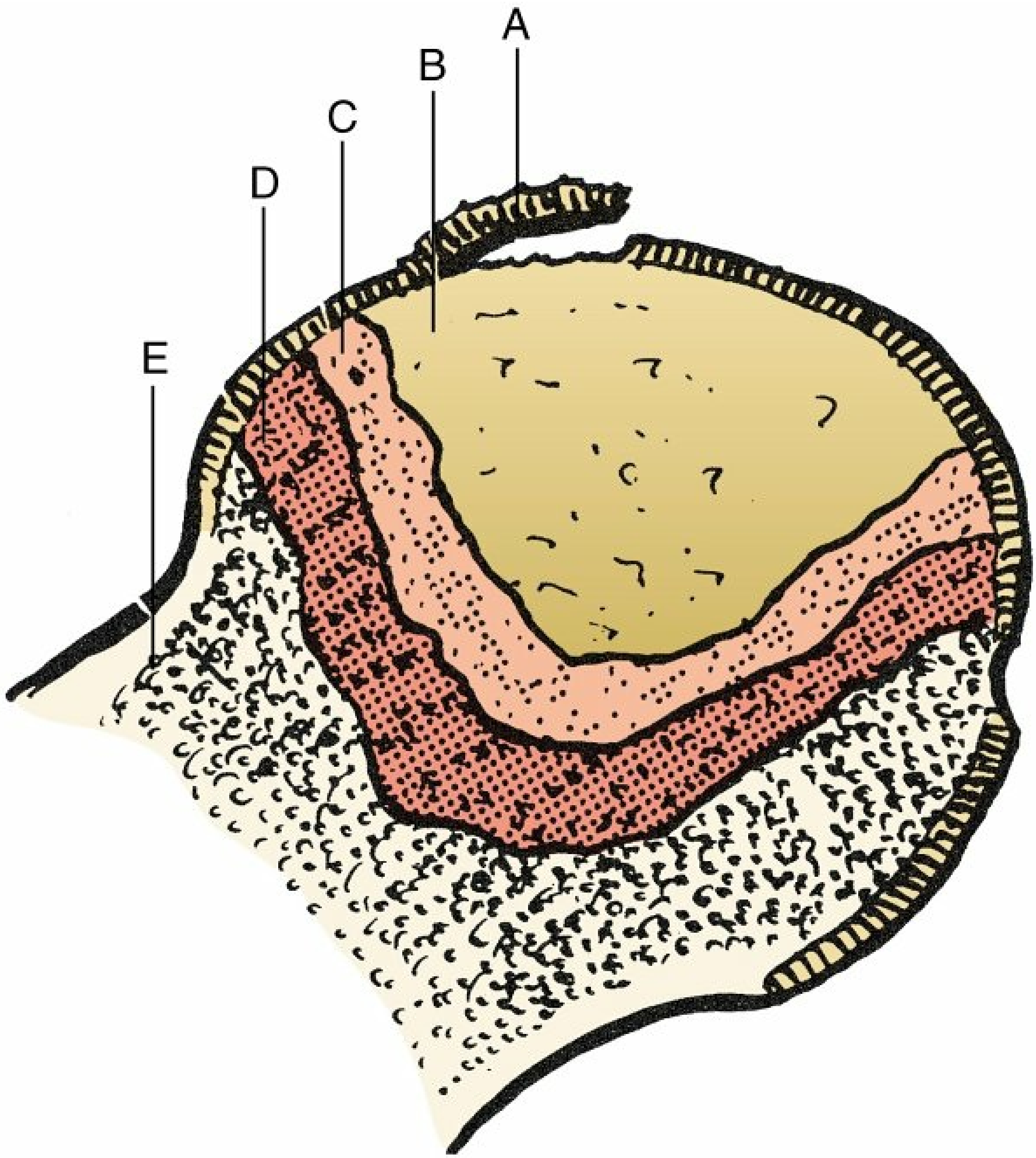


FIG. 1.25 Pathologic features of avascular necrosis. Illustration of articular cartilage *(A)*, necrotic bone *(B)*, reactive fibrous tissue *(C)*, hypertrophic bone *(D)*, and normal trabeculae *(E)*.
From Steinberg ME: *The hip and its disorders,* Philadelphia, 1991, Saunders, p 630.

  - □ Decreases friction and distributes loads
    - • Coefficient of friction in healthy human joint is less than that of ice on ice (0.002–0.04).
  - □ Shock-absorbing cushion resists shear/compression.

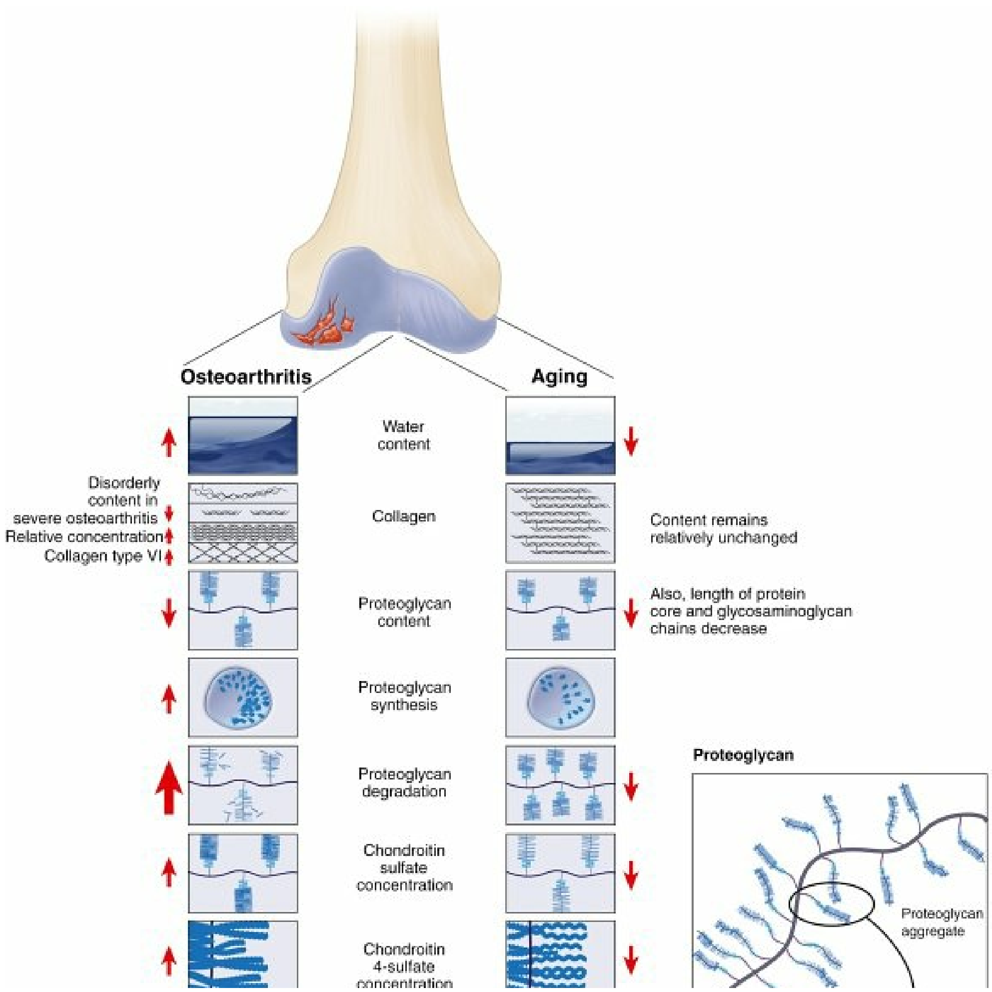
- Withstands impact loads up to 25 N/mm^2
- Avascular, aneural, and alymphatic
  - Receives nutrients and oxygen from synovial fluid via diffusion
  - Heals poorly
- Anisotropic: Properties vary with direction of force
- **Viscoelastic: Properties vary according to rate of force application**.
- Biphasic—property of liquid and solid
- Cartilage homeostasis disrupted by:
  - Direct trauma/excess or inadequate forces
  - Loss of underlying bone structure
  - Genetic defects in normal structure/function
  - Chemical/enzymatic threats

- **Hyaline cartilage composition**
  - Water
    - Approximately 75% of cartilage
    - Highest at surface or superficial layers
    - Recurrent low-level forces shifts water in and out of extracellular matrix (ECM)
    - Responsible for nutrition and lubrication
    - H_2O decreases with aging
    - H_2O increases in osteoarthritis (Fig. 1.26)
  - Collagen
    - Makes up approximately 15% of wet weight (60% of dry weight) (Fig. 1.27; Table 1.19)
    - **Type II collagen: 90%–95% of collagen**
      - Triple helix of α chains (derived from *COL2A1* gene)
      - Genetic defects of type II cause achondrogenesis (lethal at birth), spondyloepiphyseal dysplasia congenita, precocious arthritis
    - Types IX and XI are "linking collagens"
    - **Type X found only near calcified cartilage, including:**
      - Calcified zone of articular cartilage's tidemark
      - Hypertrophic zone of the physis (genetic defect of type X leads to Schmid metaphyseal chondrodysplasia)
      - Fracture callus and calcifying cartilaginous tumors
    - Provides shear and tensile strength

Table 1.18

Common Types of Osteochondrosis

Disorder	Site	Age (YR)
Van Neck disease	Ischiopubic synchondrosis	4–11
Legg-Calvé-Perthes disease	Femoral head	4–8
Osgood-Schlatter disease	Tibial tuberosity	11–15
Sinding-Larsen-Johansson syndrome	Inferior patella	10–14
Blount disease in infants	Proximal tibial epiphysis	1–3
Blount disease in adolescents	Proximal tibial epiphysis	8–15
Sever disease	Calcaneus	9–11
Köhler disease	Tarsal navicular	3–7
Freiberg infarction	Metatarsal head	13–18
Scheuermann disease	Discovertebral junction	13–17
Panner disease	Capitellum of humerus	5–10
Thiemann disease	Phalanges of hand	11–19
Kienböck disease	Carpal lunate	20–40



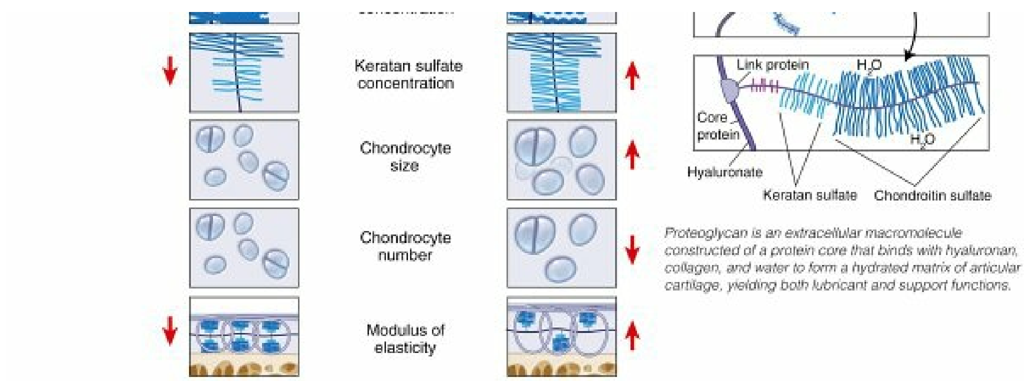


FIG. 1.26 Articular cartilage changes in osteoarthritis and aging. *Arrows* indicate an increase (when pointing up) or a decrease (when pointing down).

From Brinker MR, Miller MD: *Fundamentals of orthopaedics,* Philadelphia, 1999, Saunders, p 9.

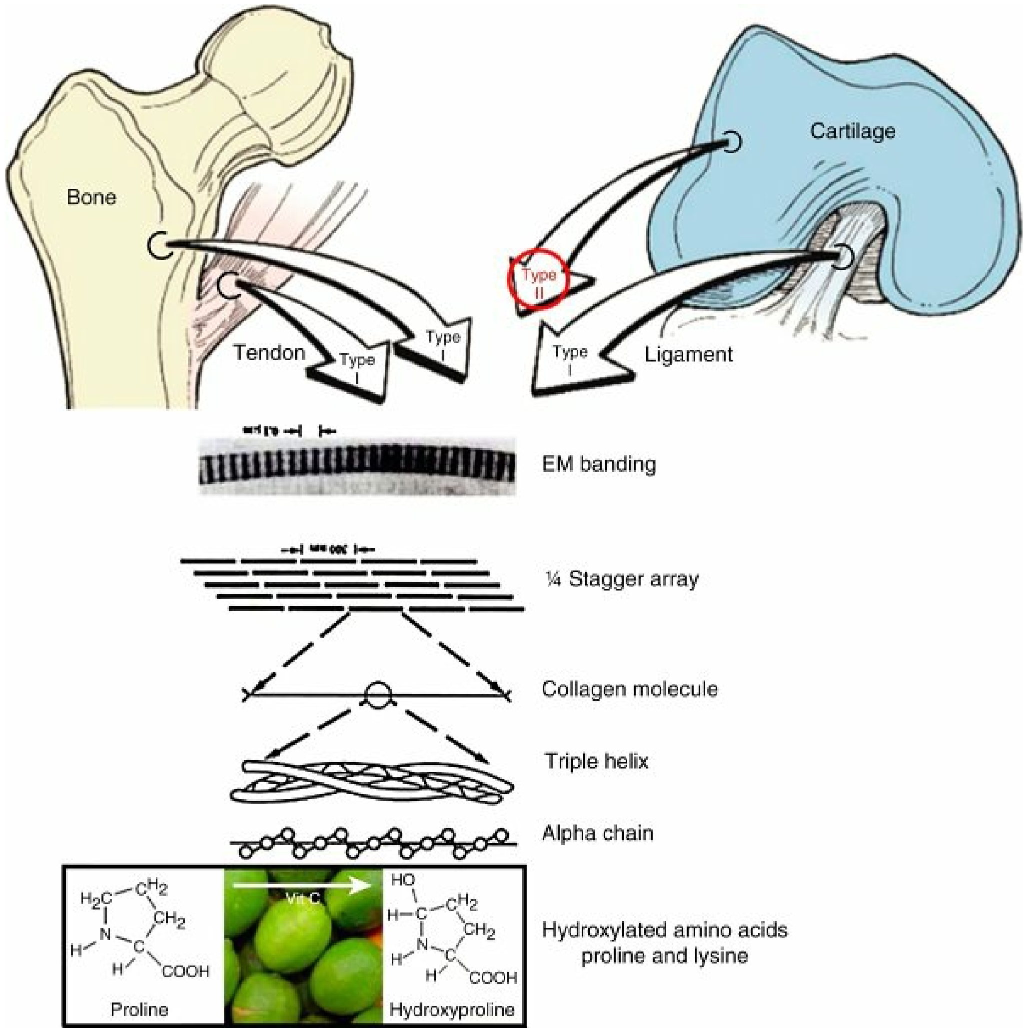


FIG. 1.27 Macrostructure to microstructure of collagen. Although the majority of the collagen in bone, tendon, and ligament is type I, most of the collagen in cartilage is type II. Collagen is composed of microfibrils that are quarter-staggered arrangements of tropocollagen. Note the hole and pore regions for mineral deposition (for calcification). Vitamin C (ascorbic acid) is an enzymatic cofactor needed to form the hydroxylated version of the amino acids proline and lysine, which allow the twists to form the triple helix from the polypeptide α chains. *EM,* Electron microscopy.

Modified from Brinker MR, Miller MD: *Fundamentals of orthopaedics,* Philadelphia, 1999, Saunders.

Table 1.19

Collagen Types, Locations, and Related Genetic Disorders [a]

Type	Location	Genetic Disease
I	Bone, tendon, meniscus	**Osteogenesis imperfecta**
	Disc annulus, eye (sclera), skin	**Ehlers-Danlos syndrome**
II	Articular cartilage Disc nucleus pulposus, eye (vitreous humor)	**Achondrogenesis (lethal)** Hypochondrogenesis **Spondyloepiphyseal dysplasia congenita** Kniest dysplasia Stickler syndrome **Precocious arthritis**
III	Skin, blood vessels	**Ehlers-Danlos syndrome**
IV	Basement membrane: kidney, ear, eye (basal lamina)	Alport syndrome
V	Articular cartilage (in small amounts)	**Ehlers-Danlos syndrome**
VI	Articular cartilage (in small amounts); tethers chondrocyte to pericellular matrix	Bethlem myopathy Ullrich congenital muscular dystrophy
VII	Basement membrane (epithelial)	Epidermolysis bullosa
VIII	Basement membrane (epithelial)	Corneal endothelial dystrophy
IX	Articular cartilage (in small amounts)	**Multiple epiphyseal dysplasia** (one type)
X	Hypertrophic zone or tidemark of cartilage (associated with calcified cartilage)	Metaphyseal chondroplasia, Schmid type
XI	Articular cartilage (in small amounts); acts as an adhesive	Otospondylomegaepiphyseal dysplasia
XII	Tendon	
XIII	Endothelial cells	

[a] More common orthopaedic diseases are in **bold**.

- **Contributes to viscoelastic behavior in that it restrains "swelling" of aggrecan**

□ Proteoglycans

- Make up approximately 10% of wet weight (30% of dry weight) (Fig. 1.28).
- Half-life of 3 months
- Provide compression strength
- Responsible for cartilage's porous structure
- **Trap and hold water**

- Produced by chondrocytes
- **Most common is aggrecan.**
    - Large macromolecules shaped like bristle brushes (see Fig. 1.28)
    - Composed of repeating disaccharide subunits or glycosaminoglycans attached to protein core
        - Repeating carboxyl and sulfate groups which are ionized in solution to COO^- and SO_3^-
        - Repel each other but attract positive cations
        - **Increase osmotic pressure, which traps and holds water and is responsible for ECM's hydrophilic behavior**
        - Provides turgor of matrix
        - Chondroitin sulfate (most prevalent glycosaminoglycan in cartilage)
            - Chondroitin 4-sulfate decreases with age
            - Chondroitin 6-sulfate remains constant
        - Keratin sulfate
            - Increases with age.
    - Multiple core proteins in turn attached to hyaluronic acid (through link proteins) producing proteoglycan aggregate

□ Chondrocytes

- 1%–5% of wet weight
- Only cells in cartilage
    - Derived from undifferentiated mesenchymal precursors
    - **BMP-2 and the transcriptional factor SOX-9 important in regulating chondrocyte differentiation and formation**
- Mechanotransduction—metabolism modulated via mechanical stimulation
    - Cyclical loads of walking stimulate chondrocytes to form matrix
    - Low loads (1–5 MPa) at moderate frequency (≈1 Hz)
    - **Primary cilia are the mechanosensory organ "antennae" for cells.**

- Produce the extracellular matrix of collagen and proteoglycans
    - Intracellular synthesis of procollagen, link peptide, hyaluronic acid, proteoglycans
    - Extracellular assembly of component parts
- Produce proteins and enzymes and maintain matrix
    - IL-1β (also from synovium and WBCs): main cartilage destroyer
    - Metalloproteinases—break down cartilage matrix
        - Collagenase—dissolves collagen (matrix metalloproteinase 13 [MMP-13])
        - Aggrecanase—degrades proteoglycans (extracellular protease enzyme ADAMT)
    - Enzyme inhibitors—protect cartilage
        - Tissue inhibitors of metalloproteinases (TIMPs)
        - Plasminogen activator inhibitor-1 (PAI-1)
- Chondrocytes are most dense and most active in the superficial zone.
- Deeper cartilage zone chondrocytes less metabolically active
    - Decreased rough endoplasmic reticulum
    - Increased intraplasmic filaments (degenerative products)

□ Other matrix components

- Nonaggregating proteoglycans

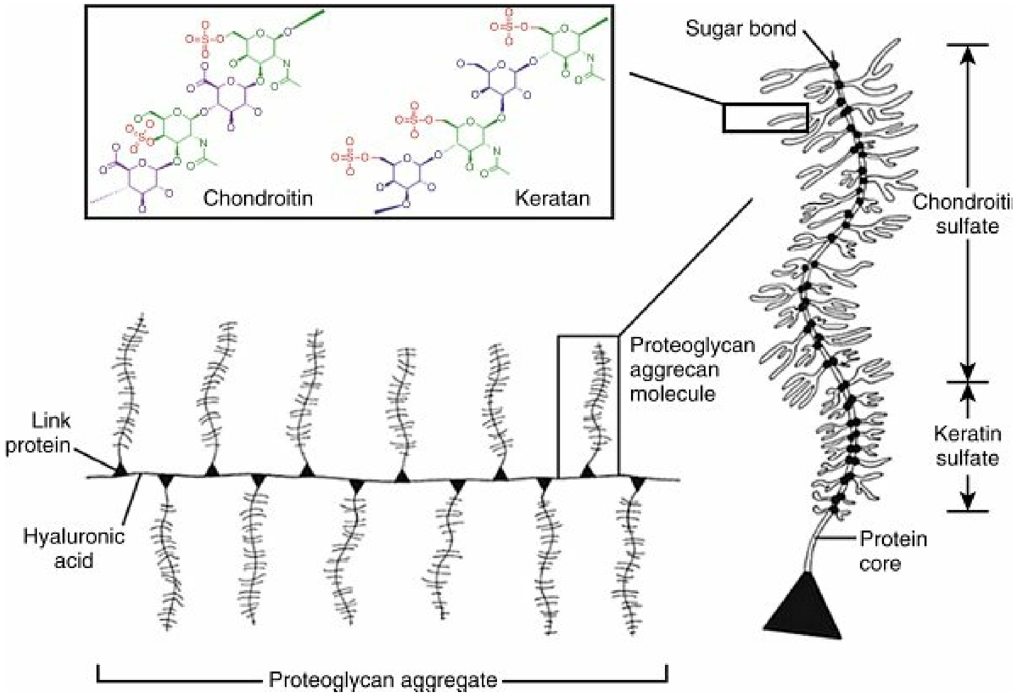


FIG. 1.28 Proteoglycan aggregate and bristle brush–shaped aggrecan molecule. Sulfate ions are transmitted by DTDST protein; a defect in the *DTSDT* gene causes diastrophic dysplasia (short stature with hitchhiker's thumbs and cauliflower ears).
Modified from Brinker MR, Miller MD: *Fundamentals of orthopaedics,* Philadelphia, 1999, Saunders, p 9.

        - Also known as small leucine-rich proteoglycans (SLRP)
        - Important in matrix assembly and cell signaling
        - Decorin and fibromodulin bind to type I and type II collagens and organize and stabilize framework
    - Other matrix proteins
        - Fibronectin—binds to integrins (transmembrane receptors)
            - Increased in osteoarthritis
        - Chondronectin—mediates attachment of chondrocytes to type II collagen
        - Anchorin CII—binds chondrocytes to type II collagen

- **Articular cartilage layers (** Fig. 1.29)
    - **Zone 1: superficial or tangential zone (10%–20% of thickness)**
        - Thin lamina splendens
        - Flat chondrocytes
        - Collagen fibers
            - **Highest concentration**
            - Parallel to joint surface strength against shear
            - Greatest tensile stiffness
        - Lowest concentration of proteoglycans

- Highest concentration of water

- **Zone 2: middle or transition zone (40%–60% of thickness)**
  - Collagen fibers more random and less dense
  - High levels of water and proteoglycan
- **Zone 3: deep zone (30% of thickness)**
  - Lower water content
  - Highest concentration of proteoglycan
  - Chondrocytes and collagen fibers arranged perpendicular to articular surface
- **Zone 4: calcified cartilage zone**
  - Begins at tidemark
  - Transitions stiffness from flexible cartilage to rigid subchondral bone
  - **Low concentration of proteoglycans**
  - **Type X collagen found here**

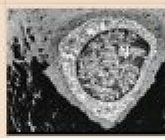
- **Articular cartilage damage and healing**
  - Cartilage is avascular tissue with very limited healing response
  - Chondrocyte viability disrupted by:
    - High-impact loads—trauma or lacerations
    - Prolonged excessive stress—obesity, dysplasia, varus/valgus
    - Prolonged lack of stress—inactivity/disuse
    - Chemical issues:
      - Changes in pH: (normally at 7.4)
      - Enzymes—metalloproteases
    - Laceration depth is key factor
      - Lacerations above tidemark demonstrate chondrocyte cloning
        - Limited increases in numbers of chondrocytes
        - Limited repair
      - Lacerations extending below the tidemark into subchondral bone
        - Cause an inflammatory response
        - **Marrow mesenchymal stem cells respond and produce less durable fibrocartilage (type I collagen)**
      - Forms the basis of the ICRS (International Cartilage Repair Society) grading system
        - Grade 0: normal cartilage
        - Grade 1: nearly normal (superficial lesions)
        - Grade 2: abnormal (lesions extend <50% of cartilage depth)

- Grade 3: severely abnormal (>50% of cartilage depth)
- Grade 4: severely abnormal (through the subchondral bone)

□ Blunt trauma and strenuous loading cause cell apoptosis
- Effects look similar to those of osteoarthritis
- Cartilage thinning and proteoglycan loss

□ Joint immobilization leads to atrophy or cartilage degeneration

Cartilage layers

Layer / Width (μm)	Characteristic	Collagen orientation (cell EM in layer)	Function
Superficial (Gliding zone) 40	↓ Metabolic activity Highest [H_2O] Highest [Lubricin] Flat chondrocytes	Tangential 	Opposes shear
Middle zones (Transitional and radial) 500 – 1000	↑ Metabolic activity ↑ Cell size ↑ Collagen size ↑ [Proteoglycan] Lowest [H_2O]	Oblique to vertical 	Opposes compression
Calcified zone (Begins at tidemark) 300	Ca^{++} crystals (Hydroxyapatite) Type X collagen		As an anchor opposes shear

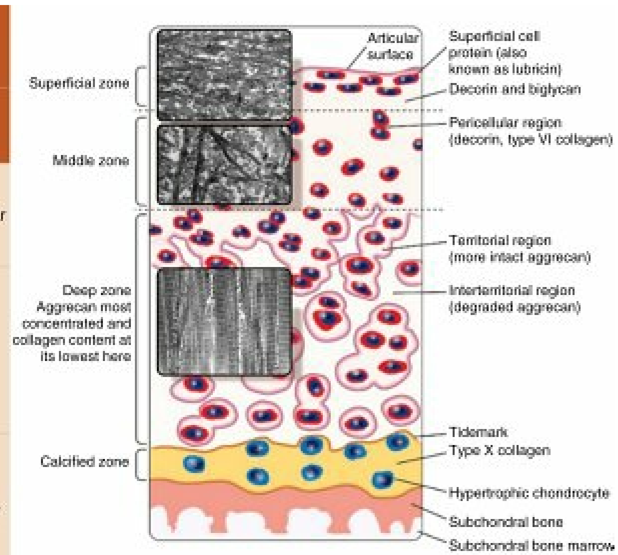


FIG. 1.29 The layers of articular cartilage and their characteristics and functions. *C,* Cytoplasm; *EM,* electron micrograph; *IF,* intermediate filaments; *N,* nucleus.
Composite from Mark R. Brinker MR, Daniel P, O'Connor DP: Basic science. In Miller MD et al, editors: *Miller orthopaedic review,* Philadelphia, 2012, Saunders, Fig. 1.40; Buckwalter JA, Mankin HJ: Articular cartilage. Part I: tissue design and chondrocyte-matrix interactions, *J Bone Joint Surg Am* 79:600–611, 1997.

- Continuous passive motion is believed to benefit cartilage healing
- Four weeks of immobilization decreases proteoglycans/collagen ratio
- Ratio returns to normal after 8 weeks of joint mobilization

□ Joint instability allows abnormal shearing loads
- Early (≈4 weeks): proteoglycan/collagen ratio is decreased.
- Late (≈12 weeks): proteoglycan/collagen is elevated and hydration is increased.
- Instability markedly reduces hyaluronan (disuse does not).

□ Beneficial effects of exercise
- Increased glycosaminoglycans
- Runners may have increased cartilage thickness
- Likely due to chondrocyte modulation through mechanotransduction

□ Growth factors and cartilage injury
- **IL-1 stimulates MMP, COX-2, and nitric oxide synthetase,**

which degrades cartilage.

- **TGF-β stimulates synthesis of ECM and decreases activity of IL-1 and MMP's**
  - Also stimulates chondrogenesis in vitro
- BMP-2, BMP-7, and IGF-1 also stimulate ECM production

▪ **Changes with aging (see** Fig. 1.26)
- □ Decreased number of chondrocytes (but larger in size)
- □ Increased lysosomal enzymes
- □ Senescence markers of chondrocytes include telomere erosion, higher β-galactosidase expression, and reduced Wnt2 expression
- □ Lower response to growth factors (TGF-β)
  - Decreased matrix production and matrix maintenance
  - **Decreased chondroitin SO_4^- (but increased keratan SO_4^-)**
- □ **Proteoglycan molecules smaller, so less able to hold water (lower water content)**
- □ **Increase in advanced glycosylation end products**
  - **Yellows and stiffens cartilage**
- □ Greater stiffness or modulus of elasticity but less tensile strength
  - Increased decorin—decorates collagen for cross-links
  - Increased collagen cross-links and diameter
- □ "Dried up old cartilage is yellow, weak, brittle, & stiff"

▪ **Changes with osteoarthritis**
- □ Increase in cells early (cloning)
- □ Loss of smooth lamina leads to fibrillation/fissures.
  - Higher coefficient of friction
- □ Chondrocytes react to IL-1β and TNF and produce nitric oxide
- □ **IL-1 stimulates MMPs, which degrade matrix**.
  - Collagenases (MMP-13)—first irreversible step
  - Aggrecanase—degrade proteoglycans (ADAMTs)
  - Stromelysin
  - Decreased size and content of proteoglycan molecules
  - Decreased keratan SO_4^- and increased chondroitin/keratan ratio
  - Increase in percentage of nonaggregated glycosaminoglycans
  - **Higher water content and greater permeability initially followed by lower water content in later stages**
- □ Decreased modulus of elasticity (less stiff) and tensile strength

▪ **Other periarticular tissue**
- □ Synovium
  - Loose connective tissue rich in capillaries
  - Lacks a basement membrane; no tight junctions

- Type A synovial cells—macrophage-like
    - Involved in phagocytosis
- Type B synovial cells derived from mesenchymal cells—fibroblast-like
    - Produce synovial fluid and lubricin
- **Lubricin**
    - **Mucinous glycoprotein that binds to hyaluronic acid**
    - Also present in lamina splendens
    - Contributes to boundary lubrication
        - Lubricant is present between two surfaces but its thickness is inadequate to prevent contact throughout the surfaces
    - **Defect associated with camptodactyly-arthropathy–coxa vara–pericarditis (CACP) syndrome**
- **Elastohydrodynamic lubrication**
    - **Major mode of lubrication in joints**
    - **Lubricant pressure causes elastic deformation of the opposing surfaces**.
    - **This elastic deformation increases conformity**.

□ Synovial fluid

- Ultrafiltrate of plasma
- Hyaluronic acid, lubricin, proteinase, collagenases, and prostaglandins
- Nourishes and lubricates cartilage
- Nonnewtonian fluid: shear thinning (thixotropic)
    - Viscosity decreases with increased shear rate.
- Normally contains no RBCs, WBCs, or clotting factors
- Joint fluid analysis
    - Noninflammatory arthritis
        - Clear, straw color, high viscosity
        - WBCs: fewer than 200 cells/μL, with 25% polymorphonuclear leukocytes (PMNs)
    - Inflammatory arthritis
        - Yellow-green tinged with low viscosity
        - WBC count: 2000–75,000 cells/μL, up to 50% PMNs
        - Complement is decreased in rheumatoid arthritis (RA) (normal in ankylosing spondylitis [AS])

- Crystals seen in gout and calcium pyrophosphate (dihydrate crystal) deposition disease (CPDD)
- Septic arthritis
  - Cloudy to opaque
  - WBC count above 50,000–80,000 cells/μL
  - Low glucose and high lactate may also be seen
- Traumatic
  - Increased RBC and protein values
  - Concern for intraarticular fracture if fat globules present
  - MRI neapolitan effusion—fat above plasma above RBCs

- □ Meniscus (labrum in hip/shoulder)
  - Increases contact area and distributes load
  - Deepens the articular surfaces of various synovial joints
  - 90% type I collagen
  - Fibroelastic cartilage
  - Fibrochondrocyte is responsible for meniscal healing
  - More elastic and less permeable than articular cartilage
  - Blood supplies only the peripheral 25% of the knee menisci.
  - Nerve fibers found in peripheral two-thirds.

- **Arthritides (** Table 1.20)
  - □ Osteoarthritis
    - Progressive loss of cartilage structure and function
    - Most common form of arthritis
    - May be idiopathic
    - May be secondary to:
      - Genetics (*Col2* defect); women affected more than men
      - Overload: obesity, labor, dysplasia/femoral acetabular impingement, varus/valgus
      - Trauma: fractures, ligament injuries, impact
    - Tissue changes:
      - Cartilage: enzymatic degradation and loss as discussed previously (Fig. 1.30)
      - Synovium: inflammation, vascular hypertrophy
      - Ligaments: tightened on concave side of deformity
      - Bone: sclerosis, osteophytes, and subchondral cysts

        - **Osteophyte formation due to pathologic activation of endochondral ossification by periarticular chondrocytes through Indian hedgehog (Ihh) mechanism**
        - Muscles: atrophied from inactivity
    - Radiographic findings (Figs. 1.31 and 1.32)
        - Joint space narrowing, often asymmetric, with osteophyte formation
        - Eburnation of bone
        - Subchondral cysts "geodes"
    - Treatment discussed within individual chapters (see Chapter 5, Adult Reconstruction)
- □ Neuropathic arthropathy (Charcot joint disease)
    - Extreme form of arthritis caused by disturbed sensory innervation
        - **Unstable, painless, swollen, red joint**
        - Effusion may show hemarthrosis
        - Histologic findings: osteochondral fragments imbedded in synovium
    - Less pain than would be expected radiographically
    - Etiology: two theories
        - Neuropathic loss of proprioception
            - Repetitive trauma causes microfractures
        - Hyperemia due to loss of sympathetic control
            - Stimulates osteoclasts, weakens bones
    - Radiographic findings (Fig. 1.33)
        - Severe destructive changes on both sides of the joint
        - Scattered "chunks" of bone embedded in fibrous tissue
        - Joint distension by fluid
        - Heterotopic ossification
    - Charcot arthropathy versus osteomyelitis
    - May be difficult with physical examination and radiograph
    - Both display swelling, warmth, and erythema and are common in diabetic patients
    - Indium (In) 111–labeled WBC scan results
        - "Hot" (positive) for osteomyelitis
        - "Cold" (negative) for Charcot arthropathy
    - Treatment includes bracing or casting (see Chapter 6)
    - Neuropathic arthropathy also seen in

- Syringomyelia (see Fig. 1.33C and D)
  - Most common cause of upper extremity neuroarthropathy
  - 80% of cases in shoulder and elbow (see Fig. 1.33D)
  - Joint disease develops in 25% of patients with syringomyelia.
- Leprosy (Hansen disease)
  - Second most common cause in upper extremity
- Other neurologic problems
  - Myelomeningocele: ankle and foot
  - Spina bifida and spinal trauma (see Fig. 1.33G)
  - Congenital insensitivity to pain

□ Rheumatoid arthritis (see Table 1.20)

- Most common inflammatory arthritis
- Affects 0.5%–1% of population; three times more common in women
- 15% concordance rate in monozygotic twins
- Clinical presentation (see Fig. 1.32)
  - Insidious subacute onset over 6 weeks
  - Fatigue, malaise, anemia
  - Morning stiffness and polyarthritis with swelling
  - Hand and foot deformities are most common and are discussed in respective subsequent chapters
  - Also common in the knees, elbows, shoulders, ankles, and cervical spine
  - Subcutaneous rheumatoid nodules (Fig. 1.34)
- Juxtaarticular erosions and periarticular osteopenia on radiographs
- 2010 American College of Rheumatology Classification Criteria for RA are summarized in Table 1.21.
  - Diagnosis requires score 6 or more
  - Criteria include
    - Number of joints involved and duration of involvement
    - Positive laboratory test results often found
      - Erythrocyte sedimentation rate (ESR), C-reactive protein (CRP)

- Rheumatoid factor (RF) titer
    - Antibody (immunoglobulin [Ig] M) against the Fc (crystallizable fragment) portion of IgG
    - Positive result in about 80%
- Test for anticyclic citrullinated protein (anti-CCP) antibodies
    - Also known as anti-CCP antibodies (ACPAs)
    - Most sensitive and specific test (≈90% specific)
    - Presence linked to more aggressive disease

- Pathogenesis
    - T cell–mediated immune response from an infectious or environmental antigen (smoking is one known trigger) in a genetically susceptible individual (HLA-DR4 and HLA-DW4)
    - Mononuclear cells are primary mediator of RA tissue damage
    - Initial response in soft tissues—neovascularization and synovitis
    - $CD4^+$ T lymphocytes (helper cells) activate synovial cells through direct cell-cell contact
    - Synoviocytes produce cytokines
        - Macrophages (type A): main source for TNF-α, IL-1
        - Fibroblast (type B): main source for MMPs, proteases, and RANKL
    - B lymphocytes (plasma cells): make RF, anti-CCP antibodies
    - TNF-α, IL-1, IL-6, IL-7 upregulated
        - IL-1: Regulator of inflammation and matrix destruction

- TNF-α:
    - Upregulates endothelial adhesion molecules and stimulates angiogenesis

Table 1.20

Comparison of Common Arthritides

Arthritis	Age Group Affected	Incidence By Sex
Noninflammatory		
Osteoarthritis	Elderly	M > F
Neuropathic	Elderly	M > F
Acute rheumatic fever	Children	M = F
Ochronosis	Adults	M = F
Inflammatory		
Rheumatoid	Young adults	F > M
Systemic lupus erythematosus	Young adults	F > M
Juvenile rheumatoid arthritis	Children	F > M
Relapsing polychondritis	Elderly	M = F
Spondyloarthropathies		
Ankylosing spondylitis	Young adults	M > F

Reactive arthritis (Reiter syndrome)	Young adults	M > F
Psoriatic	Young adults	M = F
Enteropathic	Young adults	M > F

Arthritis	Age Group Affected	Incidence By Sex
Crystal Deposition Disease		
Gout	Young	M > F
Chondrocalcinosis	Elderly	M = F
Infectious		
Pyogenic	All	M = F
Tuberculous	Elderly	M > F
Lyme disease	Young	M = F
Fungal	All	M > F
Hemorrhagic		
Hemophilia	Young	M
Sickle cell disease	Young	M = F
Pigmented villonodular synovitis	Young	M = F

↓, Decreased; *AFB,* acid-fast bacilli; *ASO,* antistreptolysin O; *CPK,* creatine phosphokinase; *PTT,* partial thromboplastin time.

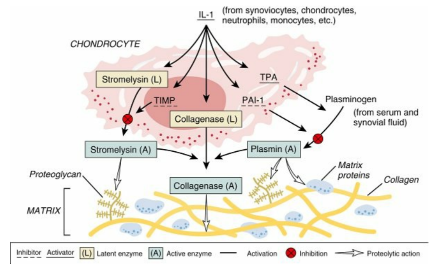


FIG. 1.30 Enzyme cascade of IL-1–stimulated degradation of articular cartilage. *TPA,* Tissue plasminogen activator. From Simon SR, editor: *Orthopaedic basic science,* Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 40.

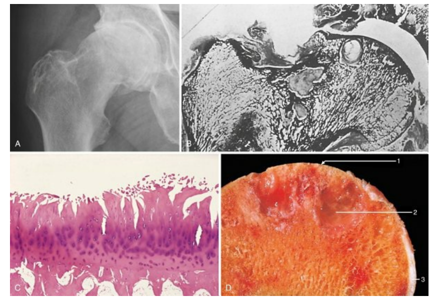


FIG. 1.31 (A) Radiograph showing joint space narrowing, osteophytes, and bony sclerosis. (B) Macrosection of an osteoarthritic human femoral head demonstrating subarticular cysts, sclerotic bone formation, and a superior femoral head osteophyte. (C) Low-power micrograph of osteoarthritis showing fibrillation, fissures, and cartilage loss. D, Gross pathology of femoral head demonstrating cartilage thinning *(1)*, subarticular cyst *(2* [“geode”]), and normal hyaline cartilage remaining *(3)*.

A Courtesy Marc DeHart, MD, and Texas Orthopedics; **B** from Simon SR, editor: *Orthopaedic basic science,* Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons; **C** and **D** from Horvai A: Bones, joints, and soft tissue tumors. In Kumar V et al, editors: *Robbins and Cotran pathologic basis of disease,* ed 9, Philadelphia, 2015, Elsevier, Fig. 26-93.

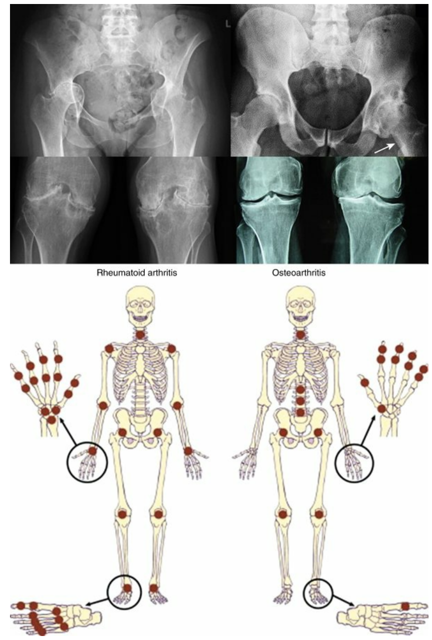
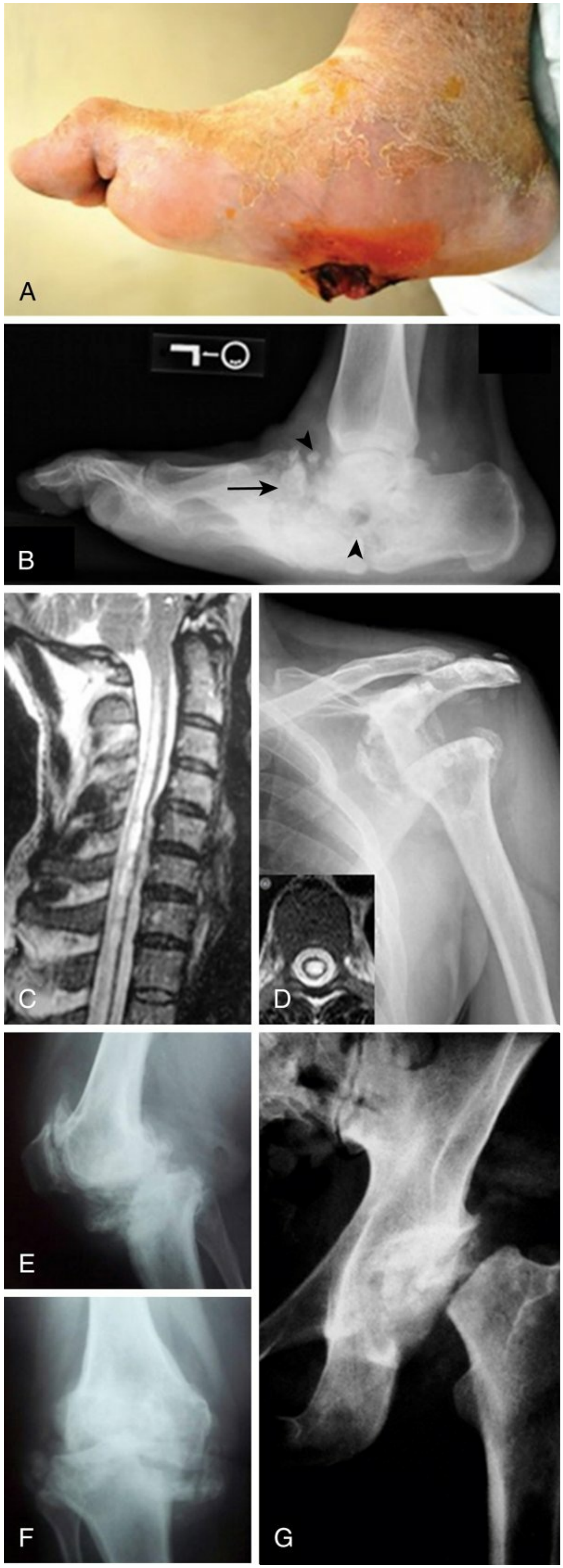


FIG. 1.32 Differences between rheumatoid arthritis and osteoarthritis. Left side of illustration demonstrates the main historical characteristics of RA, including symmetric involvement (both right and left joints as well as both medial and lateral compartments of the knees). Bilateral hand involvement is characteristic and usually involves wrist joints and proximal metacarpal joints. Right side of figure demonstrates osteoarthritis, which often is much more severe in one joint or one compartment of the knee. Hand involvement more commonly involves the distal interphalangeal joints (Heberden nodes) and proximal interphalangeal joints (Bouchard nodes) joints as well as the base of the thumb.

- Promotes influx of leukocytes and activates synovial fibroblasts

            - Promotes pain receptor pathways
            - Drives osteoclastogenesis
- Later response
    - Synovial cells invade cartilage "pannus" and release MMPs, causing chondrolysis
    - Periarticular bone erosions
    - Cytokines stimulate osteoblasts and synovial B cells to make RANKL, which joins with RANK to activate osteoclasts. Responsible for bone destruction.
    - Osteoclasts secrete cathepsin K and carbonic anhydrase.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E
F
G

FIG. 1.33 Neuropathic arthritis. Arthritic degeneration due to lack of sensation can be caused by many diseases. All share radiographic findings that are more severe than the symptoms (often painless) and the fragments from bony destruction. Often findings take many years to develop. (A and B) Diabetic Charcot arthropathy of the foot is easily recognized by most of the industrialized world. (C and D) The most common cause of upper extremity neuropathic joint is syringomyelia (*syrinx* = fluid-filled sac in central cord that causes insidious loss of pain and temperature early). (E–G) Tabetic arthropathy (tertiary syphilis) is the most common neuropathic arthritis of the knee and can often involve the hip.

From Yablon CM et al: A review of Charcot neuroarthropathy of the midfoot and hindfoot: what every radiologist needs to know, *Curr Probl Diagn Radiol* 39:187–199, 2010; Atalar AC et al: Neuropathic arthropathy of the shoulder associated with syringomyelia: a report of six cases, *Acta Orthop Traumatol Turc* 44:328–336, 2010; and Allali F et al: Tabetic arthropathy. A report of 43 cases, *Clin Rheumatol* 25:858–860, 2006.

FIG. 1.34 Upper extremity changes in common arthritis types. Left side of figure shows rheumatoid changes. (A) Swan neck deformity of index, middle, and ring fingers, with PIP joints extended and DIP joints flexed. (B) Boutonnière deformity: PIP joints flexed, DIP joints extended. (C) Bilateral wrist swelling with both ulnar metacarpal phalangeal joint deformities and swan neck deformities of fingers and left thumb. (D) Rheumatoid nodes noted on posterior olecranon region. Right side of figure shows osteoarthritic changes. (E) DIP changes (Heberden nodes) and PIP changes (Bouchard nodes). (F) Radiograph showing osteoarthritic changes at the base of the thumb.

From O'Dell JD: Rheumatoid arthritis. In Goldman L, Schafer AI, editors: *Goldman-Cecil medicine,* Philadelphia, 2016, Elsevier, Fig. 264-3; Sweeney SE et al: Clinical features of rheumatoid arthritis. In Firestein GS et al: *Kelley's textbook of rheumatology,* Philadelphia, 2013, Elsevier, Fig. 70-4; and http://medsci.indiana.edu/c602web/602/c602web/jtcs/docs/heber1.html

- Systemic manifestations
    - Rheumatoid vasculitis

            - Distal splinter hemorrhage
            - Cutaneous ulcers (pyoderma gangrenosum)
            - Visceral arteritis
        - Pericarditis and pericardial effusion
        - Pulmonary disease including nodules and fibrosis
        - Felty syndrome: severe erosive RA with splenomegaly and leukopenia
- Treatments and their perioperative considerations
    - Regimen variable and often employs multiple agents
    - NSAIDs: help symptoms early—antiinflammatory effects
        - Should be held for 7–10 days preoperatively.
    - Low-dose steroids
        - Decrease prostaglandins and leukotrienes
        - Used initially as "bridge therapy" to disease-modifying antirheumatic drugs (DMARDs)
        - "Stress dose" steroid should be used perioperatively for patients on long-term steroid therapy
    - DMARDs
        - Intended to address underlying autoimmune response
        - Conventional DMARDs take 2–6 months to work
        - Methotrexate: folate analogue
            - Inhibits purine metabolism and T-cell activation
            - Inhibits neovascularization
            - Adverse reactions (ADRs): toxic to bone marrow, liver, and lung
            - Usually can continue through surgery
        - Azathioprine: immunosuppressive agent
            - ADR: neutropenia

- Cyclosporine: immunosuppressive agent
  - Inhibits activation of $CD4^+$ T cells
  - ADRs: nephrotoxicity, neurotoxicity, gingival hyperplasia
- Hydroxychloroquine (Plaquenil)
  - Inhibits toll-like receptor 9 (TLR9)
  - ADR: retinal toxicity (requires ophthalmology follow-up)

Table 1.21

The 2010 ACR-EULAR Classification Criteria for Rheumatoid Arthritis

Criteria	Score
A. Joint Involvement	
1 Large Joint	0
2–10 Large Joints	1
1–3 Small Joints	2
4–10 Small Joints	3
>10 Joints (at least 1 small joint)	5
B. Serology (at least 1 test result is needed)	
Negative RF and negative ACPA	0
Low-positive RF or low-positive ACPA	2
High-positive RF or high-positive ACPA	3
C. Acute-Phase Reactants (at least 1 test result is needed)	
Normal CRP and normal ESR	0
Abnormal CRP or abnormal ESR	1
D. Duration of Symptoms	
<6 weeks	0
>6 weeks	1

From Aletaha D et al: 2010 rheumatoid arthritis classification criteria: an American College of Rheumatology/European League Against Rheumatism collaborative initiative, *Arthritis Rheum* 62:2569–2581, 2010.

- Usually can continue through surgery
- Sulfasalazine
    - Decreases synthesis of inflammatory mediators
    - ADRs: granulocytopenia, hemolytic anemia (glucose-6-phosphate dehydrogenase [G6PD])

        - Usually can continue through surgery
    - Minocycline
        - Inhibits MMP collagenase
        - ADR: cutaneous hyperpigmentation
    - Biologic DMARDs
        - **Target TNF-α: etanercept, infliximab, adalimumab**
        - **Targets IL-1: anakinra**
        - Targets CD20: rituximab
        - Surgery should be scheduled at end of dosing cycle (e.g., in a patient taking etanercept schedule, surgery should occur the second week after the first withheld dose).
        - **Risks of opportunistic infection and lymphoma**
- Surgical treatment is discussed within respective chapters.

□ Juvenile idiopathic arthritis (JIA) is discussed in Chapter 3, Pediatric Orthopaedics.

□ Systemic lupus erythematosus (Fig. 1.35; see Table 1.20)

- Chronic inflammatory disease of unknown origin
- 90% of cases in women (blacks > whites)
- Initially mediated by tissue-binding autoantibodies and immune complexes (type III hypersensitivity)
- Pathophysiology
    - Susceptible genetics stimulated by environment
    - Immune system autoregulatory failure
    - Sustained production of antibody to self-antigens
    - Antinuclear antibodies (ANAs)—best screen; positive in 95%
    - Anti-dsDNA, anti-Sm, anti-La (SS-B), antihistone antibodies—drug-induced lupus
    - Immune complexes accumulate in various tissues and cause chronic inflammation

            - Skin/joints—rash and arthritis
            - Heart/kidney—pericarditis/nephritis
            - Blood vessels—vasculitis
    - Clinical findings
        - Bone and joint involvement—most common feature
            - Nonerosive polyarthritis affects over 75% (hand and wrist most common).
            - Osteonecrosis (especially with steroids)
        - Butterfly malar rash—classic feature
        - Fever, pancytopenia
    - Pharmacologic treatment similar to that for RA.
- □ Seronegative spondyloarthropathies
    - Characterized by negative RF titer result and, often, positive HLA-B27 test result
    - Symptoms
        - Inflammatory back pain
        - Peripheral arthritis
        - Enthesitis—heel pain
        - Dactylitis—sausage digit
        - Eye—uveitis (iritis), conjunctivitis
        - Skin, mucosal, GI, urethral
    - Similar treatment routines, including NSAIDs, steroids, and DMARDs
- □ Ankylosing spondylitis (AS) (Fig. 1.36; see Table 1.20)
    - Male/female ratio 3:1; ages 20–40 years
    - Most common in Northern European whites
    - 90% HLA-B27 positive (Table 1.22)
    - Symptoms and findings
        - Bilateral sacroiliitis (earliest symptom)
        - Improves with exercise, not better with rest, pain at night
        - Associated morning stiffness
        - Progressive spinal flexion deformities over life
            - Chin-on-chest deformity
            - Modified Schober test (loss of lumbar flexion) (see Fig. 1.36C)
                - Two marks are made10 cm apart over lumbar spine in erect patient.
                - With patient in maximum spinal

flexion, increase of less than 4 cm between marks indicates loss of flexion.

- Hip involvement at young age—poor prognosis
- Enthesitis: inflammation of tendon insertion
- Loss of chest expansion
- Uveitis: red, painful eye in 40%
- Aortic insufficiency and heart block

- Radiographic changes
  - Squaring of the vertebrae
  - Vertical syndesmophytes
  - Bamboo spine
  - Autofusion of sacroiliac joints (see Fig. 1.36B)
  - Whiskering of the entheses
- Surgical treatment for AS is discussed within Chapter 8, Spine.

□ Reactive arthritis (Reiter syndrome) (Fig. 1.37; see Table 1.20)

- Classical triad presentation: “Can’t see, can’t pee, can’t climb a tree.”
- Young white males (18–40 years)
- Follows an infection at another site (hence “reactive”)
  - Chlamydia, Shigella, Yersinia, Salmonella
- Findings
  - Conjunctivitis, urethritis, and oligoarticular arthritis

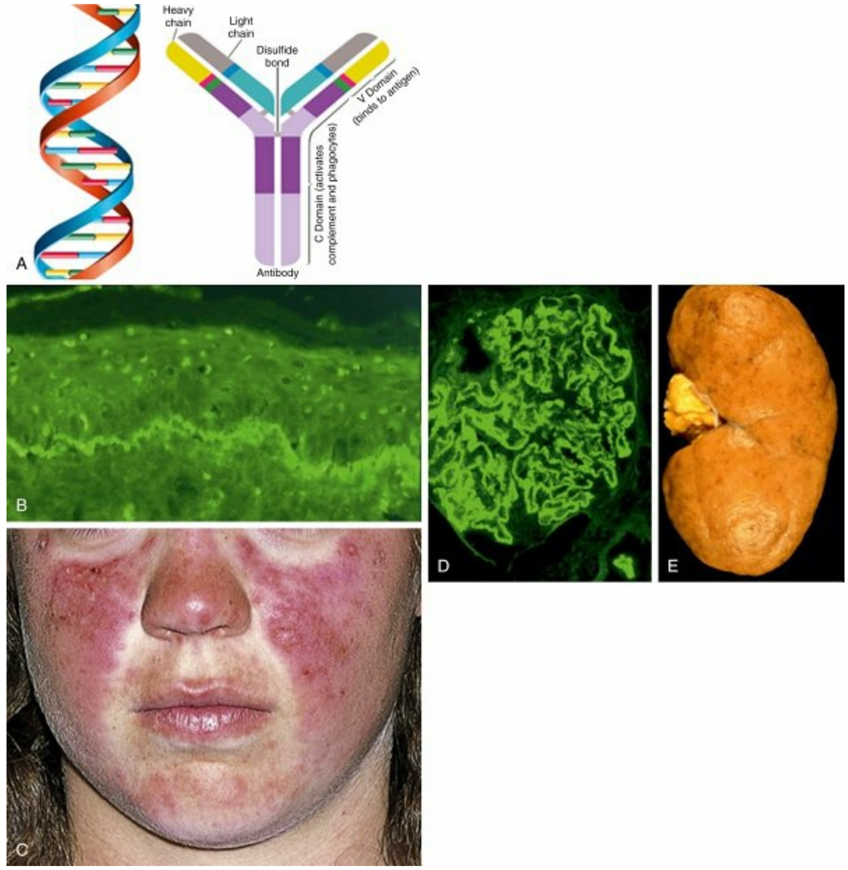


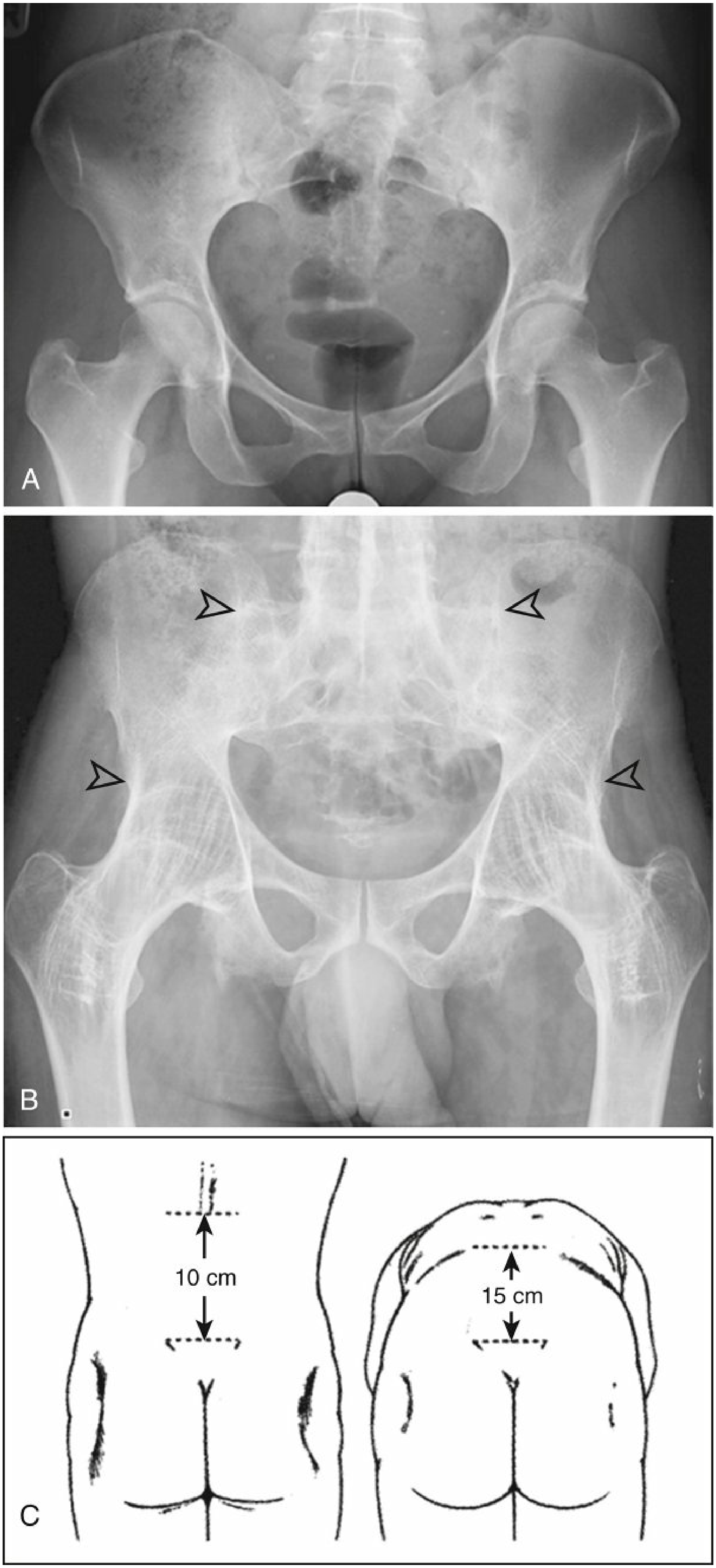
FIG. 1.35 Systemic lupus erythematosus. (A) Autoantibodies to DNA and DNA-binding proteins form immune complexes that stimulate immune system–directed inflammation throughout the body (type III hypersensitivity reaction). (B) Direct immunofluorescence with anti–immunoglobulin G antibodies shows immune complex deposits at two different places: a bandlike deposit along the epidermal basement membrane—positive result of lupus band test—and within the nuclei of the epidermal cells (ANAs). (C) Most patients have skin and joint involvement. The classic butterfly rash of SLE occurs in 10%–50% of patients with acute SLE. (D) The same immune complexes are seen in the basement membrane of the renal glomerulus. (E) Flea-bitten appearance of kidney specimen, with lupus nephritis causing various degrees of proteinuria, hematuria, and cellular casts.

From Habif TP: *Clinical dermatology,* ed 5, St Louis, Mosby/Elsevier, 2009; Wikimedia Commons: Diffuse proliferative lupus nephritis. http://en.wikipedia.org/wiki/Lupus_nephritis#mediaviewer/File:Diffuse_proliferati ; and Wikimedia Commons: Lupus band test. http://en.wikipedia.org/wiki/Systemic_lupus_erythematosus#mediaviewer/File:L

- Sudden asymmetric swelling and pain in knee, ankle, hip
- May persist 3–5 months
- Feet affected more often than hands (heel pain)
  - Calcaneal periostitis and metatarsal head erosion
- Dactylitis: sausage digit of one finger/toe (see Fig.

1.37E)

    - 60% of patients with chronic disease have sacroiliitis.
    - Painless mucocutaneous ulcers (penile) and oral stomatitis (see Fig. 1.37B)
    - Urethritis (dysuria), prostatitis, or cervicitis
    - Pustular lesions on the extremities, palms, and soles (keratoderma blennorrhagicum)
- Treatment: NSAIDs and PT



A
B
C
10 cm
15 cm

FIG. 1.36 Ankylosing spondylitis is an axial seronegative spondyloarthropathy that causes progressive cervical and thoracic kyphosis and bamboo spine but has earliest involvement in the sacroiliac joints. (A) Early sacroiliitis demonstrated by loss of clarity and sclerosis in the lower third of the sacroiliac joints, particularly affecting the iliac side of the right sacroiliac joint (hip joints are normal). (B) Advanced disease with ankylosis or fusion of both the sacroiliac and hip joints. (C) Schober test; two marks made 10 cm apart on lumbar spine in erect stance should be less than 14 to 15 cm during forward flexion.
From Raychaudhuri S: The classification and diagnostic criteria of ankylosing spondylitis, *J Autoimmun* 48–49:128–133, 2014.

- ▫ Psoriatic arthropathy (PsA) (see Table 1.20)
    - Affects 5%–30% of patients with psoriasis
    - Usually skin disease precedes arthritis
    - Men and women (aged 30–40 years) equally affected
    - Characteristic changes
        - Distal interphalangeal (DIP) involvement (rare in other inflammatory arthritides)
        - Nail changes in 90%
            - Pitting, fragmentation, and discoloration
        - 30% have sausage digits
        - Prominent enthesitis and tenosynovitis
        - Arthritis mutilans—most destructive form
        - Telescoping (shortening) of digits
    - Pathophysiology
        - Upregulated RANKL in synovium (B-type cells)
        - Marked increase in osteoclast precursors
    - Radiographic findings
        - Pencil-in-cup deformity, DIP
        - Small joint ankylosis
        - Osteolysis of metacarpal (MC) and phalangeal bone
        - Periostitis and bony enthesitis
- ▫ Enteropathic arthritis (see Tables 1.20 and 1.22)
    - Arthritis in presence of inflammatory bowel disease
    - Varied clinical picture, but joint erosions uncommon
    - 10%–50% of patients experience peripheral joint arthritis.
        - Acute monoarticular synovitis precedes bowel symptoms.
        - Nondeforming arthritis
        - More common in large weight-bearing joints
        - 10%–15% of cases associated with ankylosing spondylitis

▪ **Crystal deposition arthropathy**

- ▫ Pathology from accumulation of crystal formation or deposition in or around joints

- Gout: monosodium urate
- CPDD, also called pseudogout: calcium pyrophosphate
- Tumoral calcinosis: calcium apatite
- Calcium oxalate

□ Gout (see Table 1.20)

- Disorder of purine nucleic acid metabolism, causing hyperuricemia
- Deposition of monosodium urate crystals in joints
- Crystals activate inflammatory mediators
    - Inflammatory mediators are inhibited by colchicine.
    - Attacks precipitated by dehydration, excess alcohol or dietary purines, chemotherapy
- Diagnosis
    - Recurrent acute joint pain
    - Men aged 40–60 years, postmenopausal women
    - Usually lower extremity, great toe (podagra)
    - Crystal deposition as tophi when chronic
        - Ear helix, eyelid, olecranon, Achilles tendon
    - Renal disease or stones—second most common site
- Radiographic findings
    - Soft tissue swelling early: edema, tophi
    - Punched-out or rat bite periarticular erosions
    - Sclerotic overhanging borders
- Synovial fluid findings
    - Concomitant septic arthritis must be ruled out
    - WBC count: wide range (5,000–80,000 cells/μL; average, 15,000–20,000 cells/μL), mostly PMNs

Table 1.22

Associations Between HLA Alleles and Susceptibility to Some Rheumatic Diseases

Disease	HLA Marker	Frequency (%) in Patients (Whites)	Frequency (%) in Controls (Whites)	Relative Risk
Ankylosing spondylitis	B27	90	9	87
Reactive arthritis (Reiter syndrome)	B27	79	9	37
Psoriatic arthritis	B27	48	9	10
Inflammatory bowel disease with spondylitis	B27	52	9	10
Adult rheumatoid arthritis	DR4	70	30	6
Polyarticular juvenile rheumatoid arthritis	DR4	75	30	7
Pauciarticular juvenile rheumatoid arthritis	DR8	30	5	5
	DR5	50	20	4.5
	DR2.1	55	20	4
Systemic lupus erythematosus	DR2	46	22	3.5
	DR3	50	25	3
Sjögren syndrome	DR3	70	25	6

Adapted from Nepom BS, Nepom GT: Immunogenetics and the rheumatic diseases. In McCarty DJ, Koopman WJ, editors: *Arthritis and allied conditions: a textbook of rheumatology*, ed 12, Philadelphia, 1993, Lea & Febiger.

FIG. 1.37 Reactive arthritis (formerly Reiter syndrome). (A) Conjunctivitis. (B) Circinate balanitis (urethritis not shown). (C) Oligoarthritis (single knee effusion). (D) Fluffy calcaneal periostitis. (E) Dactylitis (sausage digit).

From Miller MD et al: *Review of orthopaedics,* ed 6, Philadelphia, 2012, Saunders; and Wu IB, Schwartz RA: Reiter's syndrome: the classic triad and more, *J Am Acad Dermatol* 59:113–121, 2008.

    - Yellow, needle-shaped crystals when parallel to compensator (Fig. 1.38A)
    - Strong negative birefringence
  - Treatment:
    - NSAIDs and colchicine (microtubule inhibitor that inhibits mitosis) for acute attack
    - Chronic/maintenance therapy
    - Weight loss, low-purine diet, limit of alcohol intake
    - Probenecid: uricosuric agent
    - Allopurinol: xanthine oxidase inhibitor
    - Febuxostat in renally impaired patients
- Pseudogout (see Table 1.20)
  - Deposition of calcium pyrophosphate dehydrate (CPPD) crystals in joints
  - Associated with lupus, renal dialysis, hemochromatosis,

hyperparathyroidism, RA, Wilson disease
- Chondrocalcinosis
- Calcification within hyaline or fibrocartilage or menisci
- Seen in pseudogout but also in other conditions
- Genetic version: *ANKH* gene mutation
- Increases extracellular pyrophosphate
- Synovial fluid findings
    - WBC counts 5000–100,000 cells/μL (average, 24,000 cells/μL)
    - Rhomboid-shaped crystals in WBCs
    - Weakly positively (blue) birefringent when parallel (see Fig. 1.38B)
- Radiographic findings: fine linear calcification in hyaline cartilage and more diffuse calcification of menisci and other fibrocartilage (triangular fibrocartilage complex, acetabular labrum)
- Treatment with NSAIDs and, potentially, steroid injection

□ Calcium hydroxyapatite crystal deposition disease
- Apatite is primary crystal of normal bone.
- Accumulates abnormally in areas of tissue damage or in hypercalcemic or hyperparathyroid states (chronic kidney disease [CKD])
- Associated with
    - Acute attacks of bursitis/synovitis
    - Severe degenerative joint disease
    - Calcific tendinitis of rotator cuff and hip abductors
- Destructive arthropathy can occur in the knee and shoulder.
    - Milwaukee shoulder: calcium phosphate deposition with cuff tear arthropathy

□ Calcium oxalate deposition
- Primary oxalosis—rare genetic defect of liver enzymes
    - Alanine glyoxylate aminotransferase (AGT)
    - Glyoxylate reductase (GR)
- Nephrocalcinosis, renal failure, and death by age 20 years
- Treatment: liver/kidney transplantation
- Secondary oxalosis—more common
    - Metabolic abnormalities of chronic renal insufficiency
    - Associated with calcium oxalate arthritis/periarthritis and nephrolithiasis
- Diagnosis: synovial fluid usually contains fewer than 2000 WBCs/μL.

• Birefringent bipyramidal crystals (see Fig. 1.38C)

- **Hemophilic arthropathy (** Fig. 1.39)
  - ▫ X-linked recessive defect of factor VIII (A) or IX (B); discussed further in Chapter 3, Pediatric Orthopaedics
  - ▫ Decreased ROM and eventually ankylosis
  - ▫ Pathophysiology
    - • Recurrent bleeds and chronic synovitis
    - • Synovial hypertrophy/hyperplasia
    - • Iron-laden phagocytic type A synovial cells
    - • Synovium destroys cartilage
  - ▫ Radiographic findings
    - • Flat condylar surface and widened notch in knee
    - • Inferior patellar squaring
    - • Talar flattening in ankle
  - ▫ Treatment
    - • Early: prevention of bleeds/factor replacement
    - • Radiation ablation of synovium with yttrium (Y) 90 microspheres and phosphorus (P) 32 colloid
    - • Late: arthroplasty

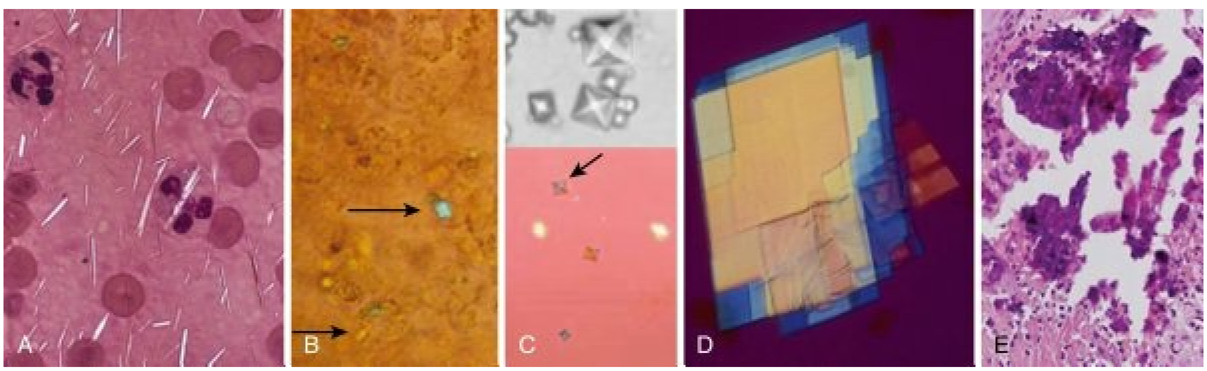


FIG. 1.38 Synovial fluid crystals. (A) Gout: yellow uric acid parallel to compensator, most common in first metatarsophalangeal joint. (B) Calcium pyrophosphate (dihydrate crystal) deposition disease (CPDD) or pseudogout crystals: blue rhomboid crystals *(arrow)* most common in knees and wrists. (C) Calcium oxalate crystals *(arrow)* are pyramidal and almost exclusively seen in patients with renal damage and oxalosis. (D) Platelike cholesterol crystals are rare and can be found in inflammatory synovial fluid and in fluids drained from bursas of patients with rheumatoid arthritis, systemic lupus erythematosus, and seronegative spondyloarthropathy. (E) Calcium apatite crystals from tumoral calcinosis on histology slide from tissue.
From McPherson RA, Pincus MR, editors: *Henry's clinical diagnosis and management by laboratory methods,* ed 21, Philadelphia, 2007, Saunders Elsevier; Firestein GS et al, editors*: Kelley's textbook of rheumatology,* ed 8, Philadelphia, 2008, Saunders; Courtney P, Doherty M: Joint aspiration and injection and synovial fluid analysis, *Best Pract Res Clin Rheumatol* 23:161–192, 2013; Martínez-Castillo A et al: Synovial fluid analysis, *Rheumatol Clin* 6:316–321, 2010; and Topaz O et al: A deleterious mutation in SAMD9 causes normophosphatemic familial tumoral calcinosis, *Am J Hum Genet* 79:759–764, 2006.

Muscle

- **Skeletal muscle anatomy (** Fig. 1.40)
  - □ Cellular anatomy
    - Sarcolemma: plasma membrane surrounding cell
      - Extends into cell surrounding myofibrils

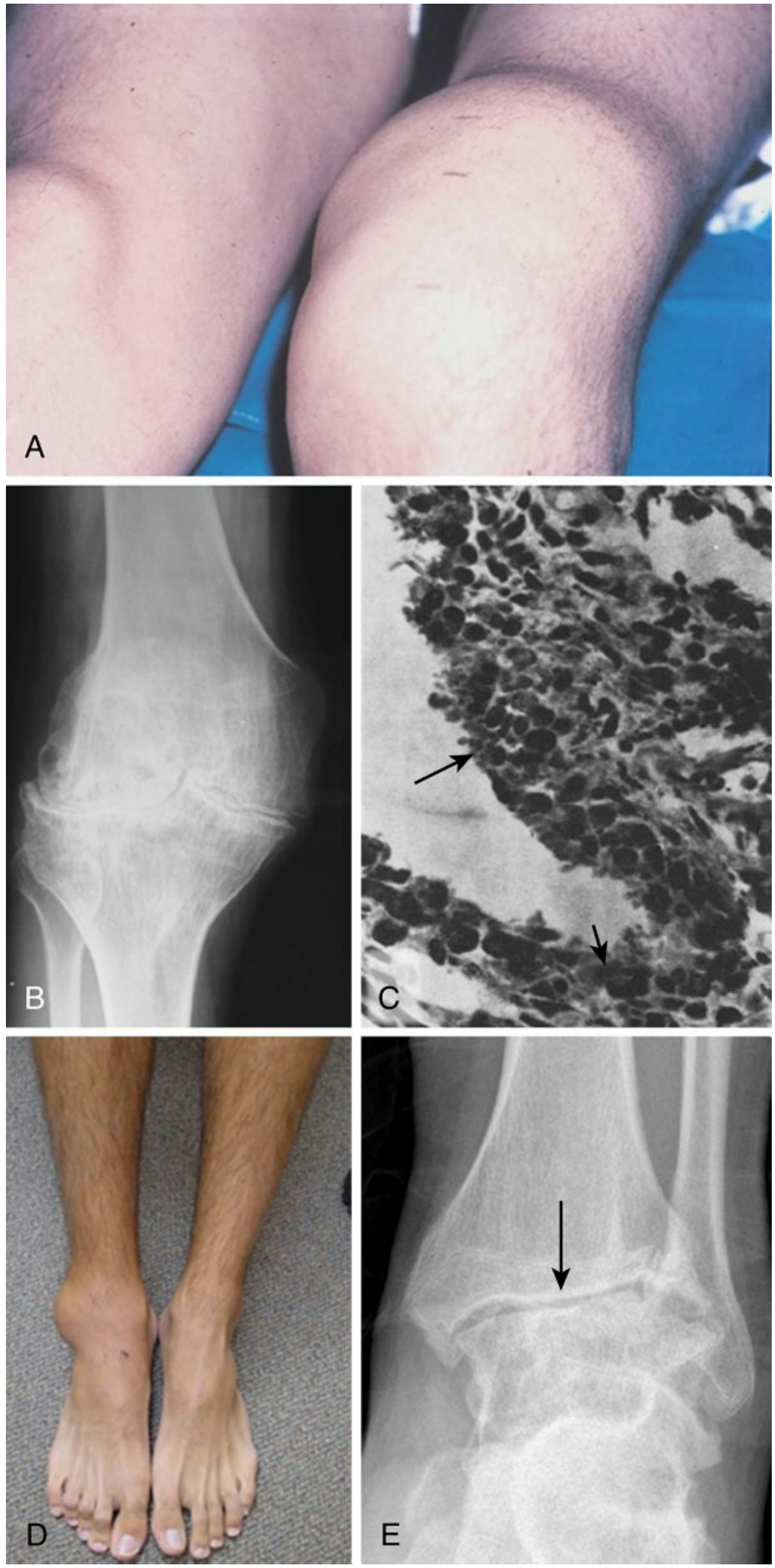


FIG. 1.39 Hemophilic arthropathy. (A) Recurrent knee effusions and synovitis. (B) Radiograph of end-stage

arthropathy. (C) Synovial proliferation of hemophilic arthropathy demonstrates phagocytic (type A) synovial cells laden with iron pigment but no giant cells, polymorphonuclear leukocytes, and rare lymphocytes. (D) Bloody ankle effusion presentation of teen whose grandfather had a history of bleeding disorder. (E) End-stage hemophilic arthropathy of ankle demonstrates flattening of the talus *(arrow)*.

From Rodriguez-Merchan EC: Musculoskeletal complications of hemophilia, *HSS J* 6:37–42, 2010; Mainardi CL et al: Proliferative synovitis in hemophilia: biochemical and morphologic observations, *Arthritis Rheum* 21:137–144, 1978; photo courtesy Texas Orthopedics Sports Medicine and Rehabilitation; and Rodriguez-Merchan EC: Prevention of the musculoskeletal complications of hemophilia, *Adv Prev Med* 2012:201271, 2012.

        - Forms the transverse tubules (Fig. 1.41).
    - Multiple nuclei: typically located adjacent to sarcolemma
    - Sarcoplasmic reticulum (SR)
        - Smooth endoplasmic reticulum that surrounds the individual myofibrils
        - Stores calcium in intracellular membrane–bound channels.
        - Ryanodine receptors (e.g., RYR-1) regulate the release of calcium from the SR and serve as a connection between the SR and sarcolemma-derived transverse tubule.
        - Abnormality of ryanodine receptors is implicated in persons susceptible to malignant hyperthermia.
            - Dantrolene decreases loss of calcium from the SR.
- □ Contractile elements
    - Sarcomere: basic functional unit of muscle contraction
    - Myofibrils
        - Set of sarcomeres parallel to axis of cell
        - (1–3 μm in diameter and 1μ2 cm long)
    - Sarcomere organization causes the banding pattern (striations) seen in skeletal muscle (Table 1.23; see Fig. 1.40).
        - Costamere connects the sarcomere to the sarcolemma at the Z disc.
        - Z disc (or line) represents terminus of sarcomere
        - Contains desmin, α-actinin, and filamin
        - A-band (or dark band) represents **thick filaments.**
            - **Thick filaments composed of myosin**
            - Also contains myosin [H-band], M protein, C protein, titin, and creatine kinase

            - I-band represents **thin filaments.**
                - Primarily composed of actin
                - Also contains
                    - Troponin: has binding site for Ca
                    - Tropomyosin: prevents myosin-actin interaction
                - Attach to Z disc
                - Involved in delayed-onset muscle soreness (DOMS)

- □ Gross anatomy
    - Fascia (tough connective tissue) covers muscle and allows sliding.
    - Epimysium (more delicate) surrounds bundles of fascicles.
    - Perimysium surrounds individual muscle fascicles (hundred of muscle fibers).
    - Endomysium surrounds individual myofibers.
    - Stretch receptors
        - Muscle spindles: located within muscle, transmit muscle length to CNS, control muscle stiffness
        - Golgi tendon organ: located at musculotendinous junction, helps prevent excess tendon lengthening
    - Myotendinous junction
        - Often the site of tears with eccentric contraction (forced lengthening of the myotendinous junction during contraction), which places maximum stress across this area
        - Myofilament bundles are linked directly onto collagen fibrils, with sarcolemma filaments interdigitating with the basement membrane (type IV collagen) and tendon tissue (type I collagen).

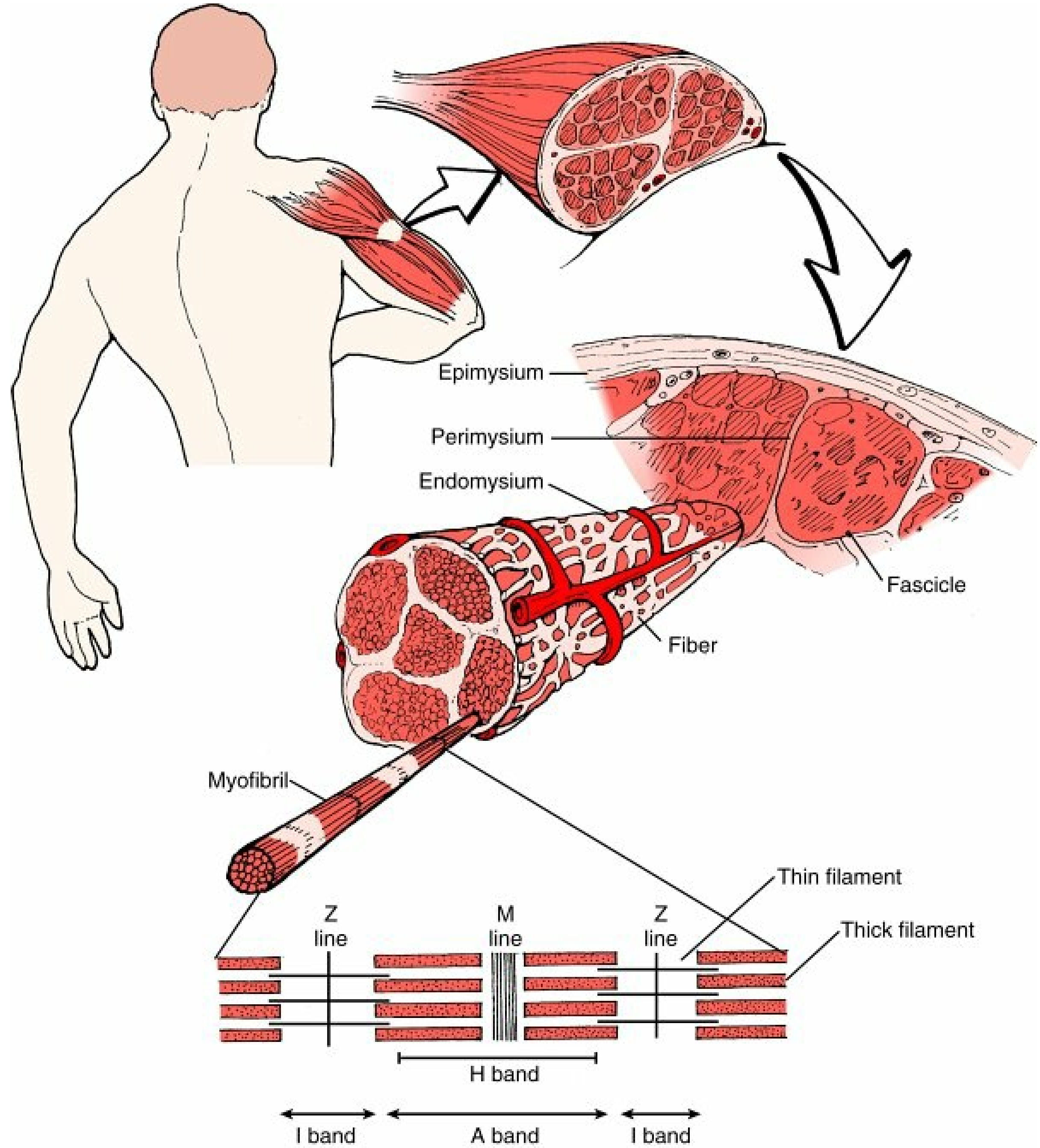


FIG. 1.40 Skeletal muscle architecture.
From Brinker MR, Miller MD: *Fundamentals of orthopaedics,* Philadelphia, 1999, Saunders, p 10.

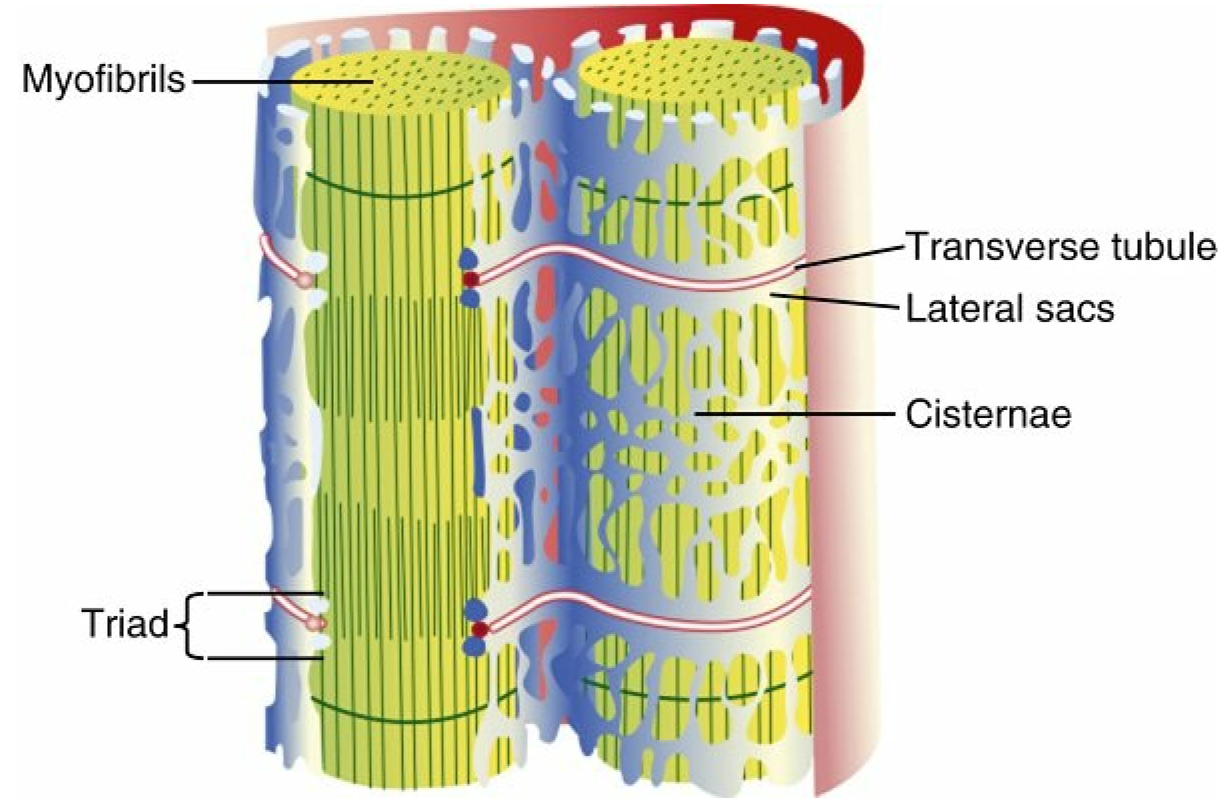


FIG. 1.41 Sarcoplasmic reticulum. Action potentials travel down the transverse tubules, causing release of calcium from the outer vesicles.
From DeLee JC et al, editors: *DeLee and Drez's orthopaedic sports medicine: principles and practice,* ed 3, Philadelphia, 2009, Saunders.

Table 1.23

Sarcomere

Band	Description
A band	Contains actin and myosin
I band	Contains actin only
H band	Contains myosin only
M line	Interconnecting site of the thick filaments
Z line	Anchors the thin filaments

From Brinker MR, Miller MD: *Fundamentals of orthopaedics,* Philadelphia, 1999, Saunders, p 11.

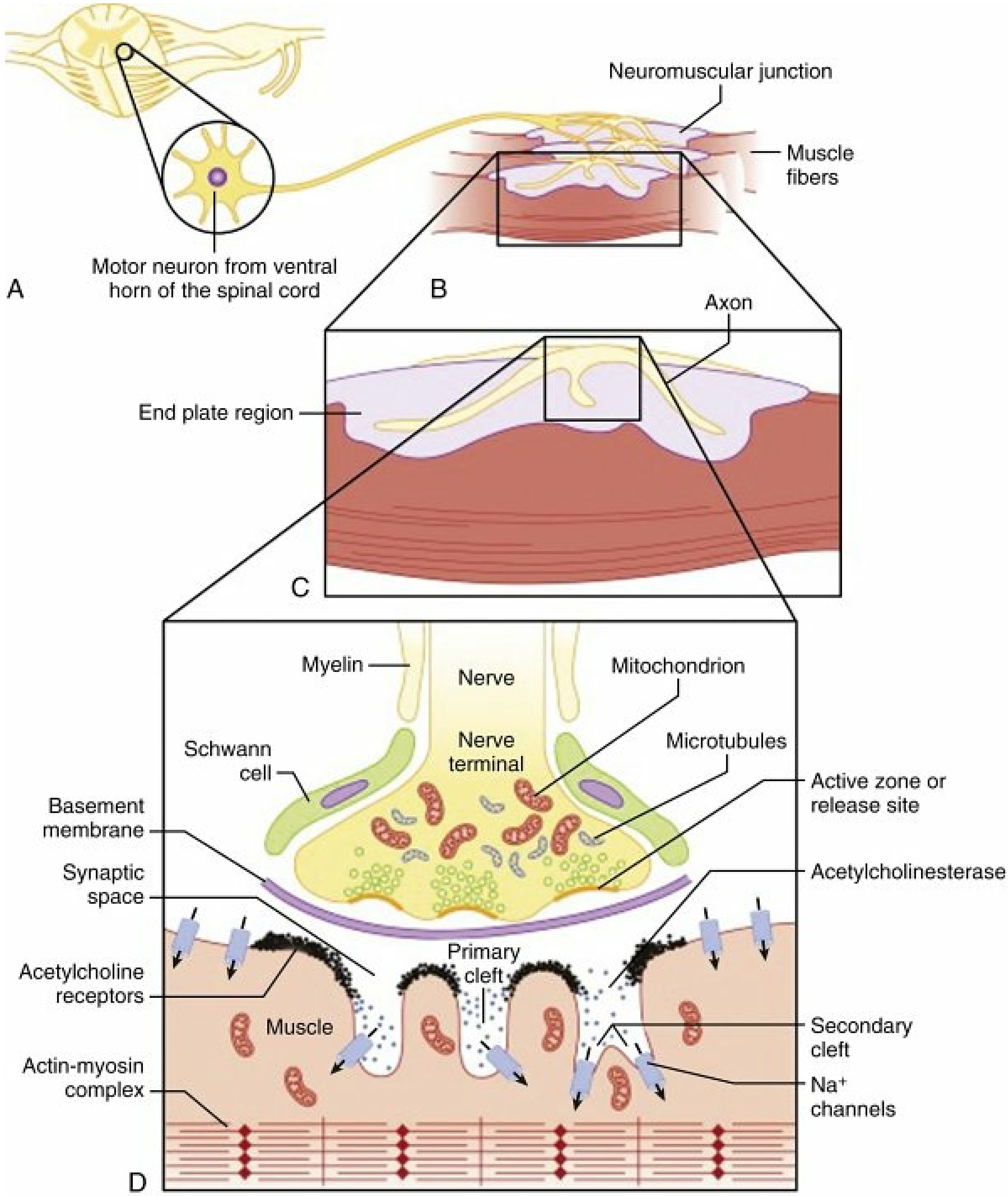


FIG. 1.42 Structure of the adult motor end plate (neuromuscular junction). (A) Motor nerve. (B) Nerve branches that innervate many individual muscle fibers. (C) Presynaptic boutons, which terminate on the muscle fiber. (D) Nerve terminal.
From Miller RD et al: *Miller's anesthesia,* ed 7, Philadelphia, 2010, Churchill Livingstone.

- **Muscle physiology**
  - Motor unit
    - The α-motoneuron and the myofibers it innervates
    - Each myofiber is innervated by a single axon but an axon can innervate multiple myofibers
      - Smaller and more delicate muscles have fewer myofibers per motor unit (<5 fibers per unit in extraocular muscles but as many as 1800 fibers per unit in gastrocnemius muscle)

□ Contraction

- Response to mechanical or electrochemical stimuli generated at the motor end plate (neuromuscular junction) where the axon contacts an individual myofiber (Fig. 1.42).
- Depolarization reaches motor neuron axon terminal, and acetylcholine (ACh) is released from presynaptic vesicles.
- ACh diffuses across the synaptic cleft (50 nm) and binds to postsynaptic receptors on sarcolemma, which begin depolarization.
    - **Myasthenia gravis is due to IgG antibodies to the Ach receptor. Manifests initially as ptosis and diplopia. Weakness worse with muscle use**.
    - Botulinum A injections reduce spasticity by blocking presynaptic acetylcholine release. Commonly used for spastic muscles in cerebral palsy.
    - Agents affecting impulse transmission are listed in Table 1.24.
- Sarcoplasmic reticulum releases calcium.
- Ca binds to troponin and causes conformational change, which stops tropomyosin inhibition of myosin-actin cross-bridges.
- Myosin binds to actin, hydrolyzes ATP, and “pushes” actin on thin filament, leading to muscle contraction.

Table 1.24

Agents That Affect Neuromuscular Impulse Transmission

Agents	Site of Action	Mechanism	Effect
Nondepolarizing drugs (curare, pancuronium, vecuronium)	Neuromuscular junction	Competitively bind to acetylcholine receptor to block impulse transmission	Paralytic agents (long term)
Depolarizing drugs (succinylcholine)	Neuromuscular junction	Bind to acetylcholine receptor to cause temporary depolarization of muscle membrane	Paralytic agents (short term)
Anticholinesterases (neostigmine, edrophonium)	Autonomic ganglia	Prevent breakdown of acetylcholine to enhance its effect	Reverse effects of nondepolarizing drugs; muscarinic effects (bronchospasm, bronchorrhea, bradycardia)

Table 1.25

Types of Muscle Contractions

Type of Muscle Contraction	Definition	Example	Phases
Isotonic	**Muscle tension is constant** throughout ROM. Muscle length changes throughout ROM. This is a measure of dynamic strength.	Biceps curls with free weights	Concentric contraction: Muscle shortens during contraction. Tension within muscle is proportional to externally applied load. Example of an isotonic concentric contraction is the curl (elbow moving toward increasing flexion) portion of a biceps curl. Eccentric contraction: Muscle lengthens during contraction (internal force < external force). Eccentric contractions are the most efficient way to strengthen muscle but have the greatest potential for high muscle tension and muscle injury. Example of an isotonic eccentric contraction is the negative (elbow moving toward increasing extension) portion of a biceps curl.
Isometric	Muscle tension is generated, but **muscle length remains unchanged.** This is a measure of static strength.	Pushing against an immovable object (e.g., wall)	
Isokinetic	Muscle tension is generated as muscle maximally contracts at a **constant velocity** over a full ROM. Isokinetic exercises are best for maximizing strength and are a measure of dynamic strength.	Isokinetic exercises require special equipment (e.g., Cybex machine).	Concentric contraction Eccentric contraction

□ Types of muscle contractions are summarized in Table 1.25.

- Muscle cross-sectional area is a reliable predictor of the potential for contractile force.
- Muscle tension is determined by the contractile force generated.
- Muscle contraction velocity is determined by fiber length.
    - A well-conditioned muscle may be able to fire more than 90% of its fibers simultaneously.
    - At any velocity, fast-twitch (type II) fibers produce more force.
- Isokinetic exercises produce more strength gains than do isometric exercises (see Table 1.25).
- Plyometric ("jumping") exercises, the most efficient method of improving power, consist of a muscle stretch followed immediately by a rapid contraction.
- Closed-chain exercise involves loading an extremity with the most distal segment stabilized or not moving, allowing for muscular cocontraction around a joint and minimizing joint shear (e.g., less stress on the ACL).
- Open-chain exercise involves loading an extremity with the distal segment of the limb moving freely (e.g., biceps curls).

▪ **Types of muscle fibers (** Table 1.26)

□ Subtypes are based on variability in myosin heavy chains

- Type I
    - Slow-twitch, oxidative, "red" fibers (mnemonic: "slow red ox")
    - Aerobic
    - Have more mitochondria, enzymes, and triglycerides (energy source) than type II fibers
    - Low concentrations of glycogen and glycolytic enzymes (ATPase)
- Enable performing endurance activities, posture, balance
- Are the first lost without rehabilitation

- Type II
    - Fast-twitch, glycolytic, "white" fibers
    - Anaerobic
    - Contract more quickly and have larger, stronger motor units (increased ATPase) than type I fibers
    - Less efficient than type I but with large amount of force per cross-sectional area, high contraction speeds, and quick relaxation times
    - Well suited for high-intensity, short-duration activities (e.g., sprinting)

Table 1.26

Characteristics of Types of Human Skeletal Muscle Fibers

Characteristic	Types		
	Type I	Type IIA	Type IIB
	Red, slow-twitch Slow oxidative	White, fast-twitch Fast oxidative glycolytic	Fast glycolytic
Speed of contraction	Slow	Fast	Fast
Strength of contraction	Low	High	High
Fatigability	Fatigue-resistant	Fatigable	Most fatigable
Aerobic capacity	High	Medium	Low
Anaerobic capacity	Low	Medium	High
Motor unit size	Small	Larger	Largest
Capillary density	High	High	Low

From Simon SR, editor: *Orthopaedic basic science*, Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 100.

- Rapid fatigue
- Low intramuscular triglyceride stores
- Two subtypes:
  - Type IIA is intermediate.
  - Type IIB is most fatigable and has highest anaerobic capacity.

▪ **Energetics (** Fig. 1.43)

□ ATP–creatine phosphate (phosphagen) system
- Converts stored carbohydrates to energy without the use of oxygen and without producing lactate.
- Intense muscle activities lasting up to 20 seconds (sprinting)
- Creatine supplementation can increase work produced in the first few maximum-effort anaerobic trials but does not increase peak force production.
- Creatine shifts fluid intracellularly; the shift may present a risk for dehydration, although cramps are the more common side effect.

□ Lactic anaerobic system (lactic acid metabolism)
- Muscle glycogen and blood glucose anaerobically converted to ATP
- Incomplete oxidation leads to excess pyruvate, which is

converted to lactic acid (via lactate dehydrogenase)
- Intense muscle activities lasting 20 to 120 seconds

□ **Aerobic system**

- **Aerobic oxidation of glycogen and fatty acids through Krebs cycle**
- **Sustained exercise such as distance running**

▪ **Athletic training, injury, and adaptation**

□ Training

- Specific training can selectively alter fiber composition.
  - Endurance athletes—higher percentage of slow-twitch fibers
  - Sprinters and athletes in "strength" sports—higher percentage of fast-twitch fibers
- Endurance training—decreased tension and increased repetitions
  - Induces hypertrophy of slow-twitch fibers
  - Increases capillary density, mitochondria, and oxidative capacity
  - Increases resistance to fatigue and cardiac output
  - Improves blood lipid profiles
- Strength training—increased tension and decreased repetitions
  - Induces hypertrophy (increased cross-sectional area) of fast-twitch (type II) fibers
  - Induces myofibrillar muscle protein synthesis (MPS)

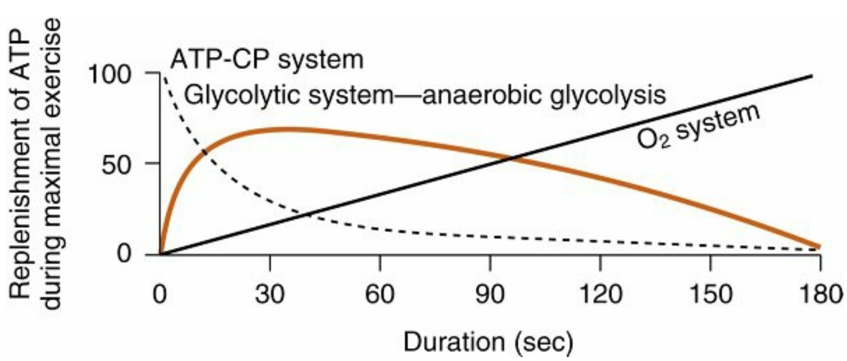


FIG. 1.43 Energy sources for muscle activity. *CP,* creatine phosphate.
From Simon SR, editor: *Orthopaedic basic science,* Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 102.

  - Improves neural activation
- Both endurance training and strength training delay the lactate response to exercise.
- A significant decline in aerobic fitness ("detraining") occurs

after only 2 weeks of no training.

- Denervation
  - Causes muscle atrophy and increased sensitivity to acetylcholine
  - Leads to spontaneous fibrillations at 2–4 weeks after injury
- Immobilization
  - **Accelerates granulation tissue response**
  - Immobilization in lengthened positions decreases contractures and maintains strength.
  - Atrophy results from disuse or altered recruitment.
    - Muscles that cross a single joint atrophy faster (nonlinear fashion).
  - Sarcomeres at the myotendinous junction are especially affected
  - Electrical stimulation can help offset these effects.
- Muscle strains
  - Most common sports injury
  - Most occur at the myotendinous junction.
  - Occur primarily in muscles crossing two joints (hamstring, gastrocnemius) that have increased type II fibers
  - Initially there is inflammation, and later, fibrosis mediated by TGF-β occurs.
  - **Immobilization or rest for 3–5 days followed by progressive stretching and strengthening**
- Muscle tears
  - Most occur at the myotendinous junction (e.g., rectus femoris tear at anterior inferior iliac spine).
  - Often occur during a rapid (high-velocity) eccentric contraction
  - Satellite cells act as stem cells and are most responsible for muscle healing.
  - **Alternatively, the defect can heal with bridging scar tissue. TGF-β stimulates proliferation of myofibroblasts and increases fibrosis.**
  - Surgical repair of clean lacerations in the muscle midbelly usually results in minimal regeneration of muscle fibers distally, scar formation at the laceration, and recovery of about half the muscle strength.
  - Prevention of tears—muscle activation (through stretching) allows twice the energy absorption before failure.
- DOMS
  - This phenomenon occurs 24–72 hours after intense exercise.
  - **Associated with eccentric muscle contractions**

- Most common in type IIB fibers
- Caused by edema and inflammation in the connective tissue, with a neutrophilic response present after acute muscle injury
- May be associated with changes in the I band of the sarcomere
- NSAIDs relieve DOMS in a dose-dependent manner.
- Other modalities (ice, stretching, ultrasonography, electrical stimulation) have not been shown to affect DOMS.

Tendon (Fig. 1.44)

- **Structure and composition**
  - Composition
    - Water: 50%–60% of total tendon weight
    - Collagen: 75% of dry weight
      - **95% type I collagen, also type III collagen**
    - Elastin: 1%–2% of dry weight
      - Highly elastic protein that allows tendon to resume its shape after stretching

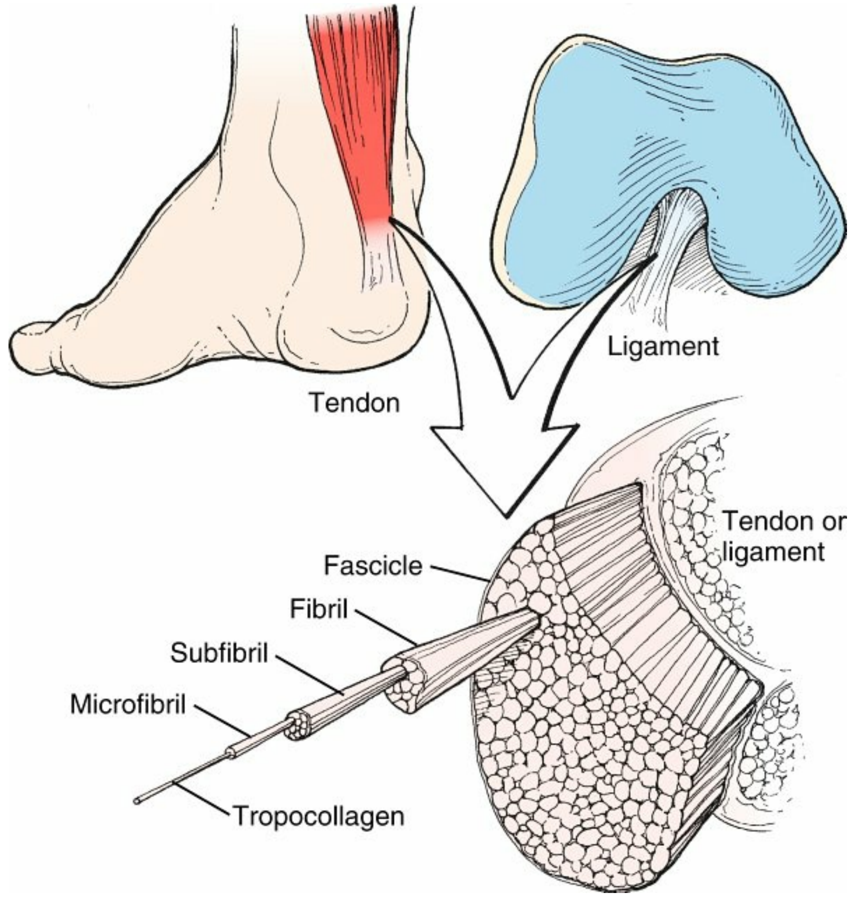


FIG. 1.44 Tendon and ligament architecture.
From Brinker MR, Miller MD: *Fundamentals of orthopaedics*, Philadelphia, 1999, Saunders, p 15.

- Also responsible for "toe region" of stress-strain curve
- Proteoglycans
  - **Decorin—most predominant proteoglycan in tendons. Regulates tendon diameter and provides cross-links between collagen fibers. Also shown to have antifibrotic properties via inhibition of TGF-β1.**
  - Aggrecan—present at points of tendon compression
  - Biglycan
- Tenocytes (fibroblasts):
  - Derived from mesoderm
  - Function to synthesize ECM, collagen, and proteoglycans
  - Assemble early collagen fibrils and produce matrix-degrading enzymes (MMPs)
  - Detect strain during tendon loading though deflection of cell cilia
  - Tenocyte production of collagen increases tendon healing and reduces repair ruptures.
  - Role in tendinopathy (due to inflammatory

mediator production)

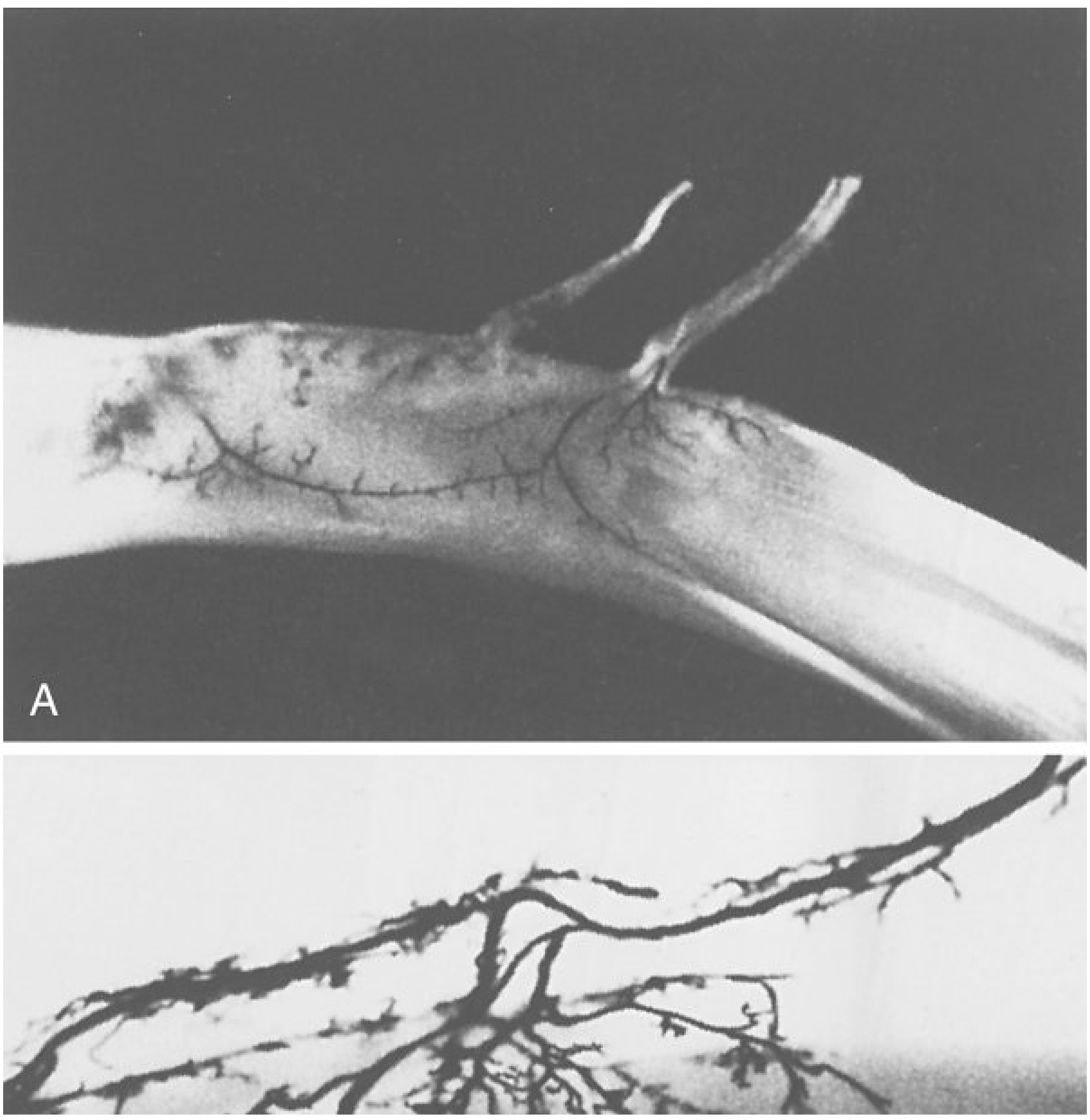
- Tenocytes produce type III collagen in response to rupture.
- Greater proportion of type III collagen, naturally seen in Achilles tendon, predisposes tendons to rupture.

□ Structure

- Strands of collagen (triple helix of two $\alpha 1$ chains and one $\alpha 2$ chain) organized into microfibrils, which in turn make up fibrils, fascicles, and tendon
- Fascicles surrounded by endotendon (contiguous with epitendon covering entire tendon)
    - Carry the neurovascular and lymphatic supply of tendons
    - Composed of type III collagen
    - With aging, more type I collagen strands interdigitate between type III collagen strands.
- Covered by paratenon (Achilles, patellar tendons) versus synovium (digital flexor tendons)
    - Higher vascularity of paratenon leads to increased healing.
- Sheathed tendons
    - **Vincula (extension of synovium) carry blood supply to one tendon segment (Fig. 1.45).**
    - Some nutrition from synovial fluid (found between the two layers of the synovial sheath) via diffusion
- Myotendinous junction
    - Actin microfilaments extend from the last Z line
    - These are linked to the sarcolemma, which in turn connects to the collagen fibril–rich matrix of the tendon.
- Bone-tendon junction (direct vs. indirect)
    - Direct (fibrocartilaginous) insertion
        - Usually in areas subject to high tensile load
        - Four layers: tendon, fibrocartilage, mineralized fibrocartilage, and bone
    - Indirect Insertion
        - Fibers insert directly into periosteum through **Sharpey fibers**

▪ **Mechanical properties**

- Anisotropic: properties vary depending on direction of applied force
- Viscoelastic: properties vary depending on rate of force application



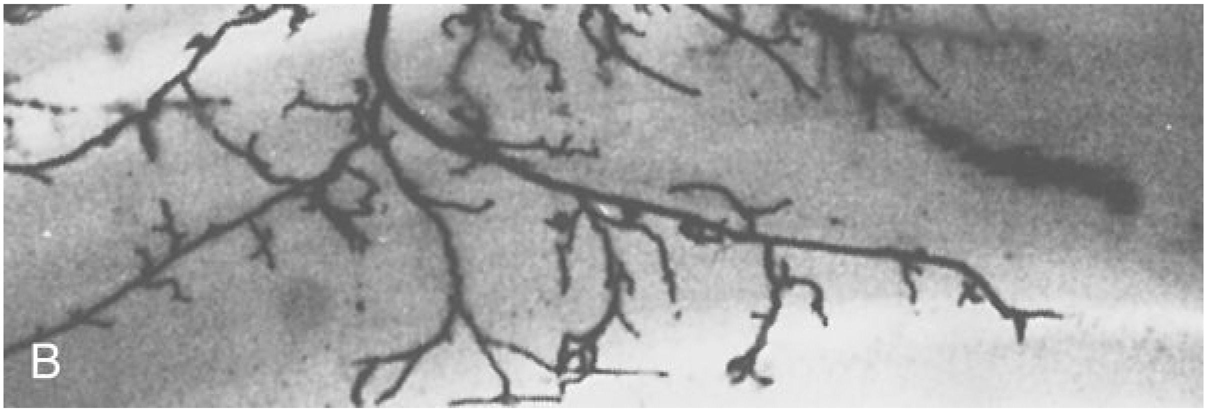


FIG. 1.45 (A) India ink specimen demonstrating the vascular supply of the flexor tendons via vincula. (B) Close-up of the specimen.
From Simon SR, editor: *Orthopaedic basic science,* ed 2, Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 51.

        - Creep: increasing deformation under constant load
        - Stress relaxation: decreasing stress with constant deformation (elongation)
        - Hysteresis: during loading and unloading, the unloading curve is different from the loading curve. The difference between the two represents the amount of energy that is lost during loading.
    - Stress-strain curve
        - Rest: collagen fibers are "crimped."
        - Toe region: flattening of crimp; nonlinear; tendon stretched easily
        - Linear region: intermediate loads
        - Failure
- **Injury and healing**
    - Three stages of tendon healing
        - Inflammation
            - Hematoma formation following by resorption
            - Type III collagen is produced at the injury site by tenocytes.
            - **Weakest stage of repair**
        - Proliferation: maximal type III collagen production
        - Remodeling:
            - Begins at 6 weeks
            - Decreases cellularity
            - Type I collagen predominates
    - Two mechanisms:
        - Intrinsic: recruitment of local stem/progenitor cells from endotenon and epitenon
        - Extrinsic: cells from surrounding tissue invade damaged area.
            - Faster but primary source of adhesions
    - Achilles, patellar, and supraspinatus tendons are prone to rupture at

hypovascular areas.

- Achilles tendon is hypovascular 4–6 cm proximal to calcaneal insertion.

□ Responsive to different cytokines and growth factors

- *PDGF* genes transfected into tenocytes show collagen formation.
- *VEGF* genes transfected into tenocytes show TGF-β upregulation and adhesion formation.
- When exposed to PMNs (as with inflammation), tenocytes upregulate genes for inflammatory cytokines, TGF-β, and MMPs while suppressing type I collagen expression.

□ Surgical tendon repairs: weakest at 7–10 days

- Maximum strength achieved at 6 months, reaching two-thirds of original strength.
- No evidence in favor of a trough (exposing tendon to cancellous bone) over direct repair to cortical bone.

□ Motion and mechanical loading have beneficial effects on tenocyte function.

□ Immobilization decreases strength at tendon-bone interface.

Ligament (see Fig. 1.44)

- **Characteristics**
  - □ Originates and inserts on bone
  - □ Stabilizes joints and prevents displacement of bones
  - □ Contains mechanoreceptors and nerve endings that facilitate joint proprioception
  - □ Like tendon, displays viscoelastic behavior
- **Structure and composition**
  - □ Composition
    - Similar to that of tendon
      - Water: 60%–70% of total weight
      - Collagen: 80% of dry weight
        - 90% type I collagen; also types III, V, VI, XI, and XIV collagen
        - More collagen type I is seen at the origin and insertion, with collagen III seen midsubstance.
      - Elastin (1% dry weight)
      - Proteoglycans (1% dry weight)—function in water retention and contribute to viscoelastic behavior
    - Fibroblast

        - Primary cell, oriented longitudinally
        - Functions to synthesize ECM, collagen, and proteoglycans
    - Epiligament
        - Similar to that in epitenon; carries the neurovascular and lymphatic supply of tendons
    - Compared with tendon
        - Less total collagen but more type III collagen
        - More proteoglycans and therefore more water
        - Less organized collagen fibers that are more highly cross-linked and intertwined
        - “Uniform microvascularity”—receives supply at insertion site by the epiligamentous plexus
    - Insertion
        - Similar to that of tendon
        - Direct (fibrocartilaginous) insertion
            - Four layers: tendon, fibrocartilage, mineralized fibrocartilage, and bone
            - More common
            - Deep fibers attach at 90-degree angles
        - Indirect
            - Superficial fibers insert into the periosteum and deep fibers insert into bone via Sharpey fibers (perforating calcified collagen fibers).

- **Injury**
    - Knee and ankle ligaments are most commonly injured
    - Ligaments do not plastically deform.
        - They “break, not bend.”
    - Midsubstance ligament tears are common in adults.
    - Avulsion injuries are more common in children.
    - Typically occurs between unmineralized and mineralized fibrocartilage layers
- **Healing**
        - **Increased number of collagen fibers but**
            - **Fewer mature cross-links (45% of normal at 1 year)**
            - **Decrease in mass and diameter**
    - Three phases, as in bone
        - Inflammatory—early acute mediators (PMNs and then macrophages), with production of type III collagen and growth factors
        - Proliferative—around 1–3 weeks, with replacement of type

III collagen by type I collagen (Think of macrophages as weakening the structure—weakest point.)
        - Remodeling and maturation
    - Factors that impair ligament healing
        - Intraarticular ligamentous injury
        - Old age, smoking, NSAID use
        - Diabetes mellitus
        - Alcohol use
        - Local injection of corticosteroids
    - Factors that improve ligament healing experimentally
        - Extraarticular ligamentous injury
        - Compromised immunity
        - IL-10 (antiinflammatory)
        - IL-1 receptor antagonists
        - Mesenchymal stem cells
        - Scaffolds (such as collagen–platelet-rich plasma hydrogels)
        - Neuropeptides
        - Calcitonin gene–related peptide
- **Immobilization**
    - Adversely affects ligament strength: elastic modulus decreases
    - In rabbits, breaking strength reduced dramatically (66%) after 9 weeks of immobilization.
    - Effects reverse slowly upon remobilization.
    - Prolonged immobilization disrupts collagen structure, which may not return to normal within insertion sites.
- **Exercise**
    - Improves mechanical and structural properties
    - Increases strength, stiffness, and failure load

Neural Tissue and Intervertebral DISC

- **The spine and spinal trauma are covered in** Chapters 2, 8, and 11. Peripheral nerve injuries are discussed in Chapter 7.
- **Anatomy and physiology of the peripheral nervous system (PNS)**
    - Neuron (see Fig. 1.49)
        - Cell body (metabolic center; 10% of size of a neuron)
        - Tapers into axon at axon hillock
        - Axons: one or more processes that connect the neuron to the spinal cord or end-organ
        - Dendrites: processes extending from the cell body that receive signals from surrounding nerve cells
        - Myelin sheath

- Composed primarily of galactocerebroside
- **Speeds wave propagation or conduction (thicker sheath increases conduction speed)**
- Produced by Schwann cells in PNS
- Schwann cells originate in neural crest and are important in posttraumatic nerve regeneration.
- Produce nerve growth factor-β, brain-derived growth factor, insulin-like growth factor 1 (IGF-1), and erythropoietin
- One Schwann cell surrounds a single axon in myelinated fibers
    - Footprint of approximately 100 μm
    - Space between cells is called node of Ranvier (concentrated Na^+ channels)
    - Allows for salutatory conduction between nodes of Ranvier
- One Schwann cell surrounds multiple axons in unmyelinated fibers

□ Neurophysiology

- Axolemma
    - Specialized membrane that surrounds axon and maintains membrane potential
    - Maintains resting potential utilizing Na-K pumps
        - Approximately −70 mV (cell interior has relative negative charge)
- Action potential (AP)
    - Neurotransmitters cross synapse and trigger opening of Na^+ channel.
        - **This triggers voltage-gated Na^+ channels (responsible for generation of AP) in axon hillock when membrane potential increases to −50 mV.**
    - Membrane potential spikes to 30 mV as membrane depolarizes.
    - Potential propagates down axon and triggers voltage-gated Ca^{2+} channel at axon terminus.
    - Ca^{2+} enters axon and triggers neurotransmitter release
    - Voltage-gated K^+ channels stay open longer than Na^+ channels.
        - Leads to hyperpolarization (−75 mV)

- Propagation faster in myelinated and larger nerves
- Absolute refractory period
  - Period when voltage-gated Na^+ channels cannot be activated
  - Responsible for antegrade propagation of signal
- Relative refractory period
  - Period when larger than normal stimuli propagate a second AP
  - Result of the hyperpolarization phase of the previous

□ Peripheral nerves

- Highly organized structures composed of nerve fibers, blood vessels, and connective tissues (Fig. 1.46)
- Nerve fibers vary in size according to function (Table 1.27).
- Erlanger and Gasser classification
  - Afferent and efferent nerves
  - Uses Roman and Greek letters

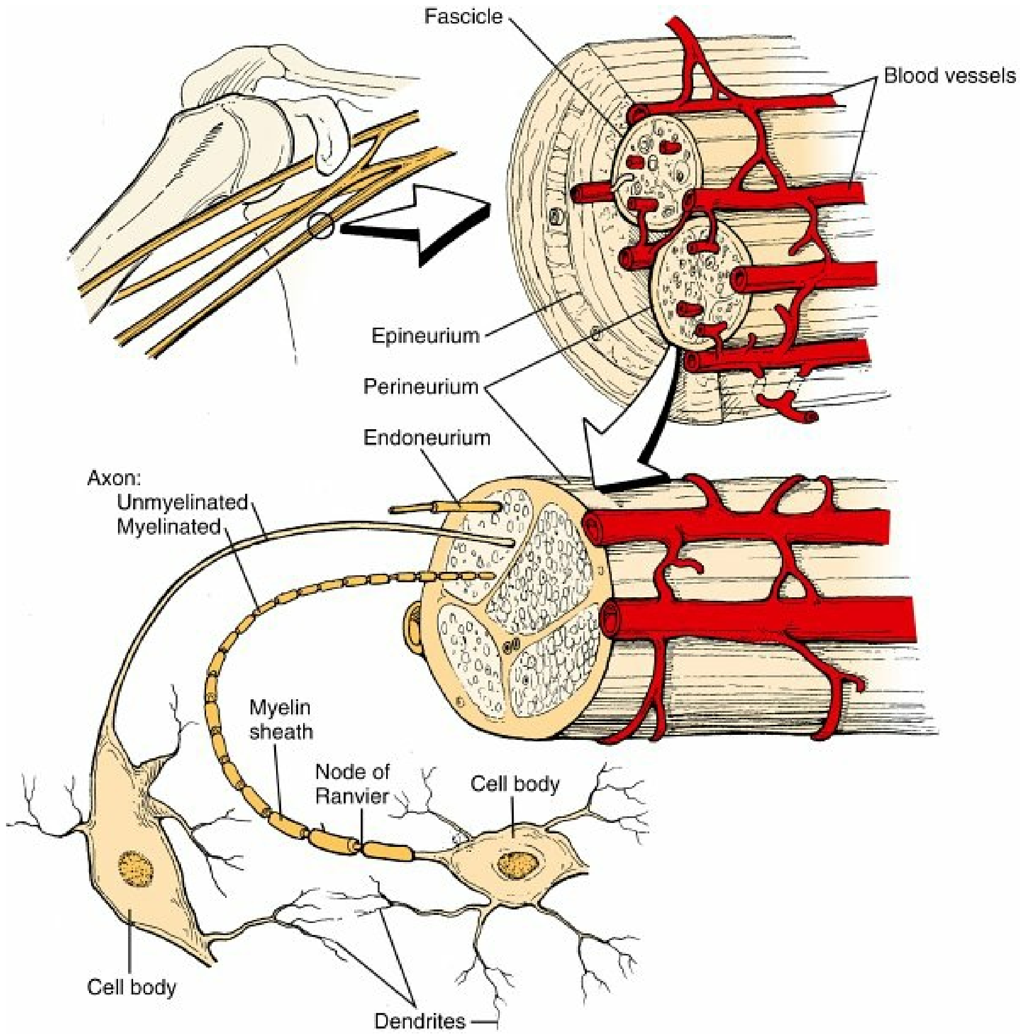


FIG. 1.46 Nerve architecture.
From Brinker MR, Miller MD: *Fundamentals of orthopaedics,* Philadelphia, 1999, Saunders, p 13.

Table 1.27

Types and Characteristics of Nerve Fibers

Type	Diameter (mm)	Myelination	Speed	Examples
A	10–20	Heavy	Fast	Touch
B	<3	Intermediate	Medium	Autonomic nervous system
C	<1.3	None	Slow	Pain

- Lloyd and Hunt classification
    - Only afferent nerves
    - Uses Roman numerals
- Can be composed of one fascicle (monofascicular), a few fascicles (oligofascicular), or several fascicles (polyfascicular)
- Axons coated with a fibrous tissue called endoneurium
- Groups of axons (fascicles) covered by perineurium
- Nerve covered by epineurium
    - External epineurium is continuous with dural sleeve of spinal cord.

- Afferent nerves convey information from sensory organ to CNS.
    - Pseudounipolar neuron with cell body in dorsal root ganglia (DRG)
    - Central branch extends away from neuron and travels through spinal cord via dorsal horn.
- Efferent nerves convey information from CNS to periphery.
    - Unipolar neuron with cell body in ventral horn of spinal cord
    - Motor unit: an α-motoneuron and the muscle fibers it innervates
- Internal topography
    - Cross section of nerve changes along length of nerve (divisions, anastomosis, and migration)
    - Fibers within fascicle organized by locations they innervate.
    - Around joints, nerves typically have more and smaller fascicles to accommodate joint motion and decrease risk of injury.
        - Radial nerve at spiral groove has fewer and larger fascicles (higher risk of neurapraxia with humeral fracture)

□ Sensory receptors (Table 1.28)

- The four attributes of a stimulus are quality, intensity, duration, and location.

Table 1.28

Receptor Types

Receptor Type	Fiber Type	Quality
Nociceptors		
Mechanical	Aδ	Sharp, pricking pain
Thermal and mechanothermal	Aγ	Sharp, pricking pain
Thermal and mechanothermal	C	Slow, burning pain
Polymodal	C	Slow, burning pain
Cutaneous and Subcutaneous Mechanoreceptors		
Meissner corpuscle	Aβ	Touch
Pacini corpuscle	Aβ	Flutter
Ruffini corpuscle	Aβ	Vibration
Merkel receptor	Aβ	Steady skin indentation
Hair-guard, tylotrich hair	Aβ	Steady skin indentation
Hair down	Aβ	Flutter
Muscle and Skeletal Mechanoreceptors		
Muscle spindle, primary	Aα	Limb proprioception
Muscle spindle, secondary	Aβ	Limb proprioception
Golgi tendon organ	Aα	Limb proprioception
Joint capsule mechanoreceptor	Aβ	Limb proprioception

Adapted from Kandel ER et al, editors: *Principles of neural science,* ed 3, Norwalk, CT, 1991, Appleton & Lange, p 342.

Table 1.29

Summary of Spinal Reflexes

Segmental Reflex	Receptor Organ	Afferent Fiber
Phasic stretch reflex	Muscle spindle (primary endings)	Type Ia (large myelinated)
Tonic stretch reflex	Muscle spindle (secondary endings)	Type II (intermediate myelinated)
Clasp-knife response	Muscle spindle (secondary endings)	Type II (intermediate myelinated)
Flexion withdrawal reflex	Nociceptors (free nerve endings), touch and pressure receptors	Flexor-reflex afferents: small unmyelinated cutaneous afferents (Aδ, C, and muscle afferent fibers, group III)
Autogenic inhibition	Golgi tendon organ	Type Ib (large myelinated)

From Simon SR, editor: *Orthopaedic basic science,* Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 350.

- Modalities
    - Nociceptors (pain and temperature)
    - Cutaneous and subcutaneous mechanoreceptors (touch and vibration)
    - Muscle and skeletal mechanoreceptors (proprioception)

□ Spinal cord reflexes (Table 1.29)

- These reflexes are “stereotyped responses” to a specific sensory stimulus.
- A reflex pathway involves a sensory organ (receptor), an interneuron, and a motoneuron.
- Monosynaptic reflex: only one synapse is involved between receptor and effector.
- Polysynaptic reflex: one or more interneurons are involved. Most reflexes are polysynaptic.

▪ **Intervertebral discs (IVDs)**

□ Allow spinal motion and stability

□ Also function as cushioning for axial loads on the spine

□ Two components

- Central nucleus pulposus
    - **Derived from notochord**
    - Hydrated gel with compressibility
    - Low collagen (type II)/high proteoglycan (and

glycosaminoglycan) content

- **Proteoglycans make up higher percentage of dry weight**.
- **With time, the nucleus pulposus undergoes loss of proteoglycans and water (desiccation)**.

- Surrounding annulus fibrosis
  - **Derived from mesoderm**
  - Extensibility and increased tensile strength
  - High collagen (type I)/low proteoglycan content
  - Proteoglycans make up lower percentage of dry weight.
  - Superficial layer contains nerve fibers.

□ Composition:

- Water (85%)
- Proteoglycans
- Type II collagen (20% of dry weight) in the nucleus pulposus
- Type I collagen (60% of dry weight) in the annulus fibrosis

□ Neurovascularity

- Dorsal root ganglion gives rise to the sinuvertebral nerve, which then innervates the superficial fibers of the annulus.
- **Avascular—nutrients and fluid diffuse from the vertebral end plates. This diffusion is impaired by calcification with aging.**

□ Aging disc

- Early degenerative disc disease is an irreversible process, with IL-1β stimulating the release of MMPs, nitric oxide, IL-6, and prostaglandin E_2 (PGE_2).
- Decreased water content and conversion to fibrocartilage
  - **A result of decreased hydrostatic pressure due to fewer large proteoglycans (aggrecan)**
- **Fibronectin cleavage or fragmentation is also associated with degeneration**.
- Increase in keratan sulfate concentration and decrease in chondroitin sulfate
- Increase in relative collagen concentration, with no change in absolute quantity

Cellular and Molecular Biology and Immunology

- **Chromosomes**
  - 46 chromosomes in 23 pairs: 22 pairs of autosomes, 1 pair of sex chromosomes
  - Composed of DNA coiled around histone proteins
    - DNA has a double-helix structure with linked nucleotides (adenine linked to thymine; guanine linked to cytosine) on a sugar-phosphate backbone
    - **Three nucleotides = 1 *codon,* which corresponds to one amino acid**

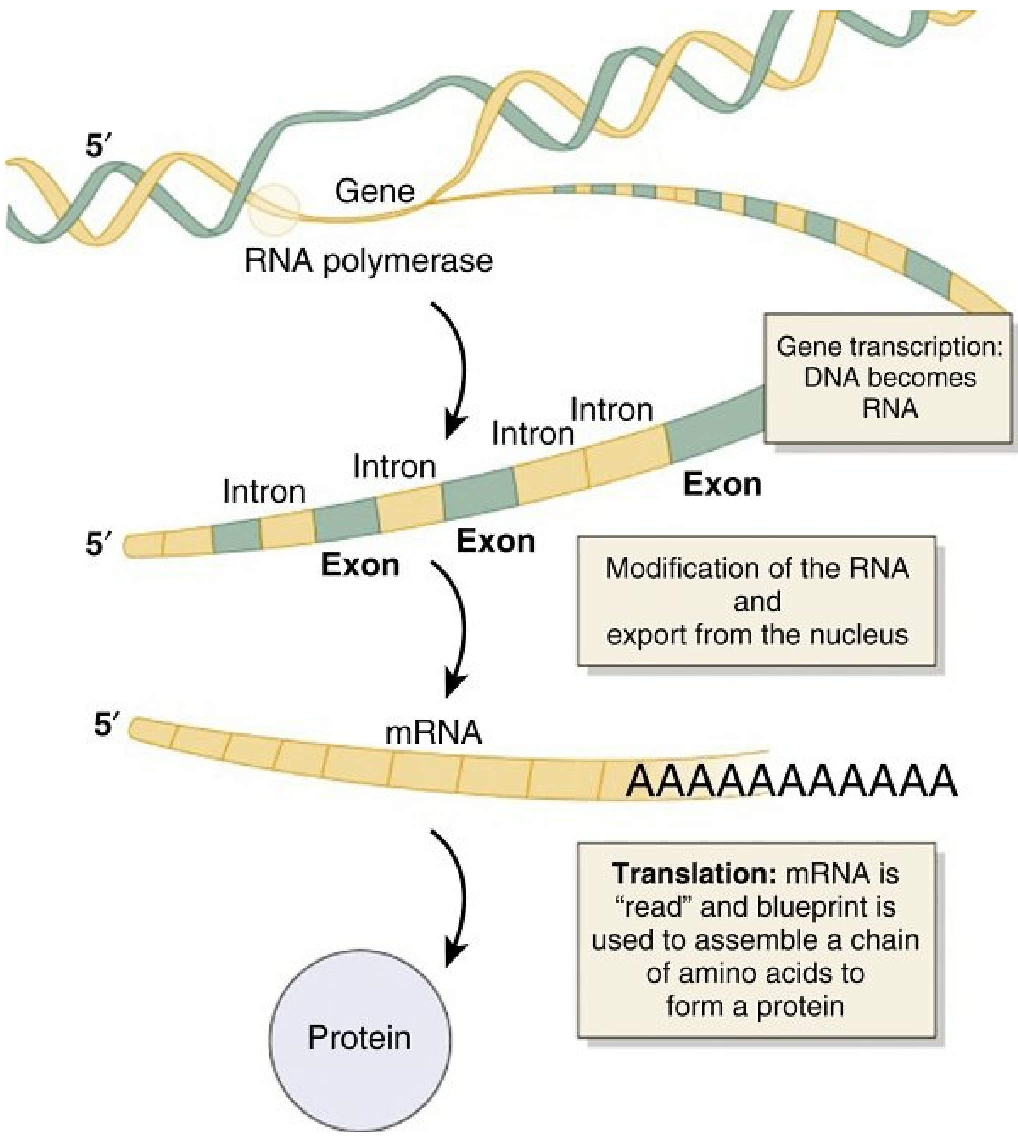


FIG. 1.47 DNA information is transcribed into RNA in the nucleus. Messenger RNA is then transported to the cytoplasm, where ribosomes complete translation into proteins.
From Jorde LB et al, editors: *Medical genetics,* ed 2, St Louis, 1999, Mosby.

- String of codons code for a string of amino acids = protein
- *Gene*: a section of DNA that codes for one protein

□ **Transcription—DNA to mRNA (Fig. 1.47)**

- Unwinding of DNA for transcription occurs by DNA topoisomerase.
    - **Topoisomerase-1 (scl-70) antibodies are seen in scleroderma and CREST** (calcinosis, Raynaud phenomenon, sclerodactyly, telangiectasia) **syndrome.**
- RNA polymerase "reads" unwound DNA and builds corresponding mRNA
    - *RNA*: single-stranded ribose sugar composed of nucleotides adenine, guanine, cytosine, and uracil
    - Uracil in RNA links to adenine of DNA because there is no thymine in RNA
- Posttranscription modification
    - *Exons* are regions of DNA that code for mRNA (mnemonic: EXons are EXpressed).
    - *Introns* are regions of DNA that are between exons; 97% of the human genome consists of noncoding DNA.
    - *Splicing* is the processing and removal of introns along with the combining of exons to make final mRNA used in translation.
        - Small nuclear ribonucleoproteins (snRNPs) are RNA-protein complexes that mediate this posttranscriptional modification.
        - Examples of these proteins are the U1 and Smith proteins.
            - Anti-Smith antibodies are specific to SLE.
            - Anti–U1-RNP antibodies are seen in mixed connective tissue disease.

□ **Translation** (see Fig. 1.47)

- Building of a protein out of amino acids from mRNA template
    - Transfer RNA carries a specific amino acid to the ribosome, based on the mRNA codon.
        - **Antibodies to tRNA synthetase (anti–Jo-1 antibodies) are seen in**

dermatomyositis.

- Cell cycle and ploidy
    - *Ploidy* is the number of sets of chromosomes in a cell annotated by XN.
    - The cell cycle entails the events within a cell that result in DNA duplication, with production of two daughter cells.
        - Growth 0 (G0)—stable phase of cells with diploid (2N) DNA content
        - Growth 1 (G1)—upon stimulus, cells begin growth but remain diploid (2N).
        - Synthesis (S)—period of DNA replication resulting in tetraploidy (4N)
        - Growth 2 (G2)—phase of cell growth and protein synthesis that is tetraploid (4N) throughout
        - Mitosis (M)—sequence of events that result in two identical daughter cells that are each 2N
            - Separation of chromosomal material for daughter cells occurs by spindle fibers' attachment to centromeres that link sister chromatids
                - **Anticentromere antibodies are seen in CREST syndrome**.
    - Certain proteins regulate progression through the cell cycle. Genetic defects and alterations of these tumor suppressor proteins can predispose a cell to dysregulated growth.
        - pRb-1 (retinoblastoma protein) undergoes progressive cell cycle–regulated phosphorylation.
            - Targets E2F, a transcription factor that regulates genes important for cell cycle control.
            - **Implicated in retinoblastoma and osteosarcoma**
        - p53—prevents entry to S phase
            - Implicated in **osteosarcoma, rhabdomyosarcoma, and chondrosarcoma**

- **Genetics**
    - Mendelian inheritance
        - Due to transmission of alleles to offspring
            - *Phenotype* refers to the features (traits) exhibited because of genetic makeup (*genotype*).
    - Mendelian traits may be inherited by one of four modes (Tables 1.30

and 1.31).

- **Autosomal dominant (AD)**
  - Involves a gene on an autosomal chromosome; one of the two alleles for the chromosome pair must be abnormal for the disease phenotype to occur.
  - Examples: syndactyly/polydactyly, **Marfan syndrome, hereditary multiple exostoses (HME), malignant hyperthermia, Ehlers-Danlos syndrome, achondroplasia, osteogenesis imperfecta (types I and IV)**
- Autosomal recessive (AR) (most enzyme/biochemical deficiencies)
  - Involves a gene on an autosomal chromosome; both alleles for the chromosome pair must be abnormal for the disease phenotype to occur.
    - Example: diastrophic dysplasia, due to a mutation in the DTDST *(SLC26A2)* gene on chromosome 5 that encodes for a sulfate transport protein
- X-linked dominant

Table 1.30

Mendelian Inheritance

Inheritance Pattern	Description	Punnett Square(s)
Autosomal dominant• A is the mutant dominant allele.	Autosomal dominant disorders typically represent **structural defects.** Disorder is manifested in the heterozygous state (Aa). Affects 50% of offspring (assuming only one parent is affected) Normal offspring do not transmit the condition. There is no gender preference.	<table><tr><td></td><td>A</td><td>a</td></tr><tr><td>a</td><td>Aa</td><td>aa</td></tr><tr><td>a</td><td>Aa</td><td>aa</td></tr></table>
Autosomal recessive• a is the mutant recessive allele.	Autosomal recessive disorders typically represent **biochemical or enzymatic defects.** Disorder is manifested in the homozygous state (aa). Parents are unaffected (they are most commonly heterozygotes).	<table><tr><td></td><td>A</td><td>a</td></tr><tr><td>A</td><td>AA</td><td>Aa</td></tr><tr><td>a</td><td>Aa</td><td>aa</td></tr></table>

	Affects 25% of offspring (assuming each parent is a heterozygote). There is no gender preference.	
X-linked dominant• X′ is the mutant dominant X allele.	X-linked dominant disorders are manifested in the heterozygous state (X′X or X′Y). Affected female (mating with unaffected male) transmits the X-linked gene to 50% of daughters and 50% of sons. Affected male (mating with unaffected female) transmits the X-linked gene to all daughters and no sons.	X / Y X′: X′X, X′Y X: XX, XY X′ / Y X: X′X, XY X: X′X, XY
X-linked recessive• X is the mutant recessive X allele.	Heterozygote (X′Y) male manifests the condition. Heterozygote (X′X) female is unaffected. Affected male (mating with unaffected female) transmits the X-linked gene to all daughters (who are carriers) and no sons. Carrier female (mating with unaffected male) transmits the X-linked gene to 50% of daughters (who are carriers) and 50% of sons (who are affected).	X′ / Y X: X′X, XY X: X′X, XY X / Y X′: X′X, X′Y X: XX, XY

Table 1.31

Comprehensive Compilation of Inheritance Pattern, Defect, and Associated Gene in Musculoskeletal Disorders

Disorder	Inheritance Pattern	Defect	Associated Gene
Dysplasias			
Achondroplasia	Autosomal dominant	Defect in the fibroblast growth factor receptor 3	***FGF3R***
Diastrophic dysplasia	Autosomal recessive	Mutation of a gene coding for a sulfate transport protein	*DTDST*
Kniest dysplasia	Autosomal dominant	Defect in type II collagen	*COL 2A1*
Laron dysplasia (pituitary dwarfism)	Autosomal recessive	Defect in the growth hormone	

		receptor	
McCune-Albright syndrome (polyostotic fibrous dysplasia, café-au-lait spots, precocious puberty)	Sporadic mutation	Germline defect in the Gsα protein	**Mutation of Gsα subunit of the receptor/aden cyclase–coupl G proteins**
Metaphyseal chondrodysplasia:			
Jansen form	Autosomal dominant		*PTH*; PTH-related protein
McKusick form	Autosomal recessive		*RMRP*
Schmid-tarda form	Autosomal dominant	Defect in type X collagen	*COL 10A1*
Multiple epiphyseal dysplasia	Autosomal dominant (most commonly)	Cartilage oligomeric matrix protein	*COMP*
Spondyloepiphyseal dysplasia	Autosomal dominant (congenita form) X-linked recessive (tarda form)	Defect in type II collagen	Linked to Xp22.1 p22.31, *SEDL* (tarda), and *C 2A1* (congenit
Achondrogenesis	Autosomal recessive	Fetal cartilage fails to mature	
Apert syndrome	Sporadic mutation/autosomal dominant		*FGF2R*
Chondrodysplasia punctata			
Conradi-Hünerman	Autosomal dominant		
Rhizomelic form	Autosomal recessive	Defect in subcellular organelles (peroxisomes)	
Cleidocranial dysplasia (dysostosis)	Autosomal dominant	Mutation of a gene coding for a protein related to	***CBFA1***

		osteoblast function	
Dysplasia epiphysealis hemimelica (Trevor disease)	Unknown		
Ellis–van Creveld syndrome (chondroectodermal dysplasia)	Autosomal recessive		*EVC*

Table Contin

Disorder	**Inheritance Pattern**	**Defect**	**Associa**
Fibrodysplasia ossificans progressiva	Sporadic mutation/autosomal dominant		
Geroderma osteodysplastica (Walt Disney dwarfism)	Autosomal recessive		
Grebe chondrodysplasia	Autosomal recessive		
Hypochondroplasia	Sporadic mutation/autosomal dominant		*FGF3R*
Kabuki makeup syndrome	Sporadic mutation		
Mesomelic dysplasia (Langer type)	Autosomal recessive		
Mesomelic dysplasia			
Nievergelt type	Autosomal dominant		
Reinhardt-Pfeiffer type	Autosomal dominant		
Werner type	Autosomal dominant		
Metatrophic dysplasia	Autosomal recessive		
Progressive diaphyseal dysplasia (Camurati-Engelmann disease)	Autosomal dominant		
Pseudoachondroplastic dysplasia	Autosomal dominant		*COMP*
Pyknodysostosis	Autosomal recessive		
Spondylometaphyseal chondrodysplasia	Autosomal dominant		

Spondylothoracic dysplasia (Jarcho-Levin syndrome)	Autosomal recessive		
Thanatophoric dwarfism	Autosomal dominant		*FGF3R*
Tooth-and-nail syndrome	Autosomal dominant		
Treacher Collins syndrome (mandibulofacial dysostosis)	Autosomal dominant		
Metabolic Bone Diseases			
Hereditary vitamin D–dependent rickets	Autosomal recessive	See Table 1.16	
Hypophosphatasia	Autosomal recessive	See Table 1.16	*PHEX*
Hypophosphatemic rickets (vitamin D–resistant rickets)	X-linked dominant	See Table 1.16	*PHEX*
Osteogenesis imperfecta	Autosomal dominant (types I and IV) Autosomal recessive (types II and III)	Defect in type I collagen (abnormal cross-linking)	*COL IA IA2*
Albright hereditary osteodystrophy (pseudohypoparathyroidism)	Uncertain	PTH has no effect at the target cells (in the kidney, bone, and intestine)	
Infantile cortical hyperostosis (Caffey disease)	Unknown		
Ochronosis (alkaptonuria)	Autosomal recessive	Defect in the homogentisic acid oxidase system	
Osteopetrosis	Autosomal dominant (mild, tarda form) Autosomal recessive (infantile, malignant form)		*CLCN7,*
Connective Tissue Disorders			
Marfan syndrome	Autosomal dominant	Fibrillin abnormalities (some patients also have type I	*FBN1 o βR2*

		collagen abnormalities)	
Ehlers-Danlos syndrome (there are at least 13 varieties)	Autosomal dominant (most common)	Defects in types I and III collagen have been described for some varieties; lysyl oxidase abnormalities	***COL*** **(I c** ***COL*** **(V**
Homocystinuria	Autosomal recessive	Deficiency of the enzyme cystathionine β-synthase	
Mucopolysaccharidosis			
Hunter syndrome (gargoylism)	X-linked recessive		
Hurler syndrome	Autosomal recessive	Deficiency of the enzyme α-L-iduronidase	
Maroteaux-Lamy syndrome	Autosomal recessive		
Morquio syndrome	Autosomal recessive		
Sanfilippo syndrome	Autosomal recessive		
Scheie syndrome	Autosomal recessive	Deficiency of the enzyme α-L-iduronidase	
Muscular Dystrophies			
Duchenne muscular dystrophy	X-linked recessive	Defect on the short arm of the X chromosome	Dystrop
Becker dystrophy	X-linked recessive		
Fascioscapulohumeral dystrophy	Autosomal dominant		
Limb-girdle dystrophy	Autosomal recessive		
Steinert disease (myotonic dystrophy)	Autosomal dominant		
			Table C

Disorder	Inheritance	Defect	Associated Gene

	Pattern		
Hematologic Disorders			
Hemophilia (A and B)	X-linked recessive	Hemophilia A: factor VIII deficiency Hemophilia B: factor IX deficiency	
Sickle cell anemia	Autosomal recessive	Hemoglobin abnormality (presence of hemoglobin S)	
Gaucher disease	Autosomal recessive	***Deficient activity of the enzyme β-glucosidase (glucocerebrosidase)***	
Hemochromatosis	Autosomal recessive		
Niemann-Pick disease	Autosomal recessive	Accumulation of sphingomyelin in cellular lysosomes	
Smith-Lemli-Opitz syndrome	Uncertain		
Thalassemia	Autosomal recessive	Abnormal production of hemoglobin A	
von Willebrand disease	Autosomal dominant		
Chromosomal Disorders With Musculoskeletal Abnormalities			
Down syndrome		Trisomy of chromosome 21	
Angelman syndrome		Chromosome 15 abnormality	
Clinodactyly		Associated with many genetic anomalies, including trisomy of chromosomes 8 and 21	
Edward syndrome		Trisomy of chromosome 18	
Fragile X syndrome	X-linked trait (does not follow the typical		Xq27-28

	pattern of an X-linked trait)		
Klinefelter syndrome (XXY)		An extra X chromosome in affected boys and men	
Langer-Giedion syndrome	Sporadic mutation	Chromosome 8 abnormality	
Nail-patella syndrome	Autosomal dominant		*LMX1B*
Patau syndrome		Trisomy of chromosome 13	
Turner syndrome (XO)		One of the two X chromosomes missing in affected girls and women	*SHOX*
Neurologic Disorders			
Charcot-Marie-Tooth disease	Autosomal dominant (most common)	***Chromosome 17 defect for encoding peripheral myelin protein-22***	***PMP22***
Congenital insensitivity to pain	Autosomal recessive		
Dejerine-Sottas disease	Autosomal recessive		
Friedreich ataxia	Autosomal recessive		
Huntington disease	Autosomal dominant		
Menkes syndrome	X-linked recessive	Inability to absorb and use copper	
Pelizaeus-Merzbacher disease	X-linked recessive	Defect in the gene for proteolipid (a component of myelin)	
Riley-Day syndrome	Autosomal recessive		
Spinal muscular atrophy (Werdnig-Hoffman disease and Kugelberg-	Autosomal recessive		

Welander disease)			
Sturge-Weber syndrome	Sporadic mutation		
Tay-Sachs disease	Autosomal recessive	Deficiency in the enzyme hexosaminidase A	
Diseases Associated with Neoplasias			
Ewing sarcoma			11;22 chromosomal translocation (*EWS/FL11* fusion gene)
Multiple endocrine neoplasia (MEN):			
Type I	Autosomal dominant		*RET*
Type II	Autosomal dominant		
Type III	Autosomal dominant	Chromosome 10 abnormality	
Neurofibromatosis (von Recklinghausen disease) type 1 (NF1) and type 2 (NF2)	Autosomal dominant	***NF1: chromosome 17 defect; codes for neurofibromin*** NF2: chromosome 22 defect	*NF1, NF2*
Synovial sarcoma			(X;18) (p11;q11) chromosomal translocations (*STT/SSX* fusion gene)
Miscellaneous Disorders			
Malignant hyperthermia	Autosomal dominant		
Osteochondromatosis	Autosomal dominant		
Postaxial polydactyly	Autosomal dominant		*GLI3* (types A, A/B)

			GJA1 (type IV)
Camptodactyly	Autosomal dominant		
Table Continued			

Disorder	Inheritance Pattern	Defect	Associa
Cerebrooculofacioskeletal syndrome	Autosomal recessive		
Congenital contractural arachnodactyly			Fibrillir (chr 5)
Distal arthrogryposis syndrome	Autosomal dominant		
Dupuytren contracture	Autosomal dominant (with partial sex limitation)		
Fabry disease	X-linked recessive	Deficiency of α-galactosidase A	
Fanconi pancytopenia	Autosomal recessive		
Freeman-Sheldon syndrome (craniocarpotarsal dysplasia; whistling face syndrome)	Autosomal dominant Autosomal recessive		
GM1 gangliosidosis	Autosomal recessive		
Hereditary anonychia	Autosomal dominant		
Holt-Oram syndrome	Autosomal dominant		
Humeroradial synostosis	Autosomal dominant		
	Autosomal recessive		
Klippel-Feil syndrome		Faulty development of spinal segments along the embryonic neural tube	
Klippel-Trénaunay-Weber syndrome	Sporadic mutation		
Krabbe disease	Autosomal recessive	Deficiency of galactocerebroside β-galactosidase	

Larsen syndrome	Autosomal dominant Autosomal recessive		
Lesch-Nyhan disease	X-linked trait	Absence of the enzyme hypoxanthine guanine phosphoribosyl transferase	
Madelung deformity	Autosomal dominant		
Mannosidosis	Autosomal recessive	Deficiency of the enzyme α-mannosidase	
Maple syrup urine disease	Autosomal recessive	Defective metabolism of the amino acids leucine, isoleucine, and valine	
Meckel syndrome (Gruber syndrome)	Autosomal recessive		
Möbius syndrome	Autosomal dominant		
Mucolipidosis (oligosaccharidosis)	Autosomal recessive	A family of enzyme deficiency diseases	
Multiple exostoses	Autosomal dominant		***EXT*** ***b*** ***a*** ***r*** ***r*** ***EXT***
Multiple pterygium syndrome	Autosomal recessive		
Noonan syndrome	Sporadic mutation		
Oral-facial-digital (OFD) syndrome			*OFD* l c *OFD* s a r
Osler-Weber-Rendu syndrome (hereditary hemorrhagic	Autosomal dominant		

telangiectasia)			
Pfeiffer syndrome (acrocephalosyndactyly)	Sporadic mutation/autosomal dominant		*FGF2R*
Phenylketonuria	Autosomal recessive	Enzyme deficiency characterized by the inability to convert phenylalanine to tyrosine because of a chromosome 12 abnormality	
Phytanic acid storage disease	Autosomal recessive		
Progeria (Hutchinson-Gilford progeria syndrome)	Autosomal dominant		
Proteus syndrome	Autosomal dominant		
Prune-belly syndrome	Uncertain	Localized mesodermal defect	
Radioulnar synostosis	Autosomal dominant		
Rett syndrome	Sporadic mutation/X-linked dominant		
Roberts syndrome (pseudothalidomide syndrome)	Sporadic mutation/autosomal recessive		
Russell-Silver syndrome	Sporadic mutation (possibly X-linked)		
Saethre-Chotzen syndrome	Autosomal dominant		
Sandhoff disease	Autosomal recessive	Enzyme deficiency of hexosaminidases A and B	
Schwartz-Jampel syndrome	Autosomal recessive		
Seckel syndrome (so-called bird-headed dwarfism)	Autosomal recessive		

Table

Disorder	Inheritance Pattern	Defect	Associated Gene
Stickler syndrome (hereditary progressive arthroophthalmopathy)	Autosomal dominant	Collagen abnormality	

Thrombocytopenia-aplasia of radius (TAR) syndrome	Autosomal recessive		
Tarsal coalition	Autosomal dominant		
Trichorhinophalangeal syndrome	Autosomal dominant		
Argininemia	Autosomal recessive		
Argininosuccinic aciduria	Autosomal recessive		
Carbamyl phosphate synthetase deficiency	Autosomal recessive		
Citrullinemia	Autosomal recessive		
Ornithine transcarbamylase deficiency	X-linked		
VATER association	Sporadic mutation		
Werner syndrome	Autosomal recessive		
Zygodactyly	Autosomal dominant		

TGF-βR2, TGF-β receptor 2; *VATER,* vertebral defects, imperforate anus, tracheoesophageal fistula, and radial and renal dysplasia.

- Example: hypophosphatemic rickets, due to *PHEX* gene mutation (Xp.22)
- **X-linked recessive**
  - Examples: **Duchenne and Becker muscular dystrophies, Hunter syndrome, hemophilia, spondyloepiphyseal dysplasia (SED) tarda**

□ Nonmendelian traits may be inherited through “polygenic” transmission caused by the action of several genes

- Charcot-Marie-Tooth disease (AD, AR, and X-linked forms)
- Osteopetrosis (AD and AR)
- Osteogenesis imperfecta (AD and AR)
- Neurofibromatosis (AD and AR)
- SED (AD and X-linked)

□ Mutations

- Genetic disorders arise from alterations (mutations) in the genetic material.

- Most skeletal dysplasias are single-gene mutations.
    - Collagen type I (bone) defects
        - Osteogenesis imperfecta (types I–IV)—*COL1A1* and *COL1A2* genes
        - Ehlers-Danlos—*COL5A1* and *COL5A2* genes
    - Collagen type II (cartilage) defects
        - SED—*COL2A1* gene, usually random mutations
    - Others
        - Multiple epiphyseal dysplasia—*COMP* (cartilage oligomeric matrix protein) gene; also associated with pseudoachondroplasia)
        - Marfan syndrome —*FBN1* (fibrillin-1) gene
        - Achondroplasia—*FGFR3* (fibroblast growth factor receptor) gene
        - Spinal muscular atrophy —*SMN1* (survival motor neuron-1) gene

□ Epigenetics

- Genetic alterations that are not caused by mutations in DNA sequence
    - DNA methylation
    - Histone posttranslational modifications
    - Genomic imprinting (parent-of-origin phenotypes)
        - An example of genomic imprinting is the loss of a region in chromosome 15 with Prader-Willi syndrome (paternal; obesity, hypogonadism, hypotonia) and Angelman syndrome (maternal; epilepsy, tremors, smiling).

- Chromosomal abnormalities
    - Disruptions in the normal arrangement or number of chromosomes
    - Trisomy: one chromosome pair has an extra chromosome (total: 47 chromosomes)
        - **Trisomy 21 (Down syndrome)—ligamentous laxity, atlantoaxial instability, patellar and hip dislocations, severe flatfoot, and bunions**
    - Deletion: absence of a section of one chromosome (in a chromosome pair).
    - Duplication: presence of an extra section of one chromosome (in a chromosome pair).
    - **Translocation: exchange of a portion of one chromosome with a portion of another chromosome**
    - Inversion: a broken portion of a chromosome reattaches to the same chromosome in the same location but in a reverse direction.
- Genetics of musculoskeletal conditions and abnormalities are summarized in Table 1.31.
- Techniques used to study genetic (inherited) disorders
    - Restriction enzymes
        - Used to cut DNA at precise, reproducible cleavage locations
        - Identify polymorphisms (alternative gene expressions)
    - Agarose gel electrophoresis
        - Molecules are suspended in agarose gel that is exposed to an electric field.
        - Molecules move through the gel according to size and polarity
            - Southern blot: detects DNA
            - Northern blot: detects RNA
            - Western blot: detects protein
    - Plasmid vectors
        - A plasmid is a small, extrachromosomal, circular piece of DNA that replicates independently of the host DNA. Plasmids can confer antibiotic resistance between bacteria.
        - The recombinant plasmid is inserted into a bacterium (the vector) by a process called *transformation*. The bacterium then produces a recombinant protein encoded by the inserted gene.

- Cytogenetic analysis

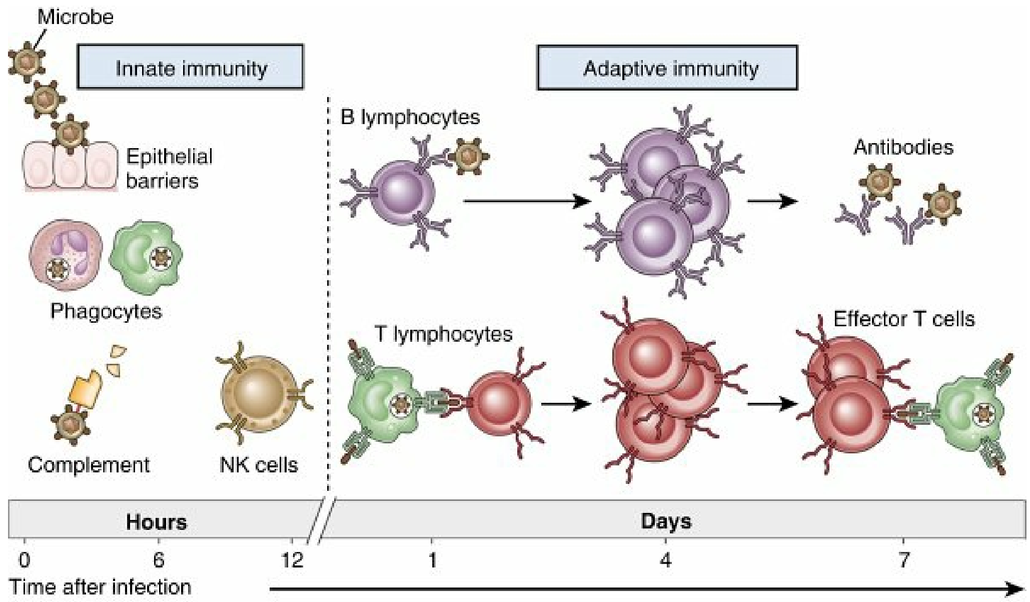


FIG. 1.48 Innate immunity and adaptive immunity. The mechanisms of innate immunity provide the initial defense against infections. Adaptive immune responses develop later and consist of activation of lymphocytes.
From Abbas AK et al: *Cellular and molecular immunology,* ed 6, Philadelphia, 2009, Saunders.

    - Gross examination of chromosomes under microscope with the use of techniques of banding and fluorescent in situ hybridization
    - **Used to detect chromosomal translocations**
        - **t(X;18)—in synovial sarcoma**
        - **t(11;22)—in Ewing sarcoma**
        - **t(2;13)—in rhabdomyosarcoma**
        - **t(12;16)—in myxoid liposarcoma**
        - **t(12;22)—in clear cell sarcoma**
- Transgenic animals
    - Bred to investigate the function of cloned genes.
- PCR amplification
    - Repetitive synthesis (amplification) of a specific DNA sequence in vitro
    - Screening DNA for gene mutations (e.g., prenatal diagnosis of sickle cell)
- Reverse transcription PCR (RT-PCR)
    - Reverse transcriptase is used to "reverse transcribe" RNA to complementary DNA.
    - Typically used to study RNA viruses
- **Silencing RNA (siRNA)**
    - **Blocks transcription of mRNA in order to study**

result of gene's loss of function

- **Immunology**
  - The immune system is broadly categorized into two branches: the innate and the adaptive, with interaction and overlap between the two (Fig. 1.48).
    - **The innate system** is primitive, nonspecific, the first line of defense using complement and leukocytes.
      - Is antigen independent and involves **NK cells**, mast cells, basophils, eosinophils, macrophages, neutrophils, and dendritic cells
      - Barriers—physical and chemical components (e.g., enzymes, pH)
        - Skin—sebum, sweat (lysozyme, RNases and DNases, defensins, cathelicidins)
        - Mucous membranes (IgA is most common immunoglobulin)
        - Respiratory epithelium
        - Urinary tract
      - Recognition of pathogens by innate system
        - **Pathogen-associated molecular patterns (PAMPs) on microbes are recognized by TLRs on innate immune system cells (e.g., macrophages and dendritic cells)**.
        - Example of a PAMP is bacterial lipopolysaccharide (LPS), which is recognized by TLR-4.
        - There is an upregulation of NF-κB transcription factor, resulting in release of immune mediators (e.g., IL-1, IL-6, TNF-α).
          - IL-6 causes the liver to release inflammatory mediators such as CRP.
        - Arachidonic acid released from cell membranes is acted on by COX and 5-lipoxygenase to make prostaglandins and leukotrienes that mediate exudation, chemotaxis, and bronchospasm.
          - **Ibuprofen inhibits COX and reduces**

prostaglandin production, preventing renal efferent arteriolar relaxation and increasing GFR.

    - Factor (XII)—inflammatory protein made in the liver
        - When exposed to collagen under damaged endothelium, activates coagulation
        - Acute production of coagulation factors elevates ESR.
- Complement
    - Activated by IgM or IgG antigen (Ag) complexes, microbial products, or mannose on microorganisms
    - Mediates chemotaxis of PMNs, opsonization (tagging of evasive bacteria for elimination in the spleen), and membrane attack complex lysis of microbes, among other functions

- The adaptive system is more complex, is antigen dependent, and works through antigen presentation with B and T lymphocytes and antibodies.
    - Response to a pathogen generates an immunologic memory in the adaptive system.
        - *Antigens* are ligands recognized by the immune system. The smallest part of an antigen "seen" by a T- or B-cell receptor is an epitope.
    - Cell mediated—T lymphocytes (helper, $CD4^+$; cytotoxic, $CD8^+$), macrophages
        - Targets intracellular bacteria, virus, fungi, parasites, tumors, and transplanted organs/orthopaedic hardware
        - Antigen-presenting cells (APCs—macrophages, dendritic cells, certain B cells, and Langerhans cells) process antigens.

- Humoral—B lymphocytes and their matured counterparts, plasma cells. Both produce antibodies.
    - Targets exotoxin-mediated disease, encapsulated bacterial infection, other viral infections
    - Each B cell makes antibodies specific to one single epitope (antigen). B cells use immunoglobulins (IgM and IgD) as cell membrane receptors.
    - Terminally differentiated B cells are called *plasma cells.* The difference is that they secrete immunoglobulins into fluid.
    - Immunoglobulins (Fig. 1.49) (mnemonic: MADGE)
        - IgM: heaviest, first in the adaptive response
        - IgA: in mucosal surfaces (e.g., MALT [mucosa-associated lymphoid tissue]) and secretions
        - IgD: only on B-cell surfaces
        - IgG: also on B-cell surface but also secreted.
            - Mediates opsonization; later in the adaptive response
        - IgE: on the surface of mast cells (allergic reactions), basophils, and eosinophils (response to parasite).

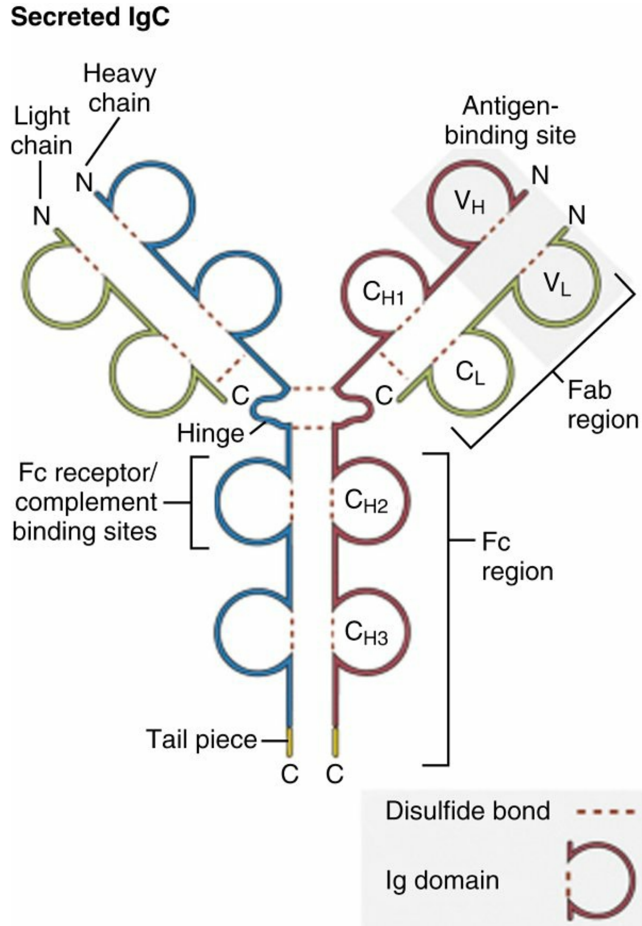


FIG. 1.49 Basic subunit structure of the immunoglobulin molecule. C_H and C_L, Constant regions; *Fab,* antigen-binding fragment; *Fc,* crystallizable fragment; V_H and V_L, variable regions.
From Katz VL et al: *Comprehensive gynecology,* ed 5, Philadelphia, 2007, Mosby.

- Once secreted, antibodies can defend by a variety of mechanisms.
    - Neutralization of viruses and toxins
    - Opsonization
    - Complement activation (IgG and IgM)
    - Antibody cellular cytotoxicity
    - Prevention of adherence and colonization (IgA)
- Cellular response in inflammation
    - Neutrophil response—first cells recruited to sites of tissue injury
        - Margination, rolling, adhesion, chemotaxis, and phagocytosis

            - Macrophage response—follows neutrophil response
        - **Initiate inflammatory response in osteolysis or aseptic loosening (occurs in response to particles <1 μm in diameter)**
            - Mast cells—activated by trauma, complement, or IgE cross-linking, releasing histamine granules
                - Histamine mediates the peripheral nerve axon reflex that results in vascular smooth muscle relaxation.
                    - Excessive endothelial vasodilation with respiratory smooth muscle constriction is an emergency mediated by **IgE–type I hypersensitivity reaction and can lead to shock and death.**
- □ Autoimmunity
    - Recognition of epitopes from the "self"
        - ANAs, which are seen in many disease processes
            - Anti-Sm—SLE
            - Anti-RNP—mixed connective tissue disease
            - **Anti–scl-70—scleroderma**
            - Anti-dsDNA—SLE; also implicated in SLE nephritis
            - Antihistone—drug-induced lupus
            - Anti-Ro and Anti-La—Sjögren syndrome
        - HLA gene on chromosome 6 can be rearranged to make an antigen-specific receptor on APCs for up to 10^{15} different epitopes.
            - HLA-B27 is associated with a variety of rheumatologic diseases (mnemonic: PAIR)

- Psoriatic arthritis
- AS
- Inflammatory bowel disease
- Reactive arthritis (Reiter syndrome)
- Also juvenile RA

- HLA-DR3: myasthenia gravis and SLE
- HLA-DR4: RA

□ Hypersensitivity reactions

- Type I: mediated by IgE
  - Anaphylaxis or allergic response, immediate response, mast cell degranulation
  - Food allergy (milk, egg, peanut, seafood, etc.) and drug allergies
- Type II: mediated by IgM or IgG, cytotoxic, antibody-mediated response
  - Heparin-induced thrombocytopenia
  - Rheumatic fever
  - Myasthenia gravis
- Type III: immune complex mediated (antigen-antibody [e.g., IgG-Ag])
  - SLE
  - RA
- Type IV: cell-mediated (no antibodies); helper T cells activate cytotoxic cells and macrophages to attack tissue; delayed response.
  - TB screening with PPD (purified protein derivative)/Mantoux test
  - Type 1 diabetes mellitus
  - Multiple sclerosis
  - **Type IV response to metallic orthopaedic implants**
  - Pseudotumor hypersensitivity response can occur years after THA.

□ Cytokines

- Low-molecular-weight proteins that bind to receptors and elicit cellular responses.
- Each cytokine can serve a variety of functions:
  - IL-1—initiates acute phase response
    - **Induces bone loss through activation of osteoclasts via RANK/RANKL pathway**.

- IL-2—promotes growth and activation of lymphocytes
- IL-6—induces synthesis of acute-phase proteins from liver (e.g., CRP)
    - **IL-6 is key to growth and survival of multiple myeloma (MM) cells**.
        - Generated in autocrine (MM cells) and paracrine (bone marrow stromal cells and osteoblasts) fashion
- IL-10—antiinflammatory
- TNF-α—helps mediate inflammatory response to intracellular infections
- TGF-β—limits inflammation and promotes fibrosis

Infection and Microbiology

- **Musculoskeletal infections overview**
    - Treatment overview
        - Empirical treatment: based on the presumed type of infection as determined from clinical findings and symptoms. *Staphylococcus* and *Streptococcus* are the most common organisms infecting skin, soft tissue, and bone.
        - Definitive treatment: based on final culture and sensitivity results when available
        - Surgical treatment: draining of contained infections, débridement of dead tissue, restoration of vascularity
    - Bacterial virulence
        - Antibiotic resistance—plasmid
            - β-Lactamase (*bla* gene)—makes staphylococci resistant to penicillin
            - Penicillin-binding protein 2a (*mecA* gene)—makes *Staphylococcus aureus* MRSA
        - Increased surface adhesion
            - *Fnb* gene—fibronectin in *S. aureus*
                - Increases adhesion to titanium
            - **Glycocalyx-biofilm-slime-polysaccharide capsule**
                - Improves attachment to inert surfaces
                - Protects bacteria from desiccation
        - Cell protection from phagocytosis

- Glycocalyx-biofilm-slime-polysaccharide capsule—inhibits phagocytosis
  - Hides PAMPs
  - Protects bacteria from toxic enzymes/chemicals
- Protein A: *S. aureus*—inhibits phagocytosis
  - Binds immunoglobulins (Fc region of IgG)
- M protein: group A *Streptococcus pyogenes*—inhibits phagocytosis
  - Inhibits activation of alternative complement pathway on cell surface

- Toxins
  - Endotoxin: gram-negative lipopolysaccharide capsules
  - Exotoxin
    - *Clostridium perfringens:* lecithinase—tissue-destroying alpha toxin
      - Myonecrosis and hemolysis of gangrene
    - ***Clostridium tetani:*** tetanospasmin—blocks inhibitory nerves
      - "Lockjaw" or muscle spasms
    - *Clostridium botulinum*: botulism—blocks acetylcholine release
      - "Floppy" baby (also wrinkle relaxers and antispasmodic for cerebral palsy)
    - Community-associated MRSA: Panton-Valentine leukocidin (PVL) cytotoxin
      - Pore-forming toxin specific to neutrophils
- Superantigens
  - Activate approximately 20% of T cells
  - Trigger cytokine release
  - Systemic inflammation; appears as septic shock
    - *S. pyogenes* (group A streptococci): M protein
    - *S. aureus:* TSS toxin-1 causes toxic shock syndrome

        - Acute febrile illness with a generalized scarlatiniform rash
        - Hypotension (shock) with organ system failure
        - Desquamation of palmar/plantar skin lesions (if the patient lives)
        - Treatment:
          - Removal of foreign object (retained sponge or tampon)
          - Supportive care with fluids and anti-*Staphylococcus* antibiotics

□ ***Staphylococcus:* roughly 80% of orthopaedic infections**

- Antibiotic resistance
  - Penicillin (β-lactam antibiotic)—inhibits peptidoglycan bonds of bacterial cell walls
  - β-Lactamases are enzymes produced by bacteria that provide resistance by breaking down the antibiotic structure.
  - MRSA
    - ***mecA* gene**
      - Located on staphylococcal chromosome cassette mobile element–carrying IV (SCCmecIV)
      - Encodes for penicillin-binding protein 2A, which has a low affinity for β-lactam antibiotics
- Community versus hospital
  - Hospital-acquired MRSA (HA-MRSA) or health care–acquired (HC-MRSA)
    - Seen in patients from nursing homes, those with recent bacteria have larger SCCmec genetic elements
      - Multiple antibiotic

resistance genes
- More drug resistance; known as "super bugs"
- Community-acquired MRSA (CA-MRSA)
  - Bacteria have smaller SCCmec genetic elements
    - Less drug resistance
    - Almost all have PVL cytotoxin
    - γ-Hemolysin: a pore-forming toxin that can lyse PMNs
    - Seen in young adults with recurrent boils and severe hemorrhagic pneumonia
- **At-risk groups: athletes, IV drug abusers, homeless persons, military recruits, prisoners**
- Risk factors
  - Previous antibiotic use within 1 year
  - Frequent skin-to-skin contact with others
  - Frequent sharing of personal items
  - Compromised skin integrity

▪ **Infection by tissue type**

□ **Soft tissue infections**: superficial to deep (Table 1.32)

- **Erysipelas**: infection of dermis and lymphatics—group A streptococci
  - Painful raised lesion with a red, edematous, indurated (peau d'orange) appearance and an advancing raised border
  - Treatment: penicillins or erythromycin
- **Cellulitis:** subcutaneous infection most commonly group A streptococci or *S. aureus*
  - Acute spreading infection with pain, erythema, and warmth, with or without lymphadenopathy; may develop into abscess (may surround abscess or ulcer)
  - Treatment: routine for cellulitis—penicillin, dicloxacillin; but IV cefazolin or nafcillin if systemic systems prominent or patient is at high risk (asplenia, neutropenia, immunocompromise, cirrhosis, cardiac or renal failure, local trauma, or

preexisting edema)

- **Abscess**: pus-filled inflammatory subcutaneous nodule (furuncle = "boil") that may be multiple and may coalesce (carbuncle): almost always *S. aureus.* Small lesions sometimes mistaken as spider bites.
    - Painful pus under pressure
    - Treatment: incision and drainage (I&D), then left open, with culture and sensitivity testing to select antibiotics.
    - For simple abscesses, addition of systemic antibiotics has not been shown to improve cure rate or decrease recurrence above I&D alone.
    - Systemic antibiotics only for (Infectious Disease Society of America Guidelines):
        - Severe or extensive disease
        - Rapid progression in the presence of associated cellulitis
        - Signs and symptoms of systemic illness
        - Associated comorbidities or immunosuppression, extremes of age
        - Abscess in an area difficult to drain
        - Associated septic phlebitis
        - Lack of response to incision and drainage
    - Empirical antibiotics selected should aim at MRSA.
- Necrotizing fasciitis
    - Rare, rapidly progressive, life-threatening infection of the fascia and subcutaneous tissue
    - Causes liquefactive necrosis with thrombosis of the cutaneous microcirculation
    - **Most commonly polymicrobial**, but group A β-hemolytic ("flesh-eating") streptococci the most common monomicrobial cause (i.e., *S. pyogenes*).
    - Risk factors: diabetes, peripheral vascular disease, liver failure
    - Death most related to delay in treatment for more than 24 hours
    - Fascial infection spreads faster than the observed skin changes.
    - Skin microcirculation thrombosis and later necrosis

        - Early—pain out of proportion, swelling and edema
        - Late
            - Blisters/bullae
            - Skin that does not blanch (skin is dying)
            - Skin becomes numb (nerves are dying)
    - Difficult diagnosis—paucity of cutaneous findings so high clinical suspicion needed
        - Less than one-fifth of cases diagnosed at admission; preadmission antibiotics mask severity
        - Repeated examinations noting margins that migrate quickly despite antibiotic treatment
    - Surgical findings
        - Grayish necrotic fascia
        - Lack of normal muscular fascial resistance to blunt dissection
        - Lack of bleeding of the fascia during dissection
        - Foul-smelling "dishwater" pus
    - Treatment: broad-spectrum antibiotics
        - Early operative débridement of all necrotic tissue—level selected should be ahead of the infection
        - Amputation/disarticulation should be considered.
        - Second-look procedure should be performed 24 hours later for reevaluation.
- Gas gangrene
    - *C. perfringens* (obligate anaerobe) most common organism that produces gas and toxins in subcutaneous tissues and muscle
    - Dirty wound managed with primary closure: war wounds, tornado, lawn mower
    - Inadequate débridement of more severe devitalizing injuries
    - Clostridial dermonecrotizing exotoxin lecithinase
    - Crepitance of soft tissue, air in soft tissues on x-rays, foul "sweet"-smelling discharge

- Treatment
    - Early, adequate, and thorough surgical débridement
    - Delayed closure and second-look procedure 24 hours later for reevaluation
    - High-dose IV penicillin and hyperbaric oxygen can help if available.
- Surgical site infection
- Infections are the product of bacteria that take hold in a favorable wound environment in a host with a susceptible immune system.
- Bacterial issues
    - Load
        - **More than 10^5 colony-forming units (CFUs) needed in normal host to cause infection**
        - Need only about 100 CFUs if foreign object present
- Prevention
    - Prophylactic antibiotics
        - Given from less than 1 hour before until 24 hours after procedure
        - Repeated if preceding time is more than 4 hours (longer than half-life of antibiotic selected)
        - Repeated if blood loss more than 1000 mL
        - Doubled if patient weighs more than 80 kg (>176 lb)
    - Avoidance of hematogenous seeding
        - No active infections in elective cases —legs, feet, toes checked preoperatively

Table 1.32

Soft Tissue Infections

Type	Affected Tissues	Clinical Findings
Cellulitis, erysipelas	Superficial, subcutaneous	Erythema; tenderr warmth; lymphangitis;

		lymphadenopa
Necrotizing fasciitis	Muscle fascia	Aggressive, life threatening may be associated v an underlyi vascular dis (particularly diabetes) Commonly occ after surger trauma, or streptococca skin infectio
Gas gangrene	Muscle; commonly in grossly contaminated, traumatic wounds, particularly those that are closed primarily	Progressive, sev pain; edema (distant fron the wound) foul-smellin serosanguir discharge; h fever; chills, tachycardia confusion Clinical finding consistent v toxemia Radiographs typically sh widespread in the soft tissues (facilitates r spread of th infection)
Tox shock syndrome:		
Staphylococcal	Toxemia, not septicemia In orthopaedics, TSS is secondary to colonization of surgical or	Fever, hypotens an erythemato macular ras with a serou exudate (gr positive coc

		traumatic wounds (even after minor trauma) TSS can be associated with tampon use through colonization of the vagina with toxin-producing *S. aureus*	are present) The infected wound may look benign which may the seriousn of the underlying condition
	Streptococcal	Toxemia, not septicemia Commonly associated with erysipelas or necrotizing fasciitis	Similar to staphylococcal
Surgical wound infection		Varies	
Marine injuries		Varies	History of fishi (or other m activity) inju with signs o infection Culture specim at 30°C (60° organisms m take several weeks to gr on culture media

- If urologic symptoms: urinalysis and culture
  - Postpone surgery if:
    - Over 10^3 CFUs and dysuria/frequency
    - Symptoms of urinary obstruction
      - Reduced force, hesitancy, straining
  - Foley catheterization should be discontinued as soon as possible after surgery.
- MRSA: carrier screening and eradication, "active detection and isolation (ADI)"
  - Nasal carriage—important risk factor, with some controversy; if patient part of high-risk population
    - Screening
      - Swab culture versus PCR
      - If positive screen result: postoperative infection rates are two to nine times higher
        - Use vancomycin 1 g every 12 hours
        - 2% intranasal mupirocin ointment twice daily × 5 days

            - 2% chlorhexidine showers daily × 5 days
- Nutrition (malnutrition associated with wound dehiscence and infection)
    - Clinical evaluation
        - History of weight loss (10% over 6 months or 5% over 1 month)
        - **Albumin value less than 3.5 g/dL,** total lymphocyte count less than 1500 cells/μL, transferrin level less than 200 mg/dL
    - Obesity—body mass index (BMI) more than 30 kg/m^2; higher numbers = more wound problems
        - Bariatric consultation should be considered early in course for patient likely to progress to need large elective procedure.
- Smoking: two to four times more infections/osteomyelitis
    - Hypoxia—CO binds to Hb = carboxyhemoglobin (HbCO)
    - Nicotine—microvascular vasoconstriction
    - Reduced bone, skin, soft tissue healing
    - Cessation of smoking 4 to 6 weeks preoperatively leads to decreased complications.
- **Alcohol:** heavy alcohol use (blood alcohol >200 mg/dL) increases rate of infections 2.6 times
    - Reduced fibroblast production of collagen type I
    - Inhibits osteoblasts: reduced osteocalcin, inhibits Wnt/β-catenin pathway

- Impairs fracture healing
- Associated with "bad behaviors," cirrhosis, and liver failure

- Diabetes
  - Chronic issues well known: cardiac, renal, peripheral vascular, neuropathy
    - Best measured with HbA_{1c}—goal is less than 6.9% of total hemoglobin
  - Acute hyperglycemia is also a threat
    - Collagen synthesis suppressed at blood glucose value of 200 mg/dL—impaired wound healing
    - WBC phagocytosis impaired at blood glucose value of 250 mg/dL—decreased ability to fight infection

□ Special soft tissue infections
- Bite infections (Table 1.33)
  - Initial treatment: exploration of wound, removal of foreign objects, débridement, and irrigation
  - Consider delayed primary closure at 48–72 hours
  - Antibiotic prophylaxis controversial
    - Should be considered for bites to hands, feet, face
    - Wounds hard to clean—deep punctures, edema/crush injury
    - Bites involving tendon, cartilage, or bone
    - Bites in immunocompromised or asplenic host
  - Bite prophylaxis antibiotics: amoxicillin-clavulanate
    - For penicillin-allergic patient, trimethoprim-sulfamethoxazole plus clindamycin
  - Antibiotic treatment: oral unless infection rapidly spreads or patient is febrile or high risk; then IV

- Bite organisms
  - Most oral flora is polymicrobial in nature. Some bacteria are more specific to source of "bite."
  - Human bites: *Streptococcus viridans* common, *Eikenella corrodens*
    - "Fight bite" x-rays for cartilage divots, broken teeth, and formal identification
  - Cat bites: *Pasteurella multocida*
    - 50% require surgery—puncture wounds to tendons/joints
  - Dog bites: *P. multocida, Pasteurella canis*
  - Marine injuries
    - *Mycobacterium marinum*
      - Slow culture at low temperature (30°C)
      - Noncaseating granulomas
      - Treatment: 3 months of minocycline or clarithromycin
    - *Erysipelothrix rhusiopathiae*
      - Erysipeloid—fish handler's (also swine handler's) disease
      - Gram-positive bacillus
      - Painful, itchy, spreading, purple ring-shaped lesion
      - Treatment: oral penicillin
    - ***Vibrio vulnificus***
      - Oyster bite
      - Bullae and necrotizing fasciitis from gram-negative motile rod
      - Gastroenteritis from eating bad oyster
      - Treatment: I&D and broad-spectrum antibiotics (ceftazidime)
  - Tick bite *(Ixodes):* Lyme disease
    - *Borrelia burgdorferi* (a spirochete)

            - *Erythema migrans:* bull's-eye lesion
            - Vector: white-footed deer mouse in northeast and Pacific north
            - Knee effusions
            - Neurologic disease: Bell palsy common
            - **Treatment: amoxicillin versus doxycycline**
        - Rabies (neurotropic virus)
            - Raccoon/skunk/bat bites
            - CNS irritation, "hydrophobia," paralysis, and death
            - Death if not treated before symptoms occur
            - **Treatment: human rabies immune globulin**
- Septic bursitis
    - Similar pathology whether in olecranon, prepatellar, or pretibial bursa
    - Redness, swelling, pain, and subcutaneous fluctuance
    - About 80% caused by *S. aureus,* others streptococci
    - Chronic recurrent cases can be fungal or mycobacterial
    - Aspiration with Gram stain and culture if redness is presence
    - Treatment
        - Serial aspirations and oral antibiotics
        - IV antibiotics for systemic symptoms and in immunocompromised patients
        - Bursectomy for persistent or recurrent cases
- Tetanus
- Potentially lethal neuroparalytic disease leading to trismus (lockjaw)
- Exotoxin from anaerobe *C. tetani*
    - Tetanospasmin blocks inhibitory nerves.
- Deep wounds and devitalized tissues are at high risk.
    - Wounds more than 6 hours old, more than 1 cm deep, ischemic, crush, grade III
    - Contaminated with soil or feces, animal bite

- Vaccination
- Tetanus toxoid (Td) 0.5-mL diphtheria-tetanus toxoid booster every 10 years
- Adults with at-risk wounds, give Td booster
- Status unknown or history of fewer than three doses: give both Td and tetanus immune globulin (TIG)

□ Osteomyelitis

- Exogenous: most common osteomyelitis in adults
    - Acute osteomyelitis from open fracture or bone exposed at surgery
    - Chronic osteomyelitis from neglected wounds: diabetic feet, decubitus ulcers
- Hematogenous: most common osteomyelitis in children
    - Pediatric patients
        - Immature immune system
        - Metaphysis or epiphysis of long bones
        - Lower extremity more often than upper
    - Adult patients
        - Immunocompromised (elderly, undergoing chemotherapy transplant recipient)
        - Vertebrae most common adult hematogenous site
        - Patient undergoing dialysis—rib and spine osteomyelitis
        - IV drug abuser—medial or lateral clavicle osteomyelitis
- Acute osteomyelitis
    - Short duration, usually less than 2 weeks
    - Symptoms include tenderness, limb, refusal to use limb
    - Fever and systemic symptoms variable
    - Laboratory findings:
        - CRP—most sensitive test (increased in ≈97%)
            - Most rapid rise and fall —good measure of treatment success
        - ESR—increased in approximately 90%
        - CBC—WBCs increased in only a third
        - Aspiration and biopsy cultures—

most specific test

- Histopathology: bony spicules with live osteocytes surrounded by inflammatory cells
- Treatment
    - 6 weeks of antibiotics directed at specific organisms identified by culture

Table 1.33

Bite Injuries

Source of Bite	Organism	Primary Antimicrobia Regimen
Human	*Streptococcus viridans* (100%) *Bacteroides* spp. (82%) *Staphylococcus epidermidis* (53%) *Corynebacterium* spp. (41%) *Staphylococcus aureus* (29%) *Peptostreptococcus* spp. *Eikenella* spp.	Early treatment (no amoxicillin/clav (Augmentin) With signs of infect ampicillin/sulba cefoxitin, ticarci (Timentin), or p tazobactam Patients with penic clindamycin plu ciprofloxacin or trimethoprim/s *Eikenella* organisms clindamycin, na metronidazole, first-generation and erythromyc to fluoroquinolo trimethoprim/s treated with cef ampicillin
Dog	*Pasteurella canis* *S. aureus* *Bacteroides* spp. *Fusobacterium* spp. *Capnocytophaga* spp.	Amoxicillin/clavula (Augmentin) or (adults); clindar trimethoprim/s (children) *P. canis* is resistant t cephalexin, clin erythromycin Antirabies treatmer considered Only 5% of dog bit become infectec
Cat	*Pasteurella multocida*	Amoxicillin/clavula cefuroxime axet

	S. aureus Possibly tularemia	doxycycline Cephalexin should *P. multocida* is resist doxycycline, cep clindamycin; m resistant to eryt Of cat bite wounds infected; cultur
Rat	*Streptobacillus moniliformis* *Spirillum minus*	Amoxicillin/clavula doxycycline Antirabies treatmen indicated
Pig	Polymicrobial (aerobes and anaerobes)	Amoxicillin/clavulanat generation cephalo ticarcillin/clavulana ampicillin/sulbacta cilastatin
Skunk, raccoon, bat	Varies	Amoxicillin/clavula doxycycline Antirabies treatmen
Pit viper (snake)	*Pseudomonas* spp. *Enterobacteriaceae* *S. epidermidis* *Clostridium* spp.	Antivenin therapy Ceftriaxone Tetanus prophylaxi
Brown recluse spider	Toxin	Dapsone
Catfish sting	Toxins (may become secondarily infected)	Amoxicillin/clavulanat

Adapted from Gilbert DN et al: *The Sanford guide to antimicrobial therapy*, Hyde Park, VT, 2010, Antimicrobial Therapy, p 48.

- Surgery is reserved for draining abscesses or failure to improve on antibiotics.

- Subacute osteomyelitis: **Brodie abscess**
  - Residual of acute osteomyelitis versus hematogenous seeding of growth plate trauma
  - Painful limp with no systemic signs
  - Adolescent to early adult (<25 years)—stronger immune system
  - Localized radiolucency with sclerotic rim at

metaphysis of long bones
        - Almost exclusively *S. aureus* (may be lower virulence)
        - Treatment: surgical débridement and 6 weeks of IV antibiotics
        - Rule out tumors (chondroblastoma): "*Biopsy all infections, culture all tumors.*"
- Chronic osteomyelitis
    - History
        - Prior trauma/surgery or soft tissue wound
        - Previous acute osteomyelitis or septic arthritis
        - Should be considered in all nonunions
        - Often chronic wound or draining sinus
    - Laboratory findings
        - Less helpful, can be normal
        - Open bone biopsy/culture best test (sinus tract cultures not helpful)
    - Histopathology
        - Dead bone (avascular) (osteocytes have no nuclei)
        - Fibrosis of marrow space
        - Chronic inflammatory cells
    - Treatment
        - Surgery required for chronic osteomyelitis
        - Basic principles
            - Multiple procedures frequently required
            - Removal of infected hardware
            - Removal of dead bone, which serves as a "foreign object"
            - Débridement of bone until punctate bleeding is restored ("paprika sign")
            - Débridement of compromised or

necrotic soft tissue

- Consideration of preoperative sinus tract injection with methylene blue
- Consideration of antibiotic spacers: PMMA cement versus biologics
- Restoration of vascularity or soft tissue muscle coverage
- Six weeks of antibiotics directed at specific cultures
- Adequate minimal inhibitory concentration (MIC) of antibiotics at site of infection

- Host classification (Cierny-Mader; Table 1.34)
  - A: healthy
  - B: wound healing comorbidities
  - BL (local): compromised vascularity

Table 1.34

Chronic Osteomyelitis: Infected Host Types

Type	Description	Risk
A	Normal immune response; nonsmoker	Minimal
B	Local or mild systemic deficiency; smoker	Moderate
C	Major nutritional or systemic disorder	High

    - Arterial disease, venous stasis, irradiation, scarring, **smoking**
  - BS (systemic): compromised immune system
    - Diabetes mellitus, malnutrition, end-stage renal disease, malignancy, alcoholism, rheumatologic diseases, immunocompromised status
      - HIV, immunosuppressive therapy, DMARDs
  - BL/S (combined local and systemic)

- C: compromised patient (palliative care or amputation)
    - No quality-of-life improvement if cured
    - Morbidity of procedure exceeds that of the disease.
    - Poor prognosis, poor cooperation with care
- Anatomic lesion classification (Fig. 1.50)
  - **I: medullary**—nidus endosteal
    - Residual hematogenous or intramuscular infected nonunion
    - Treatment: unroofing
  - **II: superficial**—infection on surface defect of coverage
    - Full-thickness soft tissue wounds: venous stasis/pressure ulcer
    - Treatment: decortication and soft tissue coverage
  - **III: localized**—cortical infection without loss of stability
    - Infected fracture union with butterfly fragment or prior plate
    - Treatment: sequestrectomy, soft tissue coverage, with or without bone graft
  - **IV: diffuse**—permeative throughout bone, unstable before or after débridement
    - Periprosthetic infection, septic arthritis or infected nonunions
    - Treatment: stabilization, soft tissue coverage, and bone graft
- Imaging of osteomyelitis
  - Radiographs
    - Acute osteomyelitis
      - Soft tissue swelling (early)

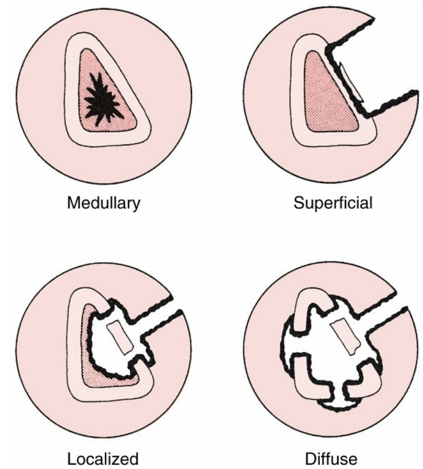


FIG. 1.50 Cierny's anatomic classification of adult chronic osteomyelitis.

- Bone demineralization or regional osteopenia (≈2 weeks after infection)
- Chronic osteomyelitis
  - Periosteal reaction, cortical erosions, bony lucency, and sclerotic changes
  - Bony lysis around hardware and prosthetic joints
  - **Sequestra—dead bone nidus with surrounding granulation tissue**
  - **Involucrum—periosteal new bone forming later**
- **MRI best method to show early osteomyelitis and anatomic location**
  - Penumbra sign
    - Bright signal in surrounding bone
    - Darker abscess and sclerotic bone
  - Negative finding rules out osteomyelitis
  - Positive finding may overestimate extent of disease
- Fluorodeoxyglucose positron emission

tomography (FDG-PET)
- Shows malignancies and infections: increased glycolysis
- Most sensitive test for chronic osteomyelitis
- More specific than MRI or bone scan

- Empiric treatment for osteomyelitis prior to definitive culture findings
  - Newborn (up to 4 months of age)
    - *S. aureus,* gram-negative bacilli, and group B streptococci
      - Nafcillin or oxacillin plus a third-generation cephalosporin
    - If MRSA: vancomycin plus a third-generation cephalosporin
  - Children 4 months of age or older
    - *S. aureus* and group A streptococci
      - Nafcillin or oxacillin versus vancomycin (MRSA)
    - Immunization has almost eliminated *Haemophilus influenzae* bone infections.
  - Adults (21 years of age or older)
    - *S. aureus*
      - Nafcillin or oxacillin versus vancomycin (MRSA)
- Antibiotic spacers/beads
  - Provide very high antibiotic levels at local area
  - 2–4 g per bag (40 g) of cement (>2 g reduces compressive strength)
  - Pouch can be formed and covered with adherent film.
  - Antibiotics must be heat stable.
    - Cephalosporins, aminoglycosides, vancomycin, clindamycin
    - Antibiotics inactivated by heat must be avoided
      - Tetracycline, fluoroquinolones, polymyxin B,

chloramphenicol

- Antibiotics elute out over 2–6 weeks.
  - Elution increased with
    - Surface area—beads
    - Higher porosity—vacuum mixing should not be used.
    - Larger antibiotic crystals—cement should be mixed until doughy, then antibiotics added.

- Atypical or unusual organisms
  - ***Salmonella* osteomyelitis—sickle cell**
    - Microinfarcts of bone and bowel
    - Spleen dysfunction
    - Bone crisis versus diaphyseal osteomyelitis
  - *Pseudomonas* osteomyelitis
    - IV drug abuse and osteomyelitis of medial/lateral clavicle
    - Puncture wounds through rubber/synthetic shoes
  - TB osteomyelitis
    - One-third of the world is infected with TB.
    - One-third of TB in pediatric and HIV-positive patients is extrapulmonary.
    - Spine most common: Pott disease (spinal gibbus)
    - One-fourth of extrapulmonary TB is in hips and knees.
    - Often involves bones on both side of joint
  - Fungal osteomyelitis
    - Long-term IV medications or parental nutrition

- Immunosuppression by disease or drugs (RA, transplantation)
- *Candida*—most common; is part of normal flora
- *Aspergillus*—rare in bone
- Regional varieties—via inhalation or direct inoculation
- *Coccidioides*—southwest United States to South America
- *Histoplasma*—soil and bird/bat guano, Ohio and Mississippi river valleys
- *Blastomyces*—rotting wood, central southeastern United States
- *Cryptococcus*—pigeon droppings, northwest United States/Canada

- Treatment
    - Débridement of osteonecrosis, resection of sinuses and/or synovitis
    - Antifungals: amphotericin
- Chronic regional multifocal osteomyelitis (CRMO) (also chronic nonbacterial osteomyelitis [CNO])
    - Children/adolescents with multifocal bone pain but no systemic symptoms
    - Exacerbations and remissions, more than 6 months of pain
    - Autoinflammatory disease; a diagnosis of exclusion
    - No abscess, fistula, or sequestrum
    - Laboratory findings: WBC count normal; ESR, CRP may be elevated
    - X-rays demonstrate multiple metaphyseal lytic or sclerotic lesions.
    - Whole-body spin tau inversion recovery (STIR) MRI more sensitive
    - Culture results negative—antibiotics do not help
    - Histologic findings
        - Early: PMNs and osteoclasts
        - Later: lymphocytes, fibrosis, and reactive bone
            - Especially in the

medial clavicle, distal tibia, and distal femur

- Treatment: symptomatic; resolves spontaneously; NSAIDs help

- SAPHO (synovitis, acne, pustulosis, hyperostosis, osteitis) syndrome
  - Also called acquired hyperostosis syndrome
  - Young to middle-aged adults with bone pain and skin involvement
  - Suspicion that ***Propionibacterium acnes*** serves as antigenic trigger
  - Humoral induction of sclerosis and erosions
  - Sternoclavicular region most commonly involved
  - Axial skeleton involvement and unilateral sacroiliitis common
  - Palmopustular psoriasis, acne, or hidradenitis suppurativa
  - Laboratory findings: ESR, CRP moderately elevated
  - Bone scan (gold standard): bull's head sign, sacroiliac joint uptake
  - MRI: erosion of vertebral body corner
  - Pathology: sterile neutrophilic pseudoabscesses
  - Cultures: occasional *P. acnes*
  - Treatment: NSAIDs, rheumatology consult, methotrexate, and biologics

□ Septic arthritis

- Sources
  - Hematogenous spread
  - **Extension of metaphyseal osteomyelitis at intraarticular physis**
    - Proximal femur—most common
    - Proximal humerus, radial neck, distal fibula
  - Direct inoculation—penetrating trauma, iatrogenic complication
- Diagnosis
  - Progressive development of joint pain, swelling

(effusion), warmth, redness
        - Progressive loss of function
        - Loading or moving a joint hurts
- Differential diagnosis of acute monoarthritis
    - Gout/pseudogout—may be history of prior episodes
    - Reactive arthritis—uveitis, urethritis, heel/back pain, colitis, psoriasis
    - Viral arthritis
    - Fever and systemic symptoms more common in younger patients
    - Laboratory findings
        - **Elevations of CRP**, ESR, WBC
        - Aspiration—best test
            - Cell count: greater than 50,000 WBCs/μL; left shift
            - Gram stain—helpful if positive
            - Cultures: aerobic and anaerobic
            - Crystals
- *S. aureus* most common bacteria, but following organisms should also be considered:
    - Group B streptococci (GBS): neonate
    - *H. influenza*: Unvaccinated children younger than 2 years
    - *Kingella kingae:* slower progressing or less virulent septic arthritis in young children
        - Toddler (aged 1–4 yr) with painful joint
        - After upper respiratory infection in fall/winter
        - Gram-negative coccobacilli—hard to culture; blood bottles should be used
        - **PCR should be considered**
    - Group A strep: post-varicella
    - *Neisseria gonorrhoeae:* sexually active young adults
    - *P. acnes*
        - Most common cause after mini–open repair of rotator cuff
        - Shoulder replacement (second only to *S. aureus*)

- Indolent low-grade common contaminant
- More than one culture needed; grows very slowly (7–10 days)
- Gram-positive anaerobic rod that fluoresces under ultraviolet light
- Less sensitive to cefazolin (penicillin, vancomycin, clindamycin)

- Fungal infections
  - Chronic effusions, synovitis
  - Immunocompromise: especially cellular immunity
  - IV drug abuse
  - Aspiration: 10,000–40,000 WBCs/μL, 70% PMNs
  - Diagnosis: potassium hydroxide (KOH) versus 6-week culture

- Treatment
  - I&D
  - IV antibiotics best based on culture results
  - Empiric antibiotics based on Gram stain results:
    - Gram-positive cocci: vancomycin
    - Gram-negative cocci: ceftriaxone
    - Gram-negative rods: ceftazidime, carbapenem, or fluoroquinolone
    - Negative Gram stain: vancomycin and ceftazidime or fluoroquinolone
  - Progress can be monitored with CBC, ESR, CRP (best measure of success)

□ Periprosthetic septic arthritis: see Chapter 5, Adult Reconstruction, for details.

▪ **Infectious risks of practice**

□ **HIV infection**

- Obligate intracellular retrovirus
- Primarily affects lymphocyte and macrophage cell lines
- **Decreases helper cells ($CD4^+$ cells)**
- Approximately 50,000 new cases/year reported by the CDC
- Increased in: homosexual men, patients with hemophilia, and IV drug abusers
- One-fifth of those infected know they are HIV positive.
- AIDS
  - Diagnosis requires an positive HIV test result plus one of the following:

            - One of the opportunistic infections (e.g., pneumocystis)
            - $CD4^+$ cell count of less than 200 cell/μL (normal, 700–1200 cells/μL)
- Transmission rate
    - Increases with amount of blood exposed and viral load
    - Decreases with postexposure antiviral prophylaxis
    - **From a contaminated needlestick: 0.3%**
    - From mucous membrane exposure: 0.09%
    - From a blood transfusion: approximately 1 per 500,000 per unit transfused
    - **From frozen bone allograft: less than 1 per 1 million**
        - Donor screening—most important factor in preventing viral transmission
        - No cases from fresh frozen bone allograft have been reported since 2001.
        - Most sensitive screen—nucleic acid amplification testing (NAAT)
- HIV positivity is not a contraindication to performing required surgical procedures.
    - HIV-positive patients more likely to have THA
    - Higher association with liver disease, drug abuse, coagulopathy
    - Development of acute renal failure and postoperative infection more likely
    - Asymptomatic HIV-positive individuals have no significant difference in short-term infection risks.
- Orthopaedic manifestations more common in later stages
    - Increased infections:
        - Polymyositis: viral muscle infection
        - Pyomyositis: *S. aureus*
        - TB
        - Bacillary angiomatosis (*Bartonella henselae*) from cats
    - Reactive arthritis (Reiter syndrome)
    - Non-Hodgkin lymphoma and Kaposi sarcoma
    - Osteonecrosis

Table 1.35

Mechanism of Action of Antibiotics

Class of Antibiotic	Examples	Mechanism of Action
β-Lactam antibiotics	Penicillin, cephalosporins	Inhibit cross-linking of polysaccharides in the cell wall by blocking transpeptidase enzyme
Aminoglycosides	Gentamicin, tobramycin	Inhibit protein synthesis (the mechanism is through binding to cytoplasmic 30S-ribosomal subunit)
Clindamycin and macrolides	Clindamycin, erythromycin, clarithromycin, azithromycin	Inhibit the dissociation of peptidyl-transfer RNA from ribosomes during translocation (the mechanism is through binding to 50S-ribosomal subunit)
Tetracyclines		Inhibit protein synthesis (binds to 50S-ribosomal subunit)
Glycopeptides	Vancomycin, teicoplanin	Interfere with the insertion of glycan subunits into the cell wall
Rifampin		Inhibits RNA polymerase F
Quinolones	Ciprofloxacin, levofloxacin ofloxacin	Inhibit DNA gyrase
Oxazolidinones	Linezolid	Inhibit protein synthesis (binds to 50S-ribosomal subunits)

Table 1.36

Antibiotic Indications and Side Effects

Antibiotics	Sensitive Organisms	Complications/Other Information
Aminoglycosides	G−, PM	Auditory (most common) and vestibular damage is caused by destruction of the cochlear and vestibular sensory cells from drug accumulation in the perilymph and endolymph Renal toxicity Neuromuscular blockade
Amphotericin	Fungi	Nephrotoxic
Aztreonam	G−	Ineffective against anaerobes
Carbenicillin/ticarcillin/piperacillin	Better against G− than G+	Platelet dysfunction, increased bleeding times
Cephalosporins:		Nausea, vomiting, diarrhea
	Prophylaxis (surgical)	Cefazolin is the drug of choice

First generation		
Second generation	Some G+, some G−	
Third generation	G−, fewer G+	Hemolytic anemia (bleeding diathesis [moxalactam])
Chloramphenicol	*Haemophilus influenzae*, anaerobes	Bone marrow aplasia
Ciprofloxacin	G−, MRSA	Tendon ruptures; cartilage erosion in children; antacids reduce absorption of ciprofloxacin; theophylline increases serum concentrations of ciprofloxacin
Clindamycin	G+, anaerobes	Pseudomembranous enterocolitis
Daptomycin	G+, MRSA	Muscle toxicity
Erythromycin	G+	In cases of PCN allergy Ototoxic
Imipenem	G+, some G−	Resistance, seizure
Methicillin/oxacillin/nafcillin	Penicillinase resistant	Same as penicillin; nephritis (methicillin); subcutaneous skin slough (nafcillin)
Penicillin	Streptococcal, G+	Hypersensitivity/resistance; hemolytic
Polymyxin/nystatin	GU	Nephrotoxic
Sulfonamides	GU	Hemolytic anemia
Tetracycline	G+	In cases of PCN allergy Stains teeth/bone (contraindicated up to age 8 yr)
Vancomycin	MRSA, *Clostridium difficile*	Ototoxic; erythema with rapid IV delivery

G − , Gram-negative; *G+*, gram-positive; *GU*, genitourinary; *PCN*, penicillin; *PM*, polymicrobial.

- □ Hepatitis
  - Hepatitis B (HB)
    - Blood transmission: bite/sexual/occupational
    - **Singlestick transmission rate in the unvaccinated: approximately 30%**
    - Causes cirrhosis, liver failure, and hepatocellular carcinoma
    - Screening and vaccination have reduced the risk of transmission for health care workers.

- Immune globulin is administered after exposure in unvaccinated persons.
- Allografts are screened for HB surface antigen and HB core antibody.

- Hepatitis C (non-A, non-B) (HCV)
  - Blood transmission: two-thirds of U.S. HCV-positive individuals have IV drug abuse history; 2% of cases are occupational
  - **Single-stick transmission rate ≈3%**
  - Advances in screening have decreased the risk of transfusion-associated infection.
  - Most sensitive method to screen and test early:
    - PCR = NAAT

- **Antibiotics**
  - Prophylactic treatment of open fractures
    - Gustilo I and II fractures: first-generation cephalosporins the treatment of choice
    - Gustilo IIIA: first-generation cephalosporin plus an aminoglycoside
    - Gustilo IIIB (grossly contaminated): first-generation cephalosporin plus an aminoglycoside plus penicillin
  - Mechanisms of action of antibiotics are summarized in Table 1.35.
  - Antibiotic indications and side effects are listed in Table 1.36.

Section 3 Perioperative and Orthopaedic Medicine

Thromboprophylaxis

- **Thromboembolic disease**
  - Common orthopaedic complication
    - Thrombosis: clotting at improper site
    - Embolism: clot that migrates
  - Most clinically silent but can be fatal
  - Complications of thromboembolic disease:
    - Postthrombotic syndrome: chronic venous insufficiency
      - Venous hypertension (HTN)
      - Chronic skin issue with swelling, pain
      - Pigmentation, induration, ulceration
    - Recurrent deep venous thrombosis (DVT): risk four to eight times higher after first DVT
    - Pulmonary embolism (PE)
  - Pathophysiology (Virchow triad) (Fig. 1.51)
    - Endothelial damage: trauma or surgery
      - Exposes collagen—triggers platelets
      - Platelets—three roles:
        - Adhesion and activation
        - Secretion of prothrombotic mediators
        - Aggregation of many platelets
    - Stasis: allows bonds of clotting proteins and cells
      - Immobility: pain, stroke, paralysis
      - Blood viscosity: polycythemia, cancer, estrogen
      - Decreased inflow: tourniquet, vascular disease
      - Decreased outflow: venous scarring, CHF
    - Hypercoagulability
      - Clotting cascade's final product is thrombin
      - Converts soluble fibrinogen to insoluble fibrin
  - Risk factors and epidemiology
    - Reported risks of thromboembolic disease vary by:
      - Definitions: asymptomatic versus symptomatic
      - Location
        - Distal: those below popliteal space have very low PE risk
        - Proximal: those above popliteal space have higher PE risk
    - Patient-specific risks factors (Fig. 1.52)
      - Prior thromboembolic disease a strong risk factor

- Risk increases exponentially with age (>40 years) (Fig. 1.53)
- Genetic factors—thrombophilias
  - Decreased anticlotting factors
    - Antithrombin III, protein C, protein S deficiencies
  - **Increased clotting factors or factor activity**
    - **Factor V Leiden**
      - **Mutated factor V not inactivated as effectively by activated protein C, so clotting process remains active for longer than normal**
    - Elevated factor VIII
    - Hyperhomocysteinemia
    - Prothrombin G20210A (factor II mutation)

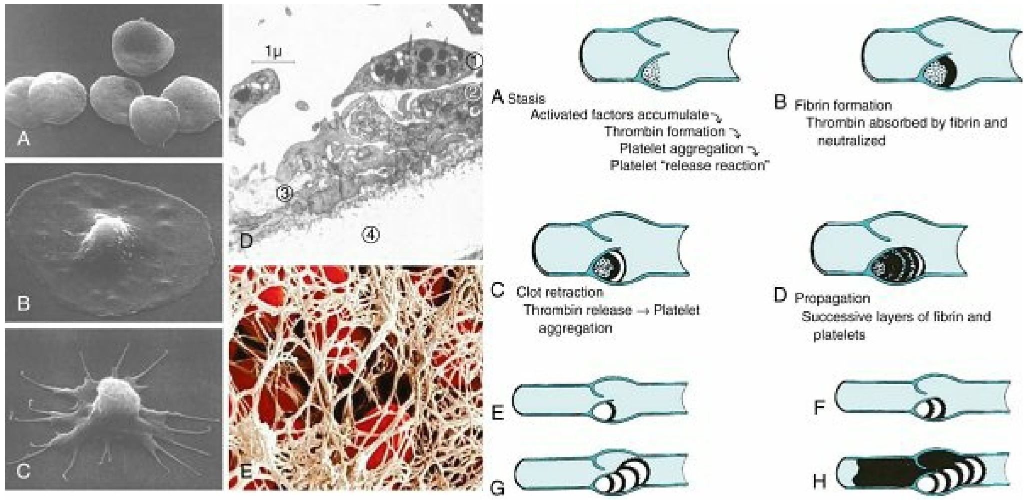


FIG. 1.51 *Left,* Electromicrograph panel (A through E). (A) Scanning electron micrograph (SEM) of free platelets. (B) SEM of platelet adhesion. (C) SEM of platelet activation. (D) Transmission electron micrograph of aggregating platelets. *1,* Platelet before secretion; *2* and *3,* platelets secreting contents of granules; *4,* collagen of endothelium. (E) SEM of fibrin mesh encasing colorized red blood cells. *Right,* Illustration panel (A through H) showing venous thromboembolus formation. (A) Stasis. (B) Fibrin formation. (C) Clot retraction. (D) Propagation. (E–H) Continuation of this process until the vessel is effectively occluded.

From Miller MD, Thompson SR, editors: *DeLee and Drez's orthopaedic sports medicine: principles and practice,* ed 4, Philadelphia, 2014, Saunders; platelet electron micrographs courtesy James G. White, MD, Department of Laboratory Medicine and Pathology, University of Minnesota School of Medicine; Miller MD et al: *Review of orthopaedics,* ed 6, Philadelphia, 2012, Saunders; and Simon SR, editor: *Orthopaedic basic science,* Rosemont, IL, 1994, American Academy of Orthopaedic Surgeons, p 492.

Most common hypercoagulable genetic (primary) disorders	Relative risk	Prevalence (%)	Venous thromboembolism patients (%)
Decreased antithrombotic factors			
Antithrombin III deficiency	20	0.02	2
Protein C deficiency	6.5	0.3	4
Protein S deficiency	5	0.003	2
Increased prothrombotic factors			
Factor V Leiden–homozygous (C resistance)	80	0.02	
Factor V Leiden–heterozygous (C resistance)	7	4.8	20
Elevated factor VIII	5	11	25
Hyperhomocysteinemia	3	6	10
Prothrombin G20210A (increased factor II)	3	2.7	7

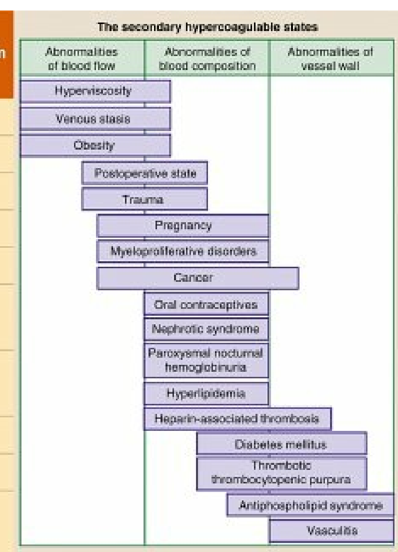
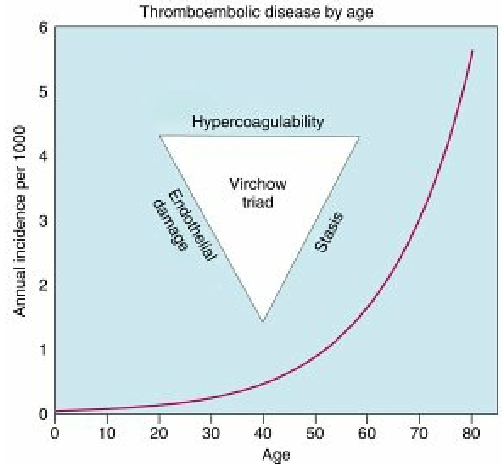


FIG. 1.52 Genetic (primary) disorders (table on *left*) and secondary hypercoagulable states (figure on *right*).

Data from Ginsberg MA: Venous thromboembolism. In Hoffman R et al, editors: *Hematology: basic principles and practice,* ed 4, Philadelphia, 2005, Churchill Livingstone, pp 2225–2236; Perry SL, Ortel TL: Clinical and laboratory evaluation of thrombophilia, *Clin Chest Med* 24:153–170, 2003; and Schafer AI: Thrombotic disorders: hypercoagulable states. In Goldman L, Ausiello D, editors: *Cecil textbook of medicine,* ed 22, Philadelphia, 2004, Saunders, pp 1082–1087.



Condition	Relative risk
Age >70 yr	10–15×
Cancer	6×
Pregnancy	5×
Lupus antiphospholipid antibodies	4×
Oral contraceptive pills	3–4×
Obesity (body mass index >29 kg/m^2)	3×
Smoking	3×
Diabetes	2×
Hypertension	2×

FIG. 1.53 *Top,* The three primary influences of thromboembolic disease (Virchow triad). *Bottom,* The relative risks of various patient conditions; note that age has an exponentially increasing risk.
Composite from Miller MD, Thompson SR, editors: *DeLee and Drez's orthopaedic sports medicine: principles and practice,* ed 3, Philadelphia, 2014, Saunders; and data from Anderson FAJr et al: Apopulation-based perspective of the hospital incidence and case-fatality rates of deep vein thrombosis and pulmonary embolism. The Worcester DVT Study, *Arch Intern Med* 151:933–938, 1991.

- Procedure-specific factors (Fig. 1.54)
    - PE risk lower with distal procedures versus hip procedures
    - Risk higher with longer procedures
    - Total knee arthroplasty (TKA) has higher total DVT risk but lower PE risk
    - Risk with hip fracture is higher than that with THA.

□ Diagnosis

- Clinical diagnosis favors assessment of risk factors.
- Physical exam is unreliable: most cases are asymptomatic.
    - DVTs can cause calf pain, palpable cords, swelling.
        - 50% with classic signs have no DVT according to studies

Procedure	sDVT (%)	PE (%)
All hospital admission	0.048–0.07	0.023–0.03
Major orthopaedic procedures: THA, TKA, HFS		
In 2 weeks no prophylaxis	1.8	1
In 35 days no prophylaxis	2.8	1.5
In hospital with prophylaxis	0.26–0.8	0.14–0.35
In 35 days with prophylaxis	0.45	0.20
Knee arthroscopy	0.25–9.9	0.028–0.17
ACL reconstruction	0.3	0.8
Hip arthroscopy	0–3.7	0
Shoulder arthroscopy	0.01–0.26	0.01–0.21
Shoulder fracture	0	0.2
Shoulder arthroplasty	0.19–0.2	0.1–0.4
Elbow arthroplasty	—	0.25
Foot and ankle surgery	0–0.22	0.02–0.15
Ankle fracture	0.05–2.5	0.17–0.47
Ankle arthroscopy	0	0

ACL, Anterior cruciate ligament; *HFS*, hip fracture surgery; *PE*, pulmonary embolism; *sDVT*, symptomatic deep vein thrombosis; *THA*, total hip arthroplasty; *TKA*, total knee arthroplasty.

FIG. 1.54 Rates of symptomatic thromboembolism in orthopaedic sports medicine.
From DeHart M: Deep venous thrombosis and pulmonary embolism. In Miller MD, Thompson SR, editors: *DeLee and Drez's orthopaedic sports medicine: principles and practice*, ed 4, Philadelphia, 2014, Saunders, p 207.

        - 50% with venogram positive for clot have normal physical findings
    - PEs: most asymptomatic
        - Signs/symptoms include pleuritic chest pain, dyspnea, tachypnea
        - Saddle emboli can manifest as death.
- Laboratory studies
    - D-dimer studies not helpful after injury/surgery but negative result rules out significant clot.
- ECG: rule out MI
    - Nonspecific findings; most common finding is sinus tachycardia.
- Radiologic studies (Fig. 1.55)
    - Venogram—best for distal (below popliteal) lesions (clinical relevance?)
    - Duplex compression ultrasound—most practical
        - Noninvasive, easily repeatable bedside test
        - Finding of "noncompressible vein" about 95% sensitive/specific
        - Guidelines strongly against routine duplex screening
    - Chest x-ray
        - Early findings: usually normal, "oligemia," or prominent hilum (Fig.

1.56B)
        - Late findings: wedge or platelike atelectasis (see Fig. 1.56C)
    - Spiral CT angiography—best for suspected PE
    - Ventilation-perfusion ($\dot{V}/\dot{Q}$) scan—most helpful for dye-sensitive patients

□ Thromboembolic prophylaxis

- Preventing DVTs has been shown to be possible, although whether such prevention avoids death is unproven.
- Guidelines vary in their recommendations (Fig. 1.57).
- Prophylaxis recommended for all patients undergoing arthroplasty.
    - Those undergoing THA may benefit from extended treatment (≈30 days).
- For patients without risk-related conditions, prophylaxis is not recommended for
    - Upper extremity procedures, arthroscopic procedures, surgery for isolated fractures at knee and below
- Mechanical measures
    - Early mobilization
    - Graduated elastic hose—not sufficient alone
    - Intermittent pneumatic compression devices (IPCDs)
        - Stimulate fibrinolytic system
        - Low bleeding risks
        - Grade IC by 2012 American College of Chest Physicians (ACCP) guidelines
    - Continuous passive motion (CPM) of no benefit
- Pharmacologic prophylaxis:
    - Surgical Care Improvement Project (SCIP) quality measures require DVT prophylaxis.
    - **Aspirin**
        - **Irreversibly binds and inactivates COX in platelets, thereby reducing thromboxane A_2**
        - Weakest: Use of IPCD encouraged

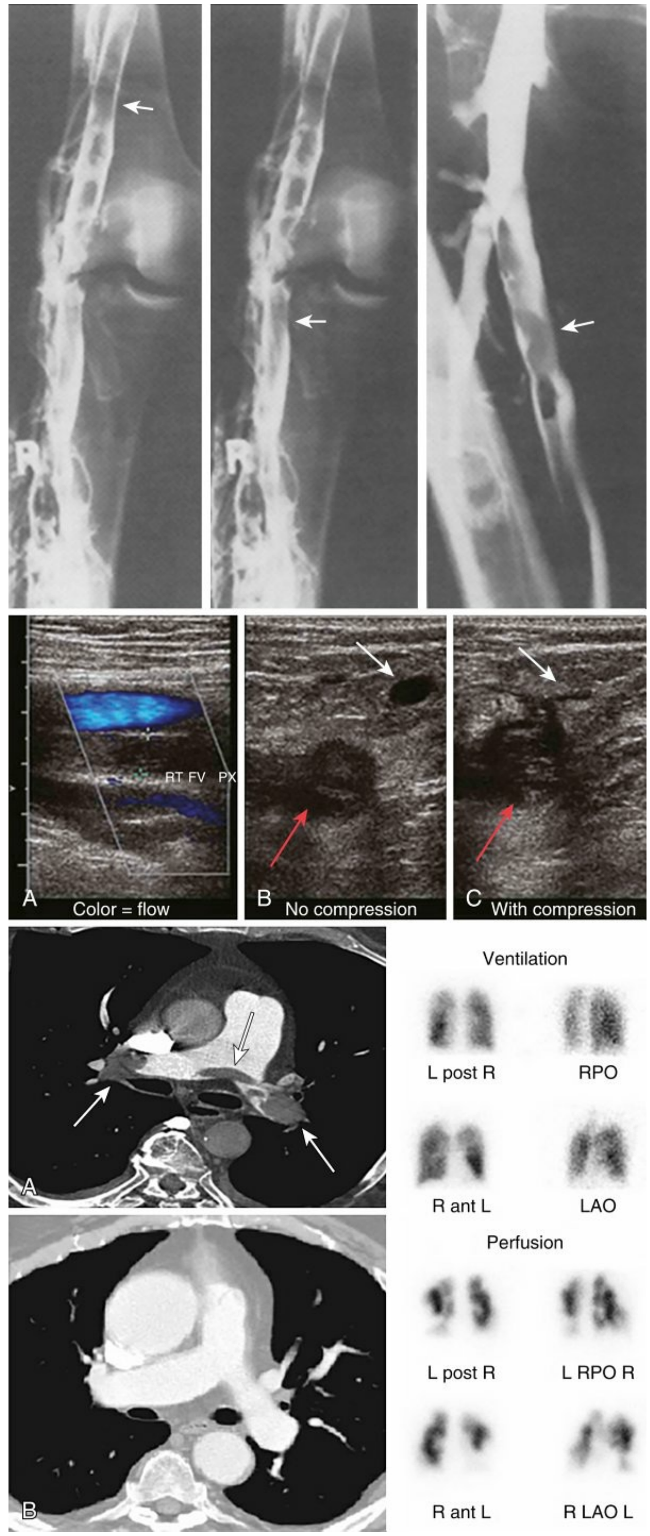


FIG. 1.55 *Top left to right,* Venogram showing deep vein thrombosis). Intraluminal filling defects *(arrows)* seen on two or more views of a venogram. The left and middle images are at the knee, and the right image is at the hip. *Middle*, Doppler ultrasound for proximal DVT in femoral vein thrombosis. (A) Longitudinal view shows presence of flow (*light blue*) in the more superficial vein over an occlusive thrombus (*dark gray*). (B) A transverse view without compression shows an open superficial vein, appearing as a black oval (*white arrow*) and a thrombosed deeper vein

as a dark gray circle with an echogenic center (*red arrow*). (C) A transverse view with compression shows the flattened compressible superficial vein (*white arrow*) and the unchanged noncompressible thrombosed deeper vein (*red arrow*). *Bottom left,* Spiral CT pulmonary angiography. (A) Large pulmonary embolism (*arrows*). (B) Normal CT. Right images, high probability $\dot{V}/\dot{Q}$ scan showing full lung fields on ventilation scan *(upper)* and multiple areas lacking tracer on the perfusion scan *(lower)*. *ant,* Anterior; *LAO,* left anterior oblique; *post,* posterior; *RPO,* right posterior oblique.
DVT panel from Jackson JE, Hemingway AP: Principles, techniques and complications of angiography. In Grainger RG, editor: *Grainger & Allison's diagnostic radiology: a textbook of medical imaging,* ed 4, Philadelphia, 2011, Churchill Livingstone. Original images courtesy Austin Radiological Association and Seton Family of Hospitals.

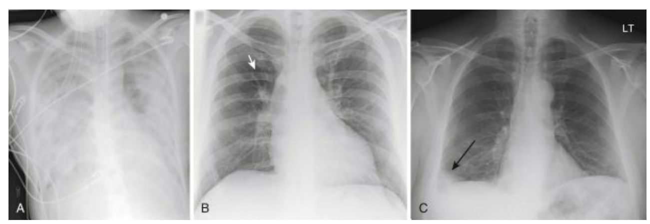


FIG. 1.56 Chest radiographs. (A) Diffuse bilateral fluffy patchy infiltrates, worse at bases, are consistent with ARDS (acute respiratory distress syndrome). (B) A focal area of oligemia in the right middle zone (Westermark sign [*white arrow*]) and cutoff of the pulmonary artery in the upper lobe of the right lung are both seen with acute pulmonary embolism. (C) The peripheral wedge-shaped density without air bronchograms at lateral right lung base (Hampton hump [*black arrow*]) develops over time after a pulmonary embolism.
B from Krishnan AS, Barrett T: Images in clinical medicine: Westermark sign in pulmonary embolism, *N Engl J Med* 366:e16, 2012; **C** from Patel UB et al: Radiographic features of pulmonary embolism: Hampton hump, *Postgrad Med J* 90:420–421, 2014.

Recommendations on prevention of VTE in hip and knee arthroplasty Grade of recommendation: ! Strong + Moderate ~ Weak * Consensus ? Inconclusive		Notes from other guidelines: 1 ACCP, 2 NICE, 3 AHRQ
!	No "screening" duplex US	
+	History of normal risks of VTE and bleeding, use drugs **and/or** IPC	
+	D/C platelet inhibitors preop (aspirin, clopidogrel, prasugrel)	Discuss with medical team, stop 1 week prior[2]
+	Neuraxial anesthesia to decrease bleeding (no effect on VTE)	Caution with drugs and neuraxial[1]; wait 12 hours after drugs[2]
~	Ask history of previous VTE	
*	Hx of VTE, get IPC **and** drugs	DRUGS: LMWH, fondaparinux, dabigatran, rivaroxaban, VKA, aspirin[1]
*	Ask Hx of bleeding disorder (hemophilia) and active liver disease	
*	Hx of bleeding disorder (hemophilia or active liver disease) **only** IPC	If bleeding risk, IPC or nothing[1]; if bleeding risk > clotting risk, IPC[2]
*	Discuss duration with patient	≥10 days, consider 35 days[1]
*	Early mobilization	
?	Assess other clotting risk factors	
?	Assess other bleeding risk factors	
?	No one technique optimal	Drugs and IPC[1,2] ; D/C drugs when TKA mobile[2]
?	IVC filter	If VTE risks high and contraindication to prophylaxis[2]
Guideline title		Source:
2011 AAOS Preventing Venous Thromboembolic Disease		http://www.aaos.org/research/guidelines
2012 ACCP Prevention of VTE in Orthopedic Surgery Patient		http://journal.publications.chestnet.org/
2012 AHRQVTE Prophylaxis in Orthopedic Surgery, CER 49		http://effectivehealthcare.ahrq.gov/
2010 NICE Reducing the Risk of VTE in patients admitted to hospital		http://guidance.nice.org.uk/CG92/

FIG. 1.57 Recommendations on prevention of VTE in hip and knee arthroplasty. Hx, history; US, ultrasonography.

- Low bleeding risk: Should be considered for patients at higher risk for bleeding.
- Warfarin (Coumadin)
  - Prevents vitamin K γ-carboxylation in liver
  - Inhibits factors II, VII, IX, X, and proteins C and S
  - Vitamin K and fresh frozen plasma can reverse
  - Multiple reactions with drugs and diet
  - Must be monitored with international normalized ratio (INR; goal, 2–3)
- **Heparin**
  - **Activates antithrombin III (ATIII), which then inactivates factor Xa and thrombin**
  - Protamine sulfate can reverse
  - Short half-life: 2 hours
  - High bleeding rate in arthroplasty
  - Binds platelets—heparin-induced thrombocytopenia
- Low-molecular-weight heparin (LMWH)
  - Reversibly inhibits factor Xa through ATIII and factor II
  - Protamine sulfate can reverse
  - No monitoring needed
  - Less heparin-induced thrombocytopenia
  - Higher risk for bleeding than with

warfarin

- **Fondaparinux**
  - **Irreversibly but indirectly inhibits factor X through ATIII**
  - Synthetic pentasaccharide
  - No monitoring
  - No antidote
  - Higher risk for bleeding than with LMWH
- **Rivaroxaban**
  - **Direct Xa inhibitor**
  - Oral drug
  - Higher risk for bleeding than with LMWH
- Hirudin
  - Direct thrombin (IIa) inhibitor
  - Intramuscular and oral (dabigatran) versions
  - No antidote
- Inferior vena cava (IVC) filter use: controversial
  - Should be considered in following conditions:
  - Contraindication to prophylaxis
  - Cerebral bleed/trauma
  - Spine surgery
  - Prior complication of prophylaxis

□ Treatment of thromboembolic disease

- Pharmacologic treatment
  - Prolonged therapy often recommended
    - Approximately 3 months after DVT, approximately 12 months after PE
- Early mobilization—*no bed rest*
  - Risk of dislodgment less than risk of more clots in these high-risk patients
- Graduated elastic compression hose for 2 years
  - May prevent postthrombotic syndrome
- Thrombolytics, thrombectomy, embolectomy controversial

□ Special venous thromboembolism (VTE) situations

- Isolated calf thrombosis smaller than 5 cm rarely needs treatment.
  - Follow with serial ultrasound scans.
- Upper extremity blood clot in athlete
  - "Effort thrombosis" (Paget-Schroetter syndrome)
  - Axillary–subclavian vein thrombosis
  - Complaints
    - Pain, swelling
    - Dilated veins
    - Feeling of heaviness
  - Diagnosis: duplex ultrasound
  - Treatment: thoracic outlet decompression should be considered

Perioperative Disease and Comorbidities

- **Orthopaedic surgeons who evaluate their patients with care** *preoperatively* can be rewarded with fewer perioperative problems.
- **Goals include finding correctable issues and identifying risks to provide accurate risk/benefit assessment for proper consent.**
- **Cardiac issues**
  - Coronary artery disease (CAD): leading cause in those older than 35 years
  - Leading cause of cardiac death in young sports population: hypertrophic cardiomyopathy
  - American College of Cardiology/American Heart Association (ACC/AHA) elements for assessing risk
    - Clinical risk factors in perioperative cardiac risk
    - Major predictors
      - Unstable/severe angina, recent MI (<6 weeks)
      - Worsening or new-onset CHF
      - Arrhythmias
        - Atrioventricular (AV) block
        - Symptomatic ventricular dysrhythmia: bradycardia (<30 beats/min), tachycardia (>100 beats/min)
      - Severe aortic stenosis or symptomatic mitral stenosis
    - Other
      - Prior ischemic heart disease
      - Prior CHF

        - Prior stroke/ TIA
        - Diabetes
        - Renal insufficiency (creatine >2 mg/dL)
    - Functional exercise capacity—measured in metabolic equivalents (METs)
        - MET: 3.5 mL O_2 uptake/kg/min
        - Perioperative risk elevated if unable to meet 4-MET demand
            - Walk up flight of steps or hill (= 4 METs)
            - Heavy work around house (>4 METs)
            - Can patient walk four blocks or climb two flights of stairs?
    - Surgery-specific risk:
        - High risk (>5% risk of death/MI)
            - Aortic, major or peripheral vascular procedures
        - **Intermediate risk (1%–5% risk of death/MI)**
            - **Orthopaedic, ENT, abdominal/thoracic or procedures**
        - **Low risk (<1% risk of death/MI)—usually do not need further clearance**
            - **Ambulatory surgery**, endoscopic or superficial procedures
- □ Twelve-lead ECG if:
    - CAD and intermediate-risk procedure
    - One clinical risk factor and intermediate-risk procedure
- □ Noninvasive evaluation of left ventricular function if:
    - Three or more clinical risk factors and intermediate-risk procedure
    - Dyspnea of unknown origin
    - CHF with worsening dyspnea without testing in 12 months
- □ β-Blockers and statins should be continued around the time of surgery.
- □ Acetylsalicylic acid (ASA) should be stopped 7 days prior to surgery.
- □ Cardiology consultation should be considered for patients taking other agents (clopidogrel, prasugrel).
    - Risk of stent thrombosis balanced with that of surgical bleed

▪ **Shock**

- □ Cardiovascular collapse with hypotension, followed by impaired tissue perfusion and cellular hypoxia. May be a result of orthopaedic pathology or a complication of surgery.
- □ Metabolic consequence
    - O_2 is unavailable—no oxidative phosphorylation

- Cells shift to anaerobic metabolism and glycolysis
- Pyruvate is converted to lactate—metabolic acidosis
- **Lactate—indirect marker of tissue hypoperfusion**
- **Best measures of adequate resuscitation**
    - **Clinical measure of organ function: urine output more than 30 mL/h**
    - **Laboratory measure: serum lactate less than 2.5 mg/dL**

□ Types of shock

- Neurogenic shock
    - High spinal cord injury (also anesthetic accidents)
    - Loss of sympathetic tone and of vasomotor tone of peripheral arterial bed
    - Bradycardia, hypotension, warm extremities
    - Treatment: vasoconstrictors and volume
- Septic shock (vasogenic)
    - Number one cause of ICU death
    - Mortality 50%
    - Bacterial toxins stimulate cytokine storm.
        - Examples: gram-negative lipopolysaccharides
        - Toxic shock superantigen
    - Inflammatory mediators cause endothelial dysfunction and peripheral vasodilation
    - Treatment
        - Identification and treatment of infections
        - Prompt resection of dead tissue
        - Appropriate antibiotics
- Cardiogenic shock
    - Bad pump
        - Extensive MI, arrhythmias
    - Blocked pump (obstructive shock)
        - Massive “saddle” pulmonary embolism
    - Tension pneumothorax
        - Decreased lung sounds, hypertympany, tracheal deviation
        - Treated with needle decompression followed by tube thoracostomy
    - Cardiac tamponade
        - Beck triad: hypotension, muffled heart sounds, neck vein distension

            - Pulsus paradoxus
                - Decreased systolic BP with inspiration
            - Treatment: pericardiocentesis
    - Hypovolemic shock
        - Most common shock of trauma
        - Volume loss from bleeds or burns
            - “Third spacing” also a cause
        - Neuroendocrine response: save heart and brain
            - Peripheral vasoconstriction
                - BP may be normal
                - Pale, cold, clammy extremities
        - Percentage of blood loss key to symptoms/signs
            - Class I: up to 15% blood volume loss
                - Vital signs can be maintained.
                - Pulse below 100 beats/min
            - Class II: 15%–30% blood volume loss
                - Tachycardia (>100 beats/min), orthostatic
                - Anxious
                - Increased diastolic BP
            - Class III: 30%–40% blood volume loss
                - Decreased systolic BP
                - Oliguria
                - Confusion, mental status changes
            - Class IV: more than 40% blood volume loss
                - Life threatening; patient is obtunded
                - Narrowed pulse pressure
                - Immeasurable diastolic BP
        - Treatment
            - First, ABCs of resuscitation: then, bleeding must be stopped.
            - Blood products make better resuscitation fluids than saline.

▪ **Perioperative pulmonary issues**

- Higher in cases that involve thorax such as scoliosis
- Highest in patients with prior disease
  - Spinal/epidural anesthesia favored over general
  - Medical treatment should be maximized around surgery.
- COPD
  - Symptomatic COPD: anticholinergic inhalers (ipratropium)
  - May require corticosteroids
- Asthma
  - Presence of wheezes or shortness of breath: β-agonist inhalers (albuterol)
  - Perioperative oral steroids safe
    - Systemic glucocorticoid should be considered if forced expiratory volume in 1 minute (FEV_1) or peak expiratory flow rate (PEFR) is below 80% predicted values/personal best.
- Postoperative atelectasis
  - Like the associated cough, the workup is usually nonproductive.
  - Deep breathing/incentive spirometry—equally effective
- Postoperative pneumonia takes up to 5 days to manifest.
  - Productive cough, fever/chills, increased WBC count
  - Radiograph: pulmonary infiltrates
- Smoking cessation improves outcomes
  - Patients should stop 6–8 weeks preoperatively.
  - Nicotine supplements do no harm to wound.
  - Fewer pulmonary complications
    - Smokers have six times more pulmonary complications.
  - Fewer wound healing issues and wound infections
  - Lower nonunion rate
  - Shoulder, neck, and thoracic pain in smokers
    - Prompts careful evaluation of lung fields
      - **Superior sulcus tumor (Pancoast tumor)**
        - **Intrinsic atrophy of hand—C8–T1**

- **Acute respiratory distress syndrome (ARDS)**
  - Pulmonary failure due to edema (see Fig. 1.56A)
  - Pathophysiology
    - Complement pathway activated
    - Increased pulmonary capillary permeability
    - Intravascular fluid floods alveoli
    - Results

- Hypoxia, pulmonary HTN
    - Right heart failure
  - 50% mortality
- Etiology
  - Blunt chest trauma, aspiration, pneumonia, sepsis
  - Shock, burns, smoke inhalation, near drowning
  - Orthopaedic: Long-bone trauma
- Clinical symptoms
  - Tachypnea, dyspnea, hypoxia, decreased lung compliance
  - PaO_2/FIO_2 ratio below 200
- Imaging
  - Radiographs: diffuse bilateral infiltrates, "snowstorm"
  - CT: ground glass appearance
- Treatment
  - Prompt diagnosis and treatment of musculoskeletal infections
  - Prompt treatment of long-bone fractures
  - Ventilation with positive end-expiratory pressure (PEEP)
  - 100% O_2

▪ **Fat emboli syndrome—classic clinical triad**
- Petechial rash: fat to skin
- Neurologic symptoms: fat to brain
  - Mental status changes: confusion, stupor
  - Rigidity, convulsions, coma
- Pulmonary collapse: fat showers lung
  - ARDS: hypoxia, tachypnea, dyspnea
- Associated with long-bone fractures

▪ **Bleeding and blood products**
- Bleeding complications can be avoided through preoperative identification of risk.
- Common inherited bleeding disorders
  - Von Willebrand disease: autosomal dominant
    - Most common genetic coagulation disorder
    - Von Willebrand factor dysfunction
      - Binds platelets to endothelium
      - Carrier for factor VIII
    - Treatment: desmopressin
  - **Hemophilia A (VIII): X-linked recessive**
  - Hemophilia B (IX) Christmas disease: X-linked recessive
- Medicines/supplements that should be stopped prior to surgery
  - Platelet-inhibitor drugs (aspirin, clopidogrel, prasugrel, NSAIDs)
  - Drugs that cause thrombocytopenia

        - Penicillin, quinine, heparin, LMWH
    - Anticoagulants (see earlier discussion on DVT)
    - Supplements
        - Fish oil, omega-3 fatty acids, vitamin E
        - Garlic, ginger, *Ginkgo biloba*
        - Dong quai, feverfew
- □ Diseases associated with increased bleeding
    - Chronic renal disease—uremia causes platelet dysfunction
    - Chronic liver failure—decreased liver proteins of clotting cascade
- □ Techniques to avoid blood loss at surgery
    - Tourniquets: tissue effect relates to time and pressure
        - Used no longer than 2 hours
            - Time to restoration of equilibrium
                - 5 minutes after 90 minutes of use
                - 15 minutes after 3 hours
        - Prolonged use can cause tissue damage.
            - Nerve damage compressive (not ischemic)
                - Electromyography: subclinical abnormalities in 70% with routine use
            - Slight increase in pain
        - Wider tourniquets distribute forces
        - Pad underneath prevents skin blisters in TKA
        - Lowest pressure needed for effect should be used
            - 100–150 mm Hg above systolic BP
                - 200 mm Hg upper extremity
                - 250 mm Hg lower extremity
    - Tranexamic acid
        - Synthetic lysine analogue; acts on fibrinolytic system
        - Competitive inhibitor of plasminogen activation
        - Reduces blood loss with no increase in DVT.
    - Temperature
        - Mild hypothermia increases bleeding time and blood loss.
    - Intraoperative "cell saver" may be cost-effective if:
        - About 1000 mL of blood loss is expected

            - Recovery of 1 or more unit of blood is anticipated.
        - Techniques not yet found to be effective or cost-effective
            - Bipolar sealant, topical sealants, autologous donation
            - Reinfusion systems, routine transfusions over 8 g/dL Hb
- □ Preoperative techniques to address anemia
    - Oral iron 30–45 days preoperatively
        - Vitamin C increases iron absorbtion
        - Folate and vitamin B12 deficiency also a source of anemia
    - Erythropoietin if preoperative Hb below 13
- □ Transfusions
    - Ratio of 1:1:1 blood product resuscitation is superior to saline fluid
    - Preoperative Hb most significant predictor of need
    - Various guidelines for when to transfuse
        - Hb less than 6 g/dL: transfusion
        - Hb 7–8 g/dL: transfusion of postoperative patients
        - Hb 8–10 g/dL: transfusion of symptomatic patients
    - Restrictive transfusion strategies
        - Lower 30-day mortality trend
        - Lower infection risk trend
            - Greatest benefits to orthopaedic patients
        - No difference in functional recovery
- □ Transfusions risks
    - Leading risk: transfusion of wrong blood to patient
        - Occurs in 1 in 10,000 to 1 in 20,000 RBC units transfused
    - Transfusion reactions
        - Febrile nonhemolytic transfusion reaction
            - Most common
            - 1–6 hours post-transfusion
            - From leukocyte cytokines released from stored cells
                - Leukoreduction decreases incidence
        - Acute hemolytic transfusion reaction
            - Medical emergency
            - ABO incompatibility
                - IgM anti-A and anti-B,

which fix complement

- Rapid intravascular hemolysis
- Classic triad: fever, flank pain, red/brown urine (rare)
- Can cause disseminated intravascular coagulation (DIC), shock, and acute renal failure (ARF) due to acute tubular necrosis (ATN)
- Positive direct antiglobulin (Coombs) test result

- Delayed hemolytic transfusion reactions
  - Reexposure to previous antigen (i.e., Rh or Kidd)
  - History of pregnancy, prior transfusion, transplantation
  - 3–30 days post-transfusion
  - Anemia, mild elevation of unconjugated bilirubin, spherocytosis
- Anaphylactic reactions: about 1 in 20,000
  - Rapid hypotension, angioedema
    - Shock, respiratory distress
  - Frequently involve anti-IgA and IgE antibodies
  - Treatment: cessation of transfusions, ABCs of resuscitation, epinephrine
- Urticarial reactions: about 1%–3%
  - Mast cell/basophils release of histamine—hives

- Infectious risks
  - Bacterial: 0.2 per million packed red blood cell (PRBC) units transfused
    - Gram-positive organisms
    - Cryophilic organisms: *Yersinia, Pseudomonas*
  - HTLV—approximately 1 in 2 million

            - HIV—approximately 1 in 2 million
            - Hepatitis C—approximately 1 in 2 million
            - Hepatitis B—approximately 1 in 250,000

- **Renal and urologic issues**
    - ARF (acute kidney injury [AKI])
        - Edema, HTN, urinary output less than 30 mL/hour (<0.5 mL/kg/h)
        - Laboratory findings: creatinine increased over 1.5 times baseline
            - Hyperkalemia can be fatal.
                - For blood potassium level more than 5.5 mmp/L, dialysis should be considered.
        - Prerenal renal failure (most common ARF): decreased kidney perfusion
            - Hypovolemia/hypotension from blood loss
        - Intrinsic renal failure
            - ATN: most frequent intrinsic ARF
            - Ischemia, sepsis, nephrotoxic drugs
                - Myoglobin from rhabdomyolysis
            - Acute interstitial nephritis (AIN): fever, eosinophils in blood/urine
        - Glomerular disease: hematuria, proteinuria, HTN, edema
            - SLE, poststreptococcal, IgA nephropathy, hepatorenal
        - Postrenal ARF: obstruction
    - Chronic kidney disease (CKD)
        - Definition: GFR below 60 mL/min per 1.73 m2 or urine albumin loss greater than 30 mg/day
            - Retained phosphate and secondary to hyperparathyroidism
            - Causes increased extraskeletal calcification
        - High perioperative complications
            - Increased cardiovascular risk
            - Hyperkalemia and fluid adjustments
            - Increased bleeding complications
            - Poor BP control
            - Higher infection rates
            - Higher complications/revisions
            - Higher morbidity
    - Perioperative urinary retention
        - Outflow obstructions: benign prostatic hypertrophy (BPH) in men (common)

      - Bladder muscle (detrusor) compromise
      - Overdistention
        - Excess fluid/long procedures
        - Neurogenic
          - Spinal trauma, tumor, stroke, diabetes
          - "Neurogenic" atonic bladder
        - Medications
          - Anticholinergic and sympathomimetic drugs
          - Opioids, antidepressants, pseudoephedrine, diphenhydramine
      - Can cause postrenal ARF (AKI)
      - Associated with higher rates of urinary tract infections
      - Increased 2-year mortality after hip fracture
      - Treatment
        - α-Blockers—tamsulosin 0.4 mg/day
        - Bladder ultrasound if no voiding by 3–4 hours
        - If ultrasound shows more than 400–600 mL, in-and-out (IO) urinary catheter should be used.
          - Trauma patient—no catheter if bloody meatus or scrotal hematoma present
    - Perioperative UTI
      - "Irritative symptoms": dysuria, urgency, frequency
      - Account for 30%–40% of hospital-acquired infections
      - Most common organisms: *Escherichia coli* and *Enterococcus*
      - Diagnosis
        - If symptoms, urinalysis and culture/sensitivity testing
        - WBCs (leukocyte esterase positive)
        - Bacterial count over 10^3 CFU/mL, treated preoperatively
      - Treatment
        - Antibiotics for gram-negative organisms
          - Trimethoprim-sulfamethoxazole or fluoroquinolone
- **GI motility disorders (** Fig. 1.58)
    - 1.5% of hip/knee arthroplasties
    - Common presentation
      - Abdominal pain
      - Distension
      - Nausea with or without vomiting
    - Prevention

- Chewing gum: vagal (parasympathetic stimulation)
- Early mobility
- Spinal (sympathetic block)
- Limiting dose and length of IV opioids

□ Postoperative adynamic ileus
- Gut autonomic nerve imbalance:
- More common in spine (≈7%) and joint arthroplasty (≈1%)
- X-rays: dilated small and large bowel (see Fig. 1.58A)
- Treatment: nothing by mouth status, nasogastric tube
  - Electrolyte control
  - Cessation of narcotics

□ Superior mesenteric artery (SMA) syndrome (cast syndrome)
- Occlusion of duodenum by SMA
- Orthopaedic causes
  - Hip spica cast
  - Following scoliosis surgery
  - Following THA with severe hip flexion contracture
  - Following traumatic quadriplegia
- Also found in patients with rapid, large weight loss
- X-rays: distended stomach and upper duodenum (see Fig. 1.58B)
- CT
  - Aortomesenteric artery angle less than 25 degrees
  - Aortomesenteric distance less than 8 mm
- Treatment: nothing by mouth status, nasogastric tube

□ Acute colonic pseudoobstruction (Ogilvie syndrome)
- Large bowel dilation
- Abdominal distension the prominent symptom
- *Colonic perforation should be avoided.*
- Risk factors
  - Elderly or male patient
  - Previous bowel surgery
  - Diabetes, hypothyroidism
  - Electrolyte disorders
- Radiographic findings
  - Distended transverse and descending colon and cecum (see Fig. 1.58C)
  - Colonic diameter more than 10 cm risks perforation.
- Treatment
  - Nothing by mouth status
  - Neostigmine
  - Colonic decompression

- Pseudomembranous colitis: *potentially fatal diarrhea*
  - Most common antibiotic-associated colitis
  - Change in colon flora favors *Clostridium difficile*
    - Makes enterotoxin-A and cytotoxin-B
  - Many antibiotics
    - Clindamycin, fluoroquinolones
    - Penicillins and cephalosporins
  - Can become severe fulminant colitis
    - Toxic megacolon and perforations
  - Risk factors
    - Elderly hospitalized patient
    - Severe illness
    - Antibiotic use
    - Proton pump inhibitor use
  - Diagnosis
    - Watery diarrhea with fever
    - Leukocytosis, lower abdominal pain
  - Laboratory findings
    - WBC count more than 15,000 cells/μL
    - Stool specimen should be tested for *C. difficile* toxin
    - PCR or ELISA
  - KUB (kidney, ureter, bladder) (plain abdominal) radiograph
    - Toxic megacolon: greater than 7 cm
    - Thumbprinting (see Fig. 1.58D)
  - Treatment
    - Oral metronidazole
    - Oral vancomycin (IV will not work)
    - Fidaxomicin
    - Colectomy if unresponsive and severe
      - Megacolon, WBC count more than 20,000 cells/μL

- **Perioperative hepatic issues**
  - Liver failure: critical for producing proteins and metabolizing toxins
    - Laboratory findings
      - Increased aspartate aminotransferase (AST), alanine aminotransferase (ALT), and bilirubin
      - INR above 1.5, low platelets (<150,000 cells/μL)
    - Acute—most commonly viral and drug induced
      - Acetaminophen—number one cause in United States
      - Other toxins: alcohol, occupational, mushrooms
      - Viral hepatitis

- Chronic—cirrhosis is end-stage fibrosis of liver
  - Common: hepatitis (B, C), alcoholism, hemochromatosis
- Classifications can be helpful to estimate risks
  - Child classification—most widely used
    - Based on laboratory results and physical examination
  - Model for End-Stage Liver Disease (MELD) score (http://www.mayoclinic.org/medical-professionals/model-end-stage-liver-disease/meld-model)
    - Formula based on bilirubin, INR, creatinine
    - Studies highlight mortality at 90 days relative to MELD score
      - <9: about 2% mortality
      - 10–19: about 6% mortality
      - 20–29: about 20% mortality
      - 30–39: about 53% mortality
      - >40: about 71% mortality
    - Complication rates from surgery are extremely high.
      - In patients undergoing arthroplasty, MELD score above 10 predicted
        - Three times the complication rate
        - Four times the rate death

▪ **Perioperative CNS issues**

□ Stroke

- Rare (0.2% of joint arthroplasties)
- Mortality roughly 25% at 1 year
- Ischemic more common than hemorrhagic
- Risk factors
  - Advanced age, CVA, TIA
  - MI, coronary artery bypass graft, atrial fibrillation, or ECG rhythm abnormality

- Left ventricular dysfunction
- Cardiac valvular disease
- General anesthesia higher risk than regional
- Diagnosis: head CT or MRI
- Treatment: ABCs of resuscitation, hospitalist/neurology consultation

□ Delirium: approximately 40% in patients with hip fractures

- Fluctuating levels of consciousness
- Impairment of memory and attention
- Disorientation, hallucinations, agitation
- Associated with increased length of stay
  - Decubitus ulcers, failure to regain function
  - Feeding issues, urinary incontinence
  - Mortality and nursing home placement
- Risk factors
  - Older patients
  - History of prior postoperative confusion
  - History of alcohol abuse
  - Acute surgery more than elective

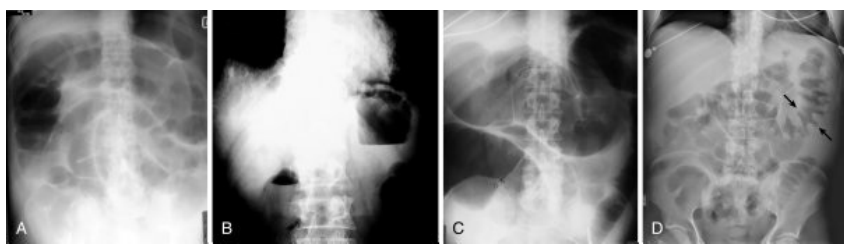


FIG. 1.58 Perioperative gastrointestinal mobility radiographs. (A) Dilated loops of both small bowel and large bowel consistent with ileus. (B) Characteristic dilation with air-fluid levels in the stomach and right-sided upper duodenum, seen in mesenteric artery syndrome (cast syndrome). (C) Isolated dilation of the large bowel seen in acute colonic pseudoobstruction (Ogilvie syndrome). (D) Dilated loops of both small and large bowel in a patient with watery diarrhea after antibiotic use. Wide, thickened, transverse bands of nodular colon wall replace normal haustral folds (thumbprinting), as seen in pseudomembranous colitis.

A and **C** from Nelson JD et al: Acute colonic pseudo-obstruction [Ogilvie syndrome] after arthroplasty in the lower extremity, *J Bone Joint Surg Am* 88:604–610, 2006; **B** from Tidjane A et al: [Superior mesenteric artery syndrome: rare but think about it], [article in French] *Pan Afr Med* J 17:47, 2014; and **D** from Thomas A et al: "Thumbprinting," *Intern Med J* 40:666, 2010.

  - Night-time surgery
  - Long duration of anesthesia
  - Intraoperative pressures below 80 mm Hg

- Use of meperidine (Demerol)
- Diagnosis: anemia ruled out, infection, electrolyte issues
- Treatment
  - O_2 saturation above 95%, systolic BP above 90 mm Hg
  - Correction of medical issues
  - Family/friends
  - Medications for sedation: used with caution
  - Restraints as last resort

- **Special anesthesia issues**
  - Obstructive sleep apnea (OSA)
    - Intermittent hypercapnia and hypoxia
      - Decreased CO_2-induced respiratory drive
      - Extreme sensitivity to opioids
      - Leads to
        - Pulmonary HTN
        - Cardiac arrhythmias
      - GERD (reflux) directly related to BMI
        - Delayed gastric emptying
        - Increased risks for aspiration/intubation
      - Higher risk for complications (2–4 times greater)
        - Respiratory failure, ICU transfers, increased length of stay
        - Increased postoperative O_2 desaturation
        - Increased intubation, aspiration pneumonia, ARDS
        - Increased MI, arrhythmias (atrial fibrillation)
      - Screening tools: STOP-BANG (Fig. 1.59)
        - ***S*** noring, ***t*** ired, ***o*** bserved apnea, ***p*** ressure (HTN)

          B MI over 35, ***a*** ge older than 50 years, ***n*** eck circumference larger than 40 cm, ***g*** ender male
        - Five or more factors present—high risk of severe OSA
      - Best practices
        - Initiation or continuation of CPAP use
          - More than 2 weeks of preoperative CPAP

improved HTN, O_2 saturation, apneic events

- Pulmonary HTN: in 20%–40% of patients with OSA
- Preoperative serum bicarbonate predicts hypoxia in OSA
    - Chronic respiratory acidosis
- Site of service (American Society of Anesthesiology consensus statement)
    - Ambulatory surgery under local/regional—lower risk
    - Avoid procedures requiring opioids—greater risk
    - Comorbid conditions must be optimized for outpatient surgery.
        - HTN, arrhythmias, CHF, cardiovascular disease, and metabolic syndrome
        - **Metabolic syndrome = obesity, hypertension, hypercholesterolem dyslipidemia, and insulin resistance**
        - Avoidance of flat supine position; sitting position opens airway.

□ Malignant hyperthermia

- **Autosomal dominant** genetic defect of T-tubule of sarcoplasmic reticulum
    - Ryanodine receptor defect *(RYR1)*
    - Dihydropyridine receptors *(DHP)*
- **Triggered by volatile anesthetics and succinylcholine**

- Creates an uncontrolled release of Ca^{2+}
- Sustained muscular contraction (masseter rigidity)

- **Increased end-tidal CO_2**
  - **Earliest and most sensitive sign**
  - Mixed respiratory and metabolic alkalosis
- Hyperthermia is classic but occurs later.
- Muscle damage
  - Myoglobin from rhabdomyolysis can cause ARF.
  - Elevated creatine kinase
  - Hyperkalemia can lead to ventricular arrhythmias.
- Treatment with dantrolene
  - Decreases intracellular Ca^{2+}
  - Stabilizes sarcoplasmic reticulum
- Treatment of high serum potassium
- Hydration
- Cooling

Section 4 Other Basic Principles

Imaging and Special Studies

- **Radiation safety**
  - Should be considered for every fluoroscopic case
  - Increased radiation exposure associated with
    - Imaging of larger body parts
    - Positioning the extremity closer to the x-source

STOP-BANG scoring method

Every Yes answer = 1 point

Snoring: Do you snore loudly (loud enough to be heard through closed doors)?	☐ Yes	☐ No
Tired: Do you often feel tired, fatigued, or sleepy during daytime?	☐ Yes	☐ No
Observed: Has anyone observed you stop breathing during your sleep?	☐ Yes	☐ No
Blood **P**ressure: Do you have or are you being treated for high blood pressure?	☐ Yes	☐ No
BMI more than 35?	☐ Yes	☐ No
Age older than 50 years?	☐ Yes	☐ No
Neck circumference greater than 40 cm?	☐ Yes	☐ No
Gender male?	☐ Yes	☐ No

5 or more = high risk for Obstructive Sleep Apnea
Initiate or continue CPAP machine
Avoid/minimize narcotics – maximize local blocks

FIG. 1.59 STOP-BANG screening questionnaire for identification of obstructive sleep apnea.
From Shilling AM et al: Anesthesia and perioperative medicine. In Miller MD, Thompson SR, editors: *DeLee and Drez's orthopaedic sports medicine: principles and practice,* ed 4, Philadelphia, 2014, Saunders, p 365.

-
  -
    - Use of large C-arm rather than mini C-arm
  - Factors to decrease the amount of radiation exposure
    - Minimizing exposure time
    - Using collimation to manipulate the x-ray beam
    - Use of protective shielding
    - Maximizing the distance between the surgeon and the radiation beam
    - Utilizing mini C-arm whenever feasible (associated with minimal radiation exposure)
    - Surgeon control of the C-arm
- **Nuclear medicine**

- □ Bone scan (Table 1.37)
  - Technetium Tc 99m phosphate complexes
    - Reflect increased blood flow and metabolism (infection, trauma, neoplasia)
    - Absorbed onto hydroxyapatite crystals in bone
  - Whole-body views and more detailed (pinhole) views possible
  - Uses
    - Subtle or stress fractures
    - Avascular necrosis
      - Hypoperfused early
      - Increased uptake in reparative phase
    - Osteomyelitis
      - Also in conjunction with gallium citrate Ga 67 or indium In 111 scan
    - THA and TKA loosening
      - Especially femoral components
      - In conjunction with gallium scan to rule out infection
    - Phase studies
    - Three-phase (or even four-phase) studies
      - Helpful for reflex sympathetic dystrophy and osteomyelitis
      - First phase (blood flow, immediate)
        - Blood flow through the arterial system
      - Second phase (blood pool, 30 minutes)
        - Equilibrium of tracer throughout the intravascular volume
      - Third phase (delayed, 4 hours)
        - Displays sites of tracer accumulation
- □ Gallium scan
  - Localizes in sites of inflammation and neoplasia
    - Exudation of labeled serum proteins
  - Delayed imaging required (24–48 hours or more)
  - Less dependent on vascular flow than technetium
    - May identify foci otherwise missed
  - Difficulty differentiating cellulitis from osteomyelitis
- □ Indium scan
  - Labeled WBCs (leukocytes)

- Collect in areas of inflammation
- Do not collect in areas of neoplasia

- Uses
  - Acute infections (e.g., osteomyelitis)
  - Possibly total joint arthroplasty (TJA) infections

Table 1.37

Nuclear Medicine Studies

Study	Uses	Comments
Bone scan	Subtle fractures Avascular necrosis Osteomyelitis Total joint loosening Osteochondritis	Three-phase scan useful for osteomyelitis, reflex sympathetic dystrophy, acute scaphoid fractures
Gallium	Inflammation Neoplasms	Localizes in sites of inflammation Requires prolonged uptake
Indium (In 111)	Acute infections Possible arthroplasty infections	Labeled WBC uptake in areas of infection

- Radiolabeled monoclonal antibodies
  - May identify primary malignancies and metastatic disease

□ DVT/PE scan
- Radioactive iodine
  - Labels fibrinogen in clot on scanning
  - Inaccurate near surgical wounds

□ Single-photon emission computed tomography (SPECT)
- Scintigraphy with CT to evaluate overlapping structures
  - Femoral head osteonecrosis
  - Patellofemoral syndrome
  - Spondylolysis

▪ **Arthrography**

□ Commonly used in association with advanced imaging (CT or MRI)

□ Improves sensitivity of intraarticular soft tissue pathology (labral tear in shoulder, triangular fibrocartilage complex [TFCC], and intercarpal ligament tears in wrist)

□ Also frequently used in pediatric population

□ Hip
- Aspiration for infection

- Following reduction of developmental dysplasia of the hip (DDH)
- Assessing deformity in Legg-Calvé-Perthes disease

- **MRI**
  - Excellent for evaluating soft tissues and bone marrow
    - Study of choice for evaluating knee ligamentous/meniscal injuries and shoulder cuff injuries
  - Ineffective in evaluating trabecular bone and cortical bone
    - These tissues have virtually no hydrogen nuclei.
  - Used to evaluate osteonecrosis, neoplasms, infection, and trauma
  - Contraindications
    - Pacemakers
    - Cerebral aneurysm clips
    - Shrapnel or hardware, in certain locations
  - Basic principles of MRI (Tables 1.38 through 1.41)
    - Radiofrequency pulses on tissues in a magnetic field
    - Images in any desired plan
    - Nuclei with odd numbers of protons/neutrons (with a normally random spin) aligned parallel to a magnetic field

Table 1.38

Magnetic Resonance Imaging Terminology

Term	Explanation
T1	Time constant of exponential growth of magnetism; T1 signal measures how rapidly a tissue gains magnetism
T2	Time constant of exponential decay of signal after an excitation pulse; a tissue with a long T2 signal (such as that with a high water content) maintains its signal (is bright on T2-weighted image)
T2*	Similar to T2 but includes the effects of magnetic field homogeneity
TR	Time to repetition; the time between successive excitation pulses; short TR <80ms, long TR >80 ms
TE	Time to echo; the time that an echo is formed by the refocusing pulse; short TE <1000ms, long TE >1000
NEX	Number of excitations; higher NEX results in decreased noise with better images
FOV	Field of view
Spin-echo	A commonly used pulse sequence
FSE	Fast spin-echo; a type of pulse sequence
GRE	Gradient-recalled echo; a type of pulse sequence

    - Field strength: 0.5–15 T (1 T = 10,000 G)
        - **3.0 T has nine times greater proton energy than 1.5T**
- Nuclear magnetic moments of these particles are deflected by radiofrequency pulses; deflection results in an image.
- The use of surface coils decreases the signal-to-noise ratio.
    - Body coils are used for large joints
    - Smaller coils are available
- Sequences developed to demonstrate the differences in T1 and T2 relaxation between tissues
    - Dark on T1- and bright on T2-weighted images
        - Water
        - Cerebrospinal fluid
        - Acute hemorrhage
        - Soft tissue tumors
- Tissues showing similar intensity on both T1- and T2-weighted images:
    - Dark: cortical bone, rapidly flowing blood, fibrous tissue
    - Gray: muscle and hyaline cartilage
    - Bright: fatty tissue, nerves, slowly flowing (venous) blood, bone marrow

Table 1.39

Signal Intensities on Magnetic Resonance Imaging

Tissue	Appearance on T1-Weighted Image	Appearance on T2-Weighted Image
Cortical bone	Dark	Dark
Osteomyelitis	Dark	Bright
Ligaments	Dark	Dark
Fibrocartilage	Dark	Dark
Hyaline cartilage	Gray	Gray
Meniscus	Dark	Dark
Meniscal tear	Bright	Gray
Yellow bone marrow (fatty-appendicular)	Bright	Gray
Red bone marrow (hematopoietic-axial)	Gray	Gray
Marrow edema	Dark	Bright
Fat	Bright	Gray
Normal fluid	Dark	Bright
Abnormal fluid (pus)	Gray	Bright
Acute blood collection	Gray	Dark
Chronic blood collection	Bright	Bright
Muscle	Gray	Gray
Tendon	Dark	Dark
Intervertebral disc (central)	Gray	Bright
Intervertebral disc (peripheral)	Dark	Gray

Modified from Brinker MR, Miller MD: *Fundamentals of orthopaedics,* Philadelphia, 1999, Saunders, p 24.

- T1-weighted images best for demonstrating anatomic structure
- T2-weighted images best for contrasting normal and abnormal tissues
- Magic angle phenomenon:
    - Tendon or ligament tissue oriented near 55 degrees to the field produces bright T1-weighted

images.
        - False appearance of pathologic process
        - Most common in shoulder, ankle, knee
    - Techniques for identifying contrast between fluid and nonfluid elements (e.g., bone, fat)
        - STIR imaging
        - Fat-suppressed T2-weighted imaging
    - Specific applications
        - Osteonecrosis
            - Highest sensitivity and specificity for early detection
                - Detects early marrow necrosis
                - Detects ingrowth of vascularized mesenchymal tissue
            - Specificity of 98% and high reliability for estimating age and extent of disease
            - Diseased marrow dark on T1-weighted images
                - Allows direct assessment of overlying cartilage
        - Infection and trauma
            - Excellent sensitivity to increased free water
            - Shows areas of infection and fresh hemorrhage
                - Dark on T1-weighted images, bright on T2-weighted images
            - Excellent (accurate and sensitive) for occult fractures
                - Particularly in hip in elderly patients
        - Neoplasms
            - MRI has many applications in the study of primary and metastatic bone tumors.
            - Primary tumors are well demonstrated.
                - Particularly tumors in

soft tissue (extraosseous and marrow)

- Used in evaluating skip lesions and spinal metastases
  - Nuclear medicine study remains the procedure of choice for seeking metastatic foci in bone.
- Demonstrates benign bony tumors
  - Typically bright on T1-weighted images and dark on T2-weighted images
- Demonstrates malignant bony lesions
  - Often bright on T2-weighted images
- Differential diagnosis is best made on the basis of plain radiographs.

- Spine
  - Disc disease is well demonstrated on T2-weighted images.
    - Degenerated discs lose water.

Table 1.40

Magnetic Resonance Imaging of Bone Marrow Disorders

Disorder	Pathologic Features	Examples	MRI Changes
Reconversion	Yellow → red	Anemia, metastasis	↓ T1-weighte intensity
Marrow infiltration		Tumor, infection	↓ T1-weighte intensity
Myeloid depletion		Anemia, chemotherapy	↓ T1-weighte intensity
Marrow edema		Trauma, complex regional pain syndrome	↓ T1-weighte intensity ↑ T2-weighte intensity
Marrow ischemia		Osteonecrosis	↓ T1-weighte intensity

↑, Increased; ↓, decreased.

Table 1.41

Magnetic Resonance Imaging Changes of Meniscal Disease

Disease Group	Characteristics
I	Globular areas of hyperintense signal
II	Linear hyperintense signal
III	Linear hyperintense signal that communicates with the meniscal surface (tears)
IV	Vertical longitudinal tear/truncation

    - Appear dark on T2-weighted images
    - Extent of herniation of discs is also well shown.
- Recurrent disc herniation is best diagnosed with gadolinium MRI scan.
    - Differentiation from scar

- T1-weighted image
  - Scar: decreased signal
  - Free fragment: increased signal
  - Extruded disc: decreased signal
- T2-weighted image
  - Scar: increased signal
  - Free fragment: increased signal
  - Extruded disc: decreased signal
- MRI is most sensitive for diagnosing early discitis.
  - Decreased signal on T1-weighted images, increased signal on T2-weighted images

- Bone marrow disorders
  - Best demonstrated by MRI (poor specificity) (see Table 1.40)

▪ **Other imaging studies**

□ Computed tomography

- Demonstrates details of bony anatomy better than any other study
- Hounsfield units used to identify tissue types
  - −100 HU = air
  - −100–0 HU = fat
  - 0 HU = water
  - 100 HU = soft tissue
  - 1000 HU = bone
- In spine, shows herniated nucleus pulposus better than myelography alone
  - CT may be helpful differentiating disc herniation from scar
  - IV contrast material is taken up in scar tissue but not in disc tissue.
- Frequently used with contrast material
  - Arthrographic CT, myelographic CT

- CT digital radiography (CT scanography)
    - Accurate demonstration of leg length discrepancy with minimal radiation exposure
        - Particularly when joint contractures exist (lateral scanography)
- Images distorted by metal implants

□ Ultrasonography: uses continue to expand
- Shoulder: evaluation of rotator cuff tears
- Hip
    - Diagnosis and follow-up of DDH
    - Dynamic examination of femoroacetabular impingement
- Knee
    - Determination of articular cartilage thickness
    - Identification of intraarticular fluid
- Soft tissue masses
- Hematoma
- Tendon rupture
- Abscesses
- Foreign body location
- Intraspinal disorders in infants
- Intraarticular injections

□ Myelography
- More invasive than MRI but shows excellent detail
- Useful in patients with contraindications to MRI
- Useful in failed back (surgery) syndrome
- Can be used with other studies such as CT

□ Discography
- Use controversial
- Helpful for evaluating symptomatic disc degeneration
- Pathologic discs: reproduction of pain with injection and characteristic changes on discograms
- Commonly used with CT

□ Measurement of bone density (noninvasive)
- Single-photon absorptiometry
    - Cortical bone density is inversely proportional to quantity of photons passing through it.
    - Radioisotope iodide 125 (^{125}I) emits a single energy beam of photons.
        - ^{125}I passes through bone.
        - A sodium iodide scintillation counter detects the transmitted photons.
    - Denser bone attenuates the photon beam.

            - Fewer photons reach the scintillation counter.
        - Best used in the appendicular skeleton
            - Radius: diaphysis or distal metaphysis
        - Findings are unreliable in the axial skeleton
            - Soft tissue depth alters the beam.
    - Dual-photon absorptiometry
        - Also an isotope-based method
        - Allows for measurement of the axial skeleton and the femoral neck
            - Accounts for soft tissue attenuation
    - Quantitative CT
        - Preferred for measurement of trabecular bone density
            - Trabecular bone is at greatest risk for early metabolic changes
        - Simultaneous scanning of phantoms of known density
            - Creating a standard calibration curve
        - Accuracy within 5%–10%
        - Radiation dose higher than that for DEXA
    - DEXA
        - Most accurate and reliable for predicting fracture risk
        - Radiation dose lower than that for quantitative CT
        - Measures bone mineral content and soft tissue components

- **Electrodiagnostic studies**
    - □ Nerve conduction studies
        - Evaluation of peripheral nerves
        - Nerve impulses stimulated and recorded by surface electrodes
            - Allows calculation of conduction velocity
        - Measures latency (time from stimulus onset to response) and response amplitude
        - Late responses (F wave, H reflex) allow evaluation of proximal lesions.
            - Impulse travels to the spinal cord and returns
    - □ Electromyography

Table 1.42

Nerve Conduction Study Results

Condition	Latency	Conduction Velocity	Evoked Response
Normal study	Normal	Upper extremities: >45 m/sec; lower extremities: >40 m/sec	Biphasic
Axonal neuropathy	Increased	Normal or slightly decreased	Prolonged, decreased amplitude
Demyelinating neuropathy	Normal	Decreased (10%–50%)	Normal or prolonged, with decreased amplitude
Anterior horn cell disease	Normal	Normal (rarely decreased)	Normal or polyphasic, with prolonged duration and decreased amplitude
Myopathy	Normal	Normal	Decreased amplitude; may be normal
Neurapraxia:			
Proximal to lesion	Absent	Absent	Absent
Distal to lesion	Normal	Normal	Normal
Axonotmesis:			
Proximal to lesion	Absent	Absent	Absent
Distal to lesion	Absent	Absent	Normal
Neurotmesis:			
Proximal to lesion	Absent	Absent	Absent
Distal to lesion	Absent	Absent	Absent

Modified from Jahss MH: *Disorders of the foot,* Philadelphia, 1982, Saunders.

- Use of intramuscular needle electrodes to evaluate muscle

units
- Used to evaluate denervation
  - Fibrillations; earliest sign usually at 4 weeks
  - Sharp waves
  - Abnormal recruitment pattern
- Interpretation
  - Peripheral nerve entrapment syndromes
  - Distal motor and sensory latencies more than 35 m/sec
  - Nerve conduction velocities less than 50 m/sec
  - Changes over a distinct interval (Table 1.42)

Biomaterials and Biomechanics

- **Basic concepts**
  - Definitions
    - Biomechanics—science of forces, internal or external, on the living body
    - Statics—action of forces on rigid bodies in a system in equilibrium
    - Dynamics—bodies that are accelerating and the related forces
      - Kinematics—study of motion (displacement, velocity, and acceleration) without reference to forces
      - Kinetics—relates the effects of forces to motion
  - Principal quantities
    - Basic quantities—described by International System of Units (SI); metric system
      - Length (m), mass (kg), time (sec)
    - Derived quantities: derived from basic quantities
      - Velocity
        - Time rate of change of displacement (meters/second)
        - Rate of translational displacement: *linear velocity*
        - Rate of rotational displacement: *angular velocity*
    - Acceleration
      - Time rate of change of velocity (m/sec^2)
      - Can also be linear or angular
    - Force

- Action causing acceleration of a mass (body) in a certain direction
- Unit of measure: newton (N) = kg • m/sec^2

□ Newton's laws

- First law: inertia
  - If the net external force (F) acting on a body is zero, the body remains at rest or moves with a constant velocity.
  - This law allows static analysis: $\Sigma F = 0$ (sum of external forces = zero)
- Second law: acceleration
  - Acceleration *(a)* of an object of mass *(m)* is directly proportional to the force *(F)* applied to the object:

$$F = ma$$

  - This law is used in dynamic analysis.
- Third law: reactions
  - For every action (force), there is an equal and opposite reaction (force).
  - This law leads to free-body analysis.
  - This law also assists in the study of interacting bodies.

□ Scalar and vector quantities

- Scalar quantities
  - Have magnitude but no direction
  - Examples: volume, time, mass, and speed (not velocity)
- Vector quantities
  - Have magnitude and direction
  - Examples: force and velocity
  - Vectors have four characteristics
    - Magnitude (length of the vector)
    - Direction (head of the vector)
    - Point of application (tail of the vector)
    - Line of action (orientation of the vector)
  - Vectors can be added, subtracted, and split into components (resolved)
    - Resultant of two vectors: principle of

"parallelogram of forces"

□ Free-body analysis

- Forces, moments, and free-body diagrams to analyze the action of forces on bodies
- Force
  - A mechanical push or pull (load) that causes external (acceleration) and internal (strain) effects
  - Unit of measure: the newton (N)
  - Force vectors (*F*): can be split into independent components for analysis
    - Usually in the *x* and *y* directions (F_x, F_y).
    - With angle (θ) between F_x and F_y.
    - A *normal* force is perpendicular to the surface on which it acts.
    - A *tangential* force is parallel to the surface.
    - A *compressive* force shrinks a body in the direction of the force.
    - A *tensile* force elongates a body.
- Moment (*M*)
  - Rotational effect of a force
  - Moment = force (*F*) multiplied by the perpendicular distance (the moment arm or lever arm = *d*) from point of rotation:

$$M = F \times d$$

  - *Torque* is a moment from a force perpendicular to the long axis of a body, causing rotation.
  - A *bending moment* is from a force parallel to the long axis.
  - The *mass moment of inertia* is the resistance to rotation.
    - Product of mass times the square of the moment arm:

$$I = m \times d^2$$

            - Affects angular acceleration
    - Free-body diagram
        - A *free-body diagram* is a sketch of a body (or segments) isolated from other bodies that shows all forces acting on it.
        - The weight of each object acts through its center of gravity.
        - Center of gravity in the human body is just anterior to S2.
- □ Finite element analysis
    - Complex geometric forms and material properties are modeled.
    - A structure is modeled as a finite number of simple geometric forms.
        - Typically triangular or trapezoidal elements
    - A computer matches forces and moments between neighboring elements.
    - Finite element analysis is often used to estimate internal stresses and strains.
        - Example: stress/strain at bone-implant interface
- □ Other important basic concepts
    - Work
        - The product of a force and the displacement it causes
        - Work (W) = force (F; vector components parallel to displacement) × distance (displacement produced by F)
        - Unit of measure: joule (J) = N • *m*
        - Energy
            - Ability to perform work (unit of measure is also joule)
            - Laws of conservation of energy:
                - Energy is neither created nor destroyed.
                - It is transferred from one state to another.
            - Potential energy
            - Stored energy
            - Potential of a body to do work as a result of its position or configuration (e.g., strain energy)
            - Kinetic energy—energy caused by motion ($\frac{1}{2}mv^2$)

- Friction (*f*)
  - Resistance to motion when one body slides over another
    - Produced at points of contact
  - Oriented opposite to the applied force
    - When applied force exceeds *f*, motion begins.
  - Proportional to coefficient of friction and applied normal (perpendicular) load
    - Independent of contact area and surface shape
- Piezoelectricity
  - Electrical charge when a force deforms a crystalline structure (e.g., bone)
  - Concave (compression) side: charge is electronegative
  - Convex (tension) side: charge is electropositive

- **Biomaterials**
  - Strength of materials
    - Study of relations between externally applied loads and resulting internal effects
    - Loads
      - Forces acting on a body
      - Compression, tension, shear, and torsion
    - Deformations
      - Temporary (elastic) or permanent (plastic) change in shape
      - Load changes produce deformational changes.
    - Elasticity—ability to return to resting length after undergoing lengthening or shortening
    - Extensibility—ability to be lengthened
    - Stress
      - Intensity of internal force
        - Stress = force/area
        - *Internal* resistance of a body to a load
      - Unit of measure: pascal (Pa) = N/m^2

- Normal stresses
  - Compressive or tensile
  - Perpendicular to the surfaces on which they act
- Shear stresses
  - Parallel to the surfaces on which they act
  - Cause a part of a body to be displaced in relation to another part
- Stress differs from *pressure:*
  - Pressure is the distribution of an *external* force to a solid body.
  - However, they share the same definition (force/area) and unit of measure (Pa).

- Strain
  - Relative measure of deformation (six components) resulting from loading
  - Strain = change in length/original length
  - Can also be normal or shear
  - Strain is a proportion; it has no units.
  - Strain rate
    - Strain divided by time load is applied (units = sec^{-1}).
  - Hooke's law: stress is proportional to strain up to a limit.
    - The proportional limit
    - Within the elastic zone
- Young's modulus of elasticity *(E)*
  - Measure of material stiffness
    - Also a measure of the material's ability to resist deformation in tension
    - *E* = stress/strain
    - *E* is the slope in the elastic range of the stress-strain curve.

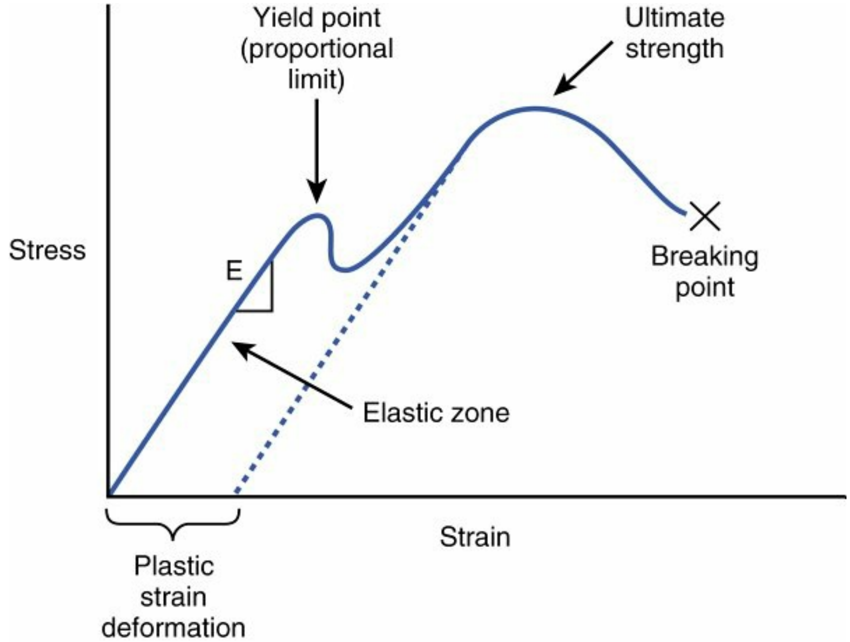


FIG. 1.60 Stress-strain curve. *E,* Young's modulus of elasticity.

- The critical factor in load-sharing capacity
- Linearly perfect elastic material
  - A straight stress-strain curve to the point of failure
  - ***Modulus* = stress at failure (ultimate stress) divided by strain at failure (ultimate strain)**
- *E* is unique for every type of material
  - A material with a higher *E* can withstand greater forces than can material with a lower *E.*

- Shear modulus
  - Ratio of shear stress to shear strain
  - A measure of stiffness
  - Unit of measure: pascal (Pa)
- Stress-strain curve (Fig. 1.60)
  - Derived by loading a body and plotting stress versus strain
    - The curve's shape varies by material.
  - Proportional limit—transition point at which stress and strain are no longer proportional
    - The material returns to its original length when stress is removed: elastic behavior.
  - Elastic limit (yield point)
    - This is the transition point from elastic to plastic behavior.

            - Beyond this point, the material's structure is irreversibly changed.
            - The elastic limit equals 0.2% strain in most metals.
        - Plastic deformation—irreversible change after load is removed
            - Occurs in the plastic range of the curve
            - After the elastic limit, before the breaking point
        - Ultimate strength—maximum strength obtained by the material
        - Breaking point—point at which the material fractures
            - Ductile—if deformation between elastic limit and breaking point is large
            - Brittle—if deformation between elastic limit and breaking point is small
        - Strain energy (toughness)
            - Capacity of material (e.g., bone) to absorb energy
            - Area under the stress-strain curve
            - Total strain energy = recoverable strain energy (resilience) + dissipated strain energy
            - A measure of the toughness of material
                - Ability to absorb energy before failure

□ Material definitions

- Brittle materials (e.g., PMMA)
    - Stress-strain curve is linear up to failure.
    - These materials undergo only recoverable (elastic) deformation before failure.
    - They have little or no capacity for plastic deformation.
- Ductile materials (e.g., metal)
    - These materials undergo large plastic deformation before failure.
    - Ductility is a measure of post-yield deformation.
- Viscoelastic materials (e.g., bone and ligaments)

- Stress-strain behavior is time-rate dependent.
  - Depends on load magnitude and rate at which the load is applied
- A function of internal friction
- Exhibit both fluid (viscosity) and solid (elasticity) properties
- Modulus increases as strain rate increases.
- Exhibit hysteresis
  - Loading and unloading curves differ.
  - Energy is dissipated during loading.
- Most biologic tissues exhibit viscoelasticity.

- Isotropic materials
  - Mechanical properties are the same for all directions of applied load (e.g., as with a golf ball).
- Anisotropic materials
  - Mechanical properties vary with the direction of the applied load.
  - Example: bone is stronger with axial load than with radial load.
- Homogeneous materials
  - Have a uniform structure or composition throughout
- Rigidity
  - Bending rigidity of a rectangular structure:
    - Proportional to the base multiplied by the height cubed:

$$bh^3/12$$

  - Bending rigidity of a cylinder
    - Related to the fourth power of the radius
    - Examples: intramedullary nails, half-pins

□ Metals

- Fatigue failure
  - Occurs with cyclic loading at stress below ultimate tensile strength
  - Depends on magnitude of stress (S) and number of cycles (n)

- Endurance limit
  - Maximum stress under which the material will not fail regardless of number of loading cycles
  - If the stress is below this limit, the material may be loaded cyclically an infinite number of times (>10^6 cycles) without breaking.
  - Above this limit, fatigue life is expressed by the *S*-*n* curve:
- Creep (cold flow)
  - Progressive deformation response to constant force over an extended period
  - Sudden stress followed by constant loading causes continued deformation.
  - Can produce permanent deformity
  - May affect mechanical function (e.g., in TJA)
- Corrosion (Table 1.43)
  - Chemical dissolving of metals

Table 1.43

Types of Corrosion

Corrosion	Description
Galvanic	Dissimilar metals [a] ; electrochemical destruction
Crevice	Occurs in fatigue cracks with low O_2 tension
Stress	Occurs in areas with high stress gradients
Fretting	From small movements abrading outside layer
Other	For example, inclusion, intergranular

[a] Metals such as 316 L stainless steel and cobalt-chromium-molybdenum (Co-Cr-Mo) alloy produce galvanic corrosion.

  - May occur in the body's high-saline environment
  - Stainless steel (type 316L)
    - The metal most susceptible to both crevice corrosion and galvanic corrosion
    - Risk of galvanic corrosion highest between 316L stainless steel and cobalt-chromium (Co-Cr) alloy

- Modular components of THA
    - Direct contact between similar or dissimilar metals at the modular junctions
    - Results in corrosion products
        - Examples: metal oxides, metal chlorides
- Corrosion can be decreased in the following ways:
    - Using similar metals
    - Proper implant design
    - Passivation by an adherent oxide layer
        - Effectively separates metal from solution
        - Example: stainless steel coated with chromium oxide

- Types of metals
    - Orthopaedic implants
        - Three types of alloys: steel (iron-based), cobalt-based, titanium-based
        - 316L stainless steel
            - Iron-carbon, chromium, nickel, molybdenum, manganese
                - Nickel: increases corrosion resistance and stabilizes molecular structure
                - Chromium: forms a passive surface oxide, improving corrosion resistance
                - Molybdenum: prevents pitting and crevice corrosion
                - Manganese: improves crystalline stability
            - "L"—low in carbon: greater corrosion

resistance

- Cobalt alloys
    - Cobalt-chromium-molybdenum (Co-Cr-Mo)
        - 65% cobalt, 35% chromium, 5% molybdenum
        - Special forging process
        - Nickel may be added to improve ease of forging.
        - Greater ultimate strength than titanium
        - Ion release
            - Co-Cr: macrophage proliferation and synovial degeneration
            - Ions excreted through the kidneys
- Titanium alloy (Ti-6Al-4V)
    - Poor resistance to wear (notch sensitivity)
        - Particulate may incite a histiocytic response.
        - The relationship between titanium and neoplasms is uncertain.

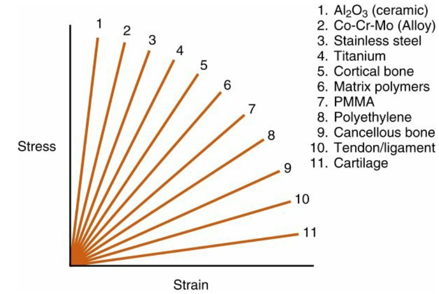


FIG. 1.61 Comparison of Young's modulus (relative values, not to scale) for various orthopaedic materials. Al_2O_3, Alumina; Co-Cr-Mo, cobalt-chromium-molybdenum; PMMA, polymethylmethacrylate.

- Polishing, passivation, and ion implantation improve its fatigue properties.
- Titanium is extremely biocompatible
  - Rapidly forms an adherent oxide coating (self-passivation); decreases corrosion
  - Most closely emulates axial and torsional stiffnesses of bone
  - High yield strength
- Tantalum—passive material designed to elicit a response (bone ingrowth)
  - Surface oxide layer as barrier to corrosion
  - Used as augmentation of cancellous defects
- Stiffness *(E)* differences (Fig. 1.61)

□ Nonmetal materials

- Polyethylene (discussed in Chapter 5, Adult R reconstruction)
- PMMA (bone cement)
    - Used for fixation and load distribution for implants
        - Acts as a grout, not an adhesive
        - Mechanically interlocks with bone
    - **Reaches ultimate strength within 24 hours**
    - Can be used as an internal splint for the patient with poor bone stock
        - PMMA can be used as a temporary internal splint until the bone heals.
        - If bone fails to heal, PMMA will ultimately fail.
    - Poor tensile and shear strength
    - Is strongest in compression and has a low *E*
        - Not as strong as bone in compression
    - Reducing voids (porosity) increases cement strength and decreases cracking.
        - Vacuum mixing, centrifugation, good technique
        - Cement failure often caused by microfracture and fragmentation.
    - Insertion can lead to a precipitous drop in BP.
        - Wear particles can incite a macrophage response
            - Leads to prosthesis loosening
    - Silicones
        - Polymers for replacement in non–weight-bearing joints
        - Poor strength and wear capabilities
            - Frequent synovitis with extended use
- Ceramics
    - Metallic and nonmetallic elements bonded ionically in a highly oxidized state
        - Good insulators (poor conductors)
        - Biostable (inert) crystalline materials such as Al_2O_3 (alumina) and ZrO_2 (zirconium dioxide)
        - Bioactive (degradable) noncrystalline substances such as bioglass

- Typically brittle (no elastic deformation)
- High modulus *(E)*
- High compressive strength
- Low tensile strength
- Low yield strain
- Poor crack resistance characteristics
    - Low resistance to fracture
- Best wear characteristics, with polyethylene and a low oxidation rate
- High surface wettability and high surface tension
    - Highly conducive to tissue bonding
    - Less friction and diminished wear ("smooth surface")
- Small grain size allows an ultrasmooth finish.
    - Less friction
- Calcium phosphates (e.g., hydroxyapatite) may be useful as coatings (plasma sprayed) to increase attachment strength and promote bone healing.

□ Mechanical properties of tissue

- Bone
    - Composite of collagen and hydroxyapatite
        - Collagen: low *E*, good tensile strength, poor compressive strength
        - Calcium apatite: stiff, brittle, good compressive strength
    - Anisotropic
        - Strongest in compression
        - Weakest in shear
        - Intermediate in tension
        - Resists rapidly applied loads better than slowly applied loads
    - Cancellous bone is 25% as dense, 10% as stiff, and 500% as ductile as cortical bone.
        - Cortical bone excellent at resisting torque.
        - Cancellous bone good at resisting compression and shear.
    - Bone is dynamic.
        - Able to self-repair
        - Changes with aging: stiffer and less ductile
        - Changes with immobilization: weaker
    - Bone aging

- To offset loss in material properties, bone remodels to increase inner and outer cortical diameters.
- Area moment of inertia increases.
    - Bending stresses decrease.

- Stress concentration effects
    - Occur at defect points within bone or at implant-bone interface (stress risers)
    - Reduce overall loading strength
- Stress shielding by load-sharing implants
    - Induces osteoporosis in adjacent bone
        - Decreases normal physiologic bone stresses
    - Common under plates and at the femoral calcar in high-riding THA
- A hole measuring 20%–30% of bone diameter reduces strength up to 50%.
    - Regardless of whether it is filled with a screw
    - Area returns to normal 9–12 months after screw removal.
- Cortical defects can reduce strength 70% or more.
    - Oval defects less than rectangular defects
        - Smaller stress riser (concentration)
- Fracture
    - Type is based on mechanism of injury.
        - Tension: typically transverse and perpendicular to load and bone axis
        - Compression: crush fracture
        - Shear
            - Commonly around joints
            - Load parallel to the bone surface

        - Fracture parallel to the load
    - Bending
        - Eccentric loading or direct blows
        - Begins on the tension side of the bone
        - Continues transversely/obliquely
        - May bifurcate to produce a butterfly fragment
        - High-velocity bending: produces comminuted butterfly fracture
        - Four-point bending: produces segmental fracture
    - Torsion
        - Shear and tensile stresses around the longitudinal axis
        - Most likely to result in a spiral fracture
        - Torsional stresses proportional to the distance from the neutral axis to the periphery of a cylinder
        - Greatest stresses in a long bone under torsion are on the outer (periosteal) surface
    - Comminution
        - A function of the amount of energy transmitted to bone
- Ligaments and tendons
    - Can sustain 5%–10% tensile strain before failure.

- In contrast, bone can sustain only 1%–4% tensile strain.
      - Failure commonly results from tension rupture of fibers and shear failure among fibers.
    - Most ligaments can undergo plastic strain to the point that function is lost but structure remains in continuity.
  - Articular cartilage
    - Ultimate tensile strength is only 5% that of bone.
    - *E* is only 0.1% that of bone.
      - However, because of its viscoelastic properties, is well suited for compressive loading.
    - Is biphasic
      - Solid phase depends on structural matrix.
      - Fluid phase depends on deformation and shift of water within solid matrix.
    - Relatively soft and impermeable solid matrix requires high hydrodynamic pressure to maintain fluid flow.
      - Significant support provided by the fluid component
      - Stress-shielding effect on the matrix
- □ Metal implants
  - Screws
    - Pitch: distance between threads
    - Lead: distance advanced in one revolution
    - Root diameter: minimal/inner diameter is proportional to tensile strength
    - Outer diameter: determines holding power (pullout strength)
    - To maximize pullout strength
      - Large outer diameter
      - Small root diameter
      - Fine pitch
  - Plates
    - Strength varies with material and moment of inertia.
    - **Bending stiffness is proportional to the third power of the thickness (t^3).**
      - Doubling thickness increases

bending stiffness eightfold.

- Plates are load-bearing devices.
  - Most effective on a fracture's tension side
- Types include:
  - Static compression
    - Best in upper extremity
    - Can be stressed for compression
  - Dynamic compression
    - Example: tension band plate
  - Neutralization
    - Resists torsion
  - Buttress
    - Protects bone graft
    - Stress concentration at open screw holes can lead to implant failure.
  - Blade
    - Increased resistance to torsional deformation
  - Locking
    - Absorb axial forces transmitted from screws
    - Do not require compression to bone; preserve periosteal blood supply
    - Biomechanical advantages for osteoporotic fractures without cortical contact
  - Hybrid locking
    - Both nonlocked and locked screws are used.
    - Nonlocked screws assist in reduction.
    - Locked screws create a fixed-angle device or can be used in patients with osteoporosis.

            - **Bicortical locked screws provide increased strength in torsion compared with unicortical locked screws.**
- Intramedullary nails
    - Load-sharing devices
    - Require high polar moment of inertia to maximize torsional rigidity and strength
    - Mechanical characteristics
        - Torsional rigidity
            - Amount of torque needed to produce a unit angle of torsional deformation
            - Depends on both material properties (shear modulus) and structural properties (polar moment of inertia)
        - Bending rigidity
            - Amount of force required to produce a unit amount of deflection
            - Depends on both material properties (elastic modulus) and structural properties (area moment of inertia, length)
            - **Related to the fourth power of the nail's radius**
                - Increasing nail diameter by 10% increases bending rigidity by 50%.
                - Better at resisting bending forces than rotational

forces

- Reaming
  - Allows greater torsional resistance
    - Larger contact area
    - A larger nail; increased rigidity and strength
  - Unslotted nails
    - Smaller diameter
    - Stronger fixation
      - At the expense of flexibility
    - Increased torsional stiffness: greatest advantage of closed-section nails over slotted nails
- Intramedullary nail insertion for femoral shaft fracture
  - Hoop stresses are lowest for a slotted titanium alloy nail with a thin wall
  - Posterior starting points decrease hoop stresses and iatrogenic comminution of fractures
  - Implant failure is more common with smaller-diameter unreamed nails

□ External fixators

- Conventional external fixators
  - Fracture reduction is the most important factor for stability of fixation with external fixation.
  - Other factors to enhance stability (rigidity) include
    - Larger-diameter pins (second most important factor)
    - Additional pins
    - Decreased bone-rod distance
    - Pins in different planes
    - Pins separated by more than 45 degrees
    - Increased mass of the rods or stacked rods
    - A second rod in the same plane increases resistance to bending.
    - Rods in different planes

            - Increased spacing between pins
            - Placement of central pins closer to the fracture site
            - Placement of peripheral pins farther from the fracture site (near-near, far-far).
- Circular (Ilizarov) external fixators
    - Thin wires (usually 1.8 mm in diameter)
        - Fixed under tension (usually between 90 and 130 kg)
        - Circular rings
    - Half-pins may also be used.
        - Offer better purchase in diaphyseal (not metaphyseal) bone
    - Optimum orientation of implants on the ring
        - At a 90-degree angle to each other
            - Maximizes stability
        - A 90-degree angle not always possible
            - Anatomic constraints such as neurovascular structures
    - Bending stiffness of frame
        - Independent of the loading direction
            - Because the frame is circular
    - Each ring should have at least two implants.
        - Wires or half-pins may be used.
        - The construct is most stable when an olive wire and a half-pin are at a 90-degree angle to each other on a ring.
        - Two wires are used on a ring.
            - One wire should be superior to the ring and one inferior.
            - Tensioned wires on the same side can cause the ring to deform.
    - Factors that enhance stability of circular external fixators
        - Larger-diameter wires (and half-pins)
        - Decreased ring diameter
        - Use of olive wires
        - Additional wires or half-pins (or

both)
- Wires (or half-pins or both) crossing at a 90-degree angle
- Increased wire tension (up to 130 kg)
- Placement of the two central rings close to the fracture site
- Decreased spacing between adjacent rings
- Increased number of rings

- Joint arthroplasty implants: discussed in Chapter 5, Adult Reconstruction chapter

- **Biomechanics**
  - General definitions
    - Degrees of freedom
      - Rotations and translations each occur in the *x, y,* and *z* planes.
        - Thus six parameters, or degrees of freedom, describe motion.
      - Translations may be relatively insignificant for many joints.
        - Are often ignored in biomechanical analyses
    - Joint reaction force *(R)*
      - *R* is the force within a joint in response to forces acting on the joint.
        - Both intrinsic and extrinsic
        - Muscle contraction about a joint: the major contributing factor
      - *R* is correlated with predisposition to degenerative changes.
      - Joint contact pressure (stress) can be minimized by
        - Decreasing *R*
        - Increasing contact area
    - Coupled forces—rotation about one axis causes obligatory rotation about another axis (occurs in some joints).
      - Such movements (and associated forces) are *coupled.*
      - Example: lateral bending of the spine accompanied by axial rotation
    - Joint congruence
      - Related to the fit of two articular surfaces
        - A necessary condition for joint

motion

    - Can be evaluated radiographically
    - High congruence increases joint contact area
    - Low congruence decreases joint contact area
    - Movement out of a position of congruence increases stress in cartilage.
        - Allows less contact area for distribution of joint reaction force
        - Predisposes the joint to degeneration
- Instant center of rotation
    - Point about which a joint rotates
    - In some joints (knee), the instant center changes during the arc of motion, following a curved path.
        - Effect of joint translation and morphologic features
    - It normally lies on a line perpendicular to the tangent of the joint surface at all points of contact.
- Rolling and sliding (Fig. 1.62)
    - During motion, almost all joints roll and slide to remain in congruence.
    - Pure rolling:
        - Instant center of rotation is at the rolling surfaces.
        - Contacting points have zero relative velocity.
            - No “slipping” of one surface on the other

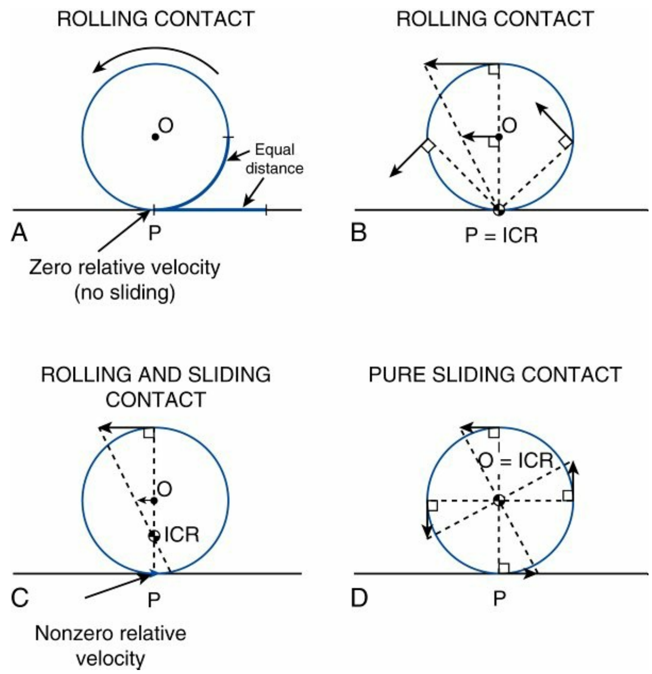


FIG. 1.62 (A) Rolling contact occurs when the circumferential distance of the rolling object equals the distance traced along the plane. This can occur only when there is no sliding—that is, when the relative velocity at the point of contact *(P)* is zero. (B) For rolling contact, the point P of the wheel has zero velocity because it is in contact with the ground. Therefore P is the instant center of rotation *(ICR)* of the wheel. This diagram shows the actual velocity of points along the wheel as it rolls along the ground. (C) Rolling and sliding contact occurs when the relative velocity at the contact point is not zero. (D) Pure sliding occurs when the wheel rotates about a stationary axis *(O)*. In this case, the wheel would have no forward motion.

From Buckwalter JA et al: *Orthopaedic basic science: biology and biomechanics of the musculoskeletal system,* ed 2, Rosemont, IL, 2000, American Academy of Orthopaedic Surgeons, p 145.

- Pure sliding
- Occurs with pure translation or rotation about a stationary axis
- No angular change in position
- No instant center of rotation
  - "Slipping" of one surface on the other

- Friction and lubrication
  - *Friction*: resistance between two objects as one slides over the other

    - Not a function of contact area
    - Coefficient of friction: 0 = no friction
  - Lubrication: decreases resistance between surfaces
    - Articular surfaces, lubricated with synovial fluid, have a coefficient of friction 10 times better than that of the best synthetic systems.
  - Coefficient of friction for human joints: 0.002–0.04
  - Coefficient of friction for metal-on-UHMWPE (ultra-high-molecular-weight polyethylene) joint arthroplasty: 0.05–0.15
    - Not as good as that of human joints
  - **Elastohydrodynamic lubrication**
    - **Primary lubrication mechanism for articular cartilage during dynamic function**

- ◻ Hip biomechanics
  - Kinematics
    - ROM (Table 1.44)
    - Instant center
      - Simultaneous triplanar motion for this ball-and-socket joint makes analysis impossible.
  - Kinetics
    - Joint reaction force *(R)* in the hip can reach three to six times body weight *(W)*.
      - Primarily as a result of contraction of the muscles crossing the hip
      - Decreases with cane in contralateral hand
  - Other considerations
    - Stability
      - Deep-seated ball-and-socket joint is intrinsically stable.
    - Sourcil
      - Condensation of subchondral bone under superomedial acetabulum
      - *R* is maximal at this point
    - Gothic arch
      - Remodeled bone supporting the acetabular roof
      - Sourcil at its base

- Neck-shaft angle
    - Varus angulation
        - Decreases *R*
        - Increases shear across the neck
        - Leads to shortening of the lower extremity
        - Alters muscle tension resting length of the abductors
            - May cause a persistent limp
        - Valgus angulation
        - Increases *R*
        - Decreases shear
        - Neutral or valgus angulation better for THA
        - PMMA resists shear poorly
- Arthrodesis (Fig. 1.63)
    - Position: 25–30 degrees of flexion, 0 degrees of abduction and rotation
        - External rotation is better than internal rotation.
    - If the implant is fused in abduction, the patient will lurch over the affected lower extremity with an excessive trunk shift.
        - This will later result in low back pain.
    - Effects
        - Increases oxygen consumption
        - Decreases gait efficiency to approximately 50% of normal
        - Increases transpelvic rotation of the contralateral hip

□ Knee biomechanics

- Kinematics

- ROM
  - 10 degrees of extension (recurvatum) to 130 degrees of flexion
    - Functional ROM is nearly full extension to about 90 degrees of flexion.
    - 117 degrees: required for squatting and lifting
    - 110 degrees: required for rising from a chair after TKA
  - Rotation varies with flexion
    - At full extension, rotation is minimal.
    - At 90 degrees of flexion, ROM is 45 degrees of external rotation and 30 degrees of internal rotation.
  - Amount of abduction or adduction is essentially 0 degrees.
    - A few degrees of passive motion are possible at 30 degrees of flexion.

Table 1.44

Hip Biomechanics: Range of Motion

Motion	Average Range (Degrees)	Functional Range (Degrees)
Flexion	115	90 (120 to squat)
Extension	30	
Abduction	50	20
Adduction	30	
Internal rotation	45	0
External rotation	45	20

- Knee motion is complex about a

changing instant center of rotation.
        - Polycentric rotation
    - Excursions of 0.5 cm for the medial meniscus and 1.1 cm for the lateral meniscus are possible during a 120-degree arc of motion.
- Joint motion
    - Instant center traces a J-shaped curve about the femoral condyle.
        - Moves posteriorly with flexion
    - Flexion and extension involve both rolling and sliding.
    - Femur rotates internally (tibia rotates externally) during the last 15 degrees of extension
        - "Screw home" mechanism
        - Related to differences in radii of curvature for the medial and lateral femoral condyles and the musculature
    - Posterior rollback increases maximum knee flexion.
        - Tibiofemoral contact point moves posteriorly.
        - Normal rollback is compromised by PCL sacrifice of posterior cruciate ligament (PCL), as in some TKAs.
    - Axis of rotation of the intact knee is in the medial femoral condyle.
    - Patellofemoral joint has sliding articulation
        - Patella slides 7 cm caudally with full flexion.
        - Instant center is near the posterior cortex above the condyles.

- Kinetics

- Knee stabilizers
  - Ligaments and muscles play the major stabilizing role (Table 1.45).
    - ACL
    - Typically subjected to peak loads of 170 N during walking
      - Up to 500 N with running
    - Ultimate strength in young patients: about 1750 N
    - Failures by serial tearing at 10%–15% elongation
  - PCL: sectioning increases contact pressures in the medial compartment and the patellofemoral joint.
- Joint forces
  - Tibiofemoral joint
    - Knee joint surface loads
      - Three times body weight during level walking
      - Up to four times body weight with stair walking
    - Menisci
    - Help with load transmission
    - Bear one-third to one-half body weight
    - Removal increases contact stresses

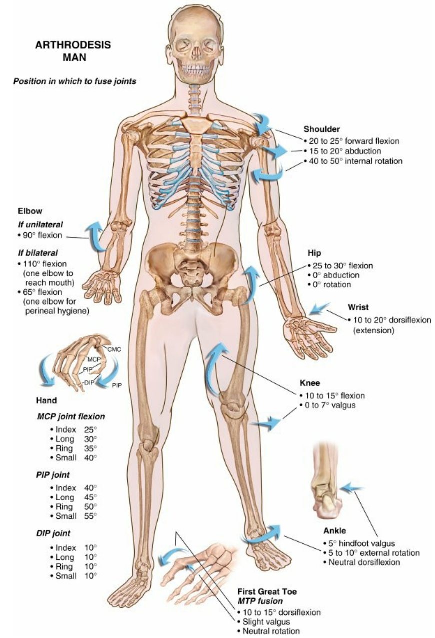


FIG. 1.63 Recommended positions for arthrodesis of common joints. *CMC,* Carpometacarpal; *DIP,* distal interphalangeal; *MCP,* metacarpophalangeal; *MTP,* metatarsophalangeal; *PIP,* proximal interphalangeal.

        - Up to four times the load transfer to bone
    - Quadriceps produces maximum anterior force on the tibia at 0–60 degrees of knee flexion
- Patellofemoral joint
    - Patella aids in knee extension.
        - Increases the lever arm
        - Stress distribution
    - Has the thickest cartilage in the entire body
        - Bears the greatest load
        - Bears half the body

weight with normal walking

Table 1.45

Knee Stabilizers

Direction	Structures
Medial	Superficial MC (primary), joint capsu medial meniscus, ACL/PCL
Lateral	Joint capsule, I band, LCL (middle), lateral meniscus, ACL/PCL (degrees)
Anterior	ACL (primary) joint capsu
Posterior	PCL (primary) joint capsu PCL tighter with intern rotation
Rotatory	Combinations MCL check external rotation; A checks internal rotation

IT, Iliotibial.

- Bears seven times the body weight with squatting and jogging
- Loads proportional to ratio of quadriceps force to knee flexion

- In descending stairs, compressive force reaches two to three times body weight.

- Patellectomy
  - Length of the moment arm is decreased by width of patella: 30% reduction.
  - Power of extension is decreased by 30%.
- During TKA, the following factors enhance patella tracking
  - External rotation of the femoral component
  - Lateral placement of the femoral and tibial components
  - Medial placement of the patellar component
  - Avoidance of malrotation of the tibial component
    - These actions avoid internal rotation.

- Axes of the lower extremity (Fig. 1.64)
  - Mechanical axis of the lower extremity
    - Center of femoral head to center of ankle
    - Normally passes just medial to the medial tibial spine
  - Vertical axis
    - From the center of gravity to the ground
  - Anatomic axes
    - Along the shafts of the femur and tibia

- Where these axes intersect at the knee, valgus angle is normal.
- Mechanical axis of the femur
  - From center of the femoral head to center of the knee
- Mechanical axis of the tibia
  - From center of the tibial plateau to center of the ankle
- Relationships
  - Mechanical axis of the lower extremity is in 3 degrees of valgus angulation from the vertical axis.
  - Anatomic axis of the femur is in 6 degrees of valgus angulation from the mechanical axis.
    - Nine degrees versus the vertical axis
  - Anatomic axis of the tibia is in 2–3 degrees of varus angulation from the mechanical axis.
- Arthrodesis (see Fig. 1.63)
  - Position: 0 to 7 degrees of valgus angulation, 10 to 15 degrees of flexion

□ Ankle and foot biomechanics
- Ankle
  - Kinematics

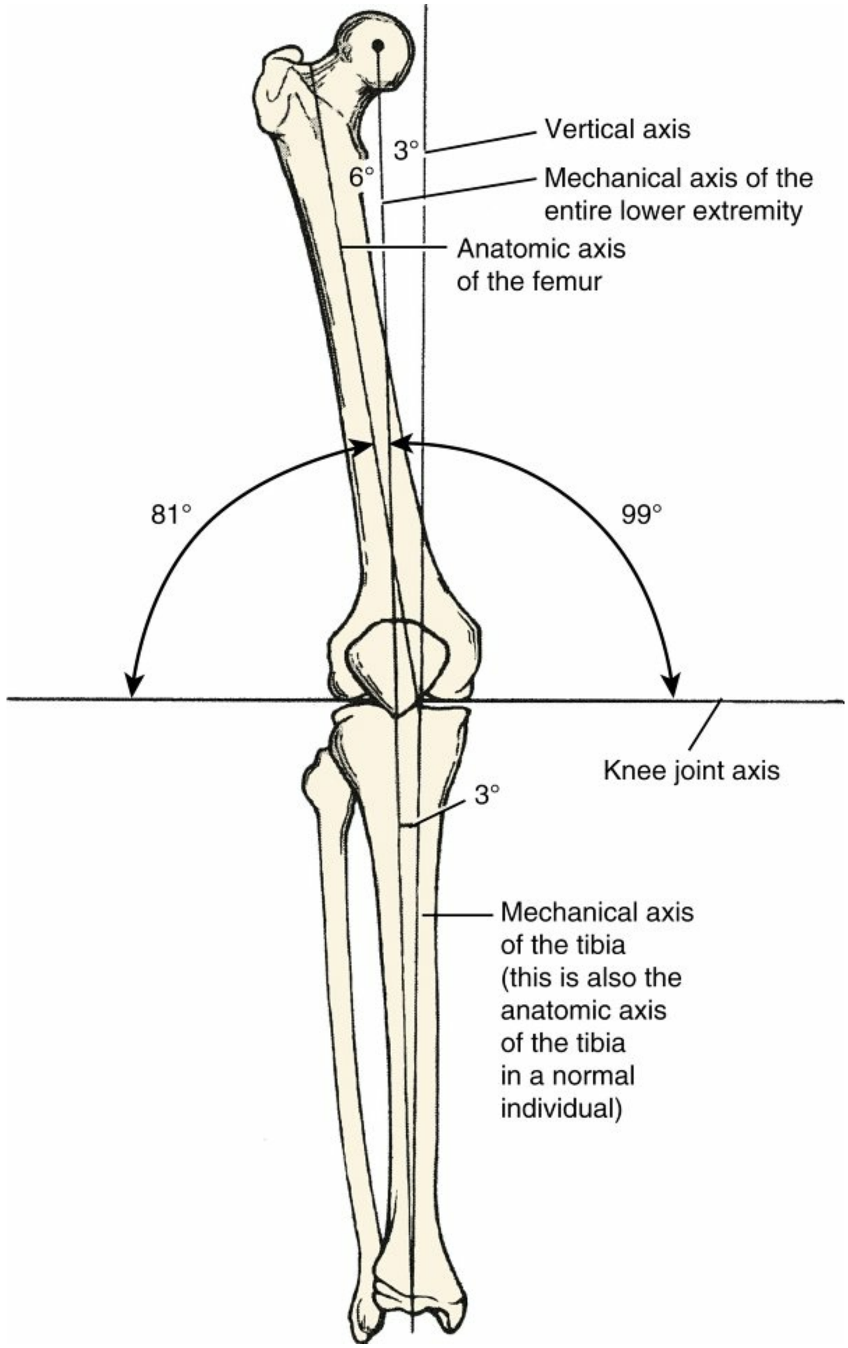


FIG. 1.64 Axes of the lower extremity.
Modified from Helfet DL: Fractures of the distal femur. In Browner BD et al, editors: *Skeletal trauma,* Philadelphia, 1992, Saunders, p 1645.

- Instant center of rotation within the talus
  - Lateral and posterior points at the tips of the malleoli
  - Change slightly with movement
- Talus described as a cone
  - Body and trochlea wider anteriorly and laterally
  - Therefore talus and fibula externally rotate

slightly with dorsiflexion

- Dorsiflexion and abduction are coupled.
- ROM
    - Dorsiflexion: 25 degrees
    - Plantar flexion: 35 degrees
    - Rotation: 5 degrees

- Kinetics
    - Tibiotalar articulation
        - Major weight-bearing surface of the ankle
        - Supports compressive forces up to five times body weight *(W)*
        - Shear (backward to forward) forces are decreased by muscle activation/contraction
    - Large weight-bearing surface area decreases joint stress
    - Fibular/talar joint transmits about one sixth of the force

Table 1.46

Arches of the Foot

Arch	Skeletal Components	Keystone	Ligament Sup
Medial longitudinal	Calcaneus, talus, navicular, three cuneiform bones, first to third metatarsals	Talus head	Spring (calcaneona
Lateral longitudinal	Calcaneus, cuboid, fourth and fifth metatarsals		Plantar aponeu
Transverse	Three cuneiform bones, cuboid, metatarsal bases		

Table 1.47

Range of Motion of Spinal Segments

Level	Flexion/Extension (Degrees)	Lateral Bending (Degrees)	Rotation (Degrees)	Ins Cen
Occiput–C1	13	8	0	Sku
C1–C2	10	0	45	Wa
C2–C7	10–15	8–10	10	Ver
Thoracic spine	5	6	8	Ver
Lumbar spine	15–20	2–5	3–6	Dis

    - Highest net muscle moment occurs during terminal-stance phase of gait.
- Other considerations
    - Stability based on articulation shape (mortise maintained by talar shape) and ligament support
        - Stability is greatest in dorsiflexion.
        - During weight bearing, tibial and talar articular surfaces contribute most to stability.
    - Windlass action
        - Full dorsiflexion is limited by the plantar aponeurosis.
        - Further tension on the aponeurosis (toe dorsiflexion) raises the arch.
    - A syndesmosis screw limits external rotation.

        - Arthrodesis (see Fig. 1.63): neutral dorsiflexion, 5–10 degrees of external rotation, 5 degrees of hindfoot valgus angulation
            - Surgeon should anticipate 70% loss of sagittal plane motion of the foot.
- Subtalar joint (talus-calcaneus-navicular)
    - Axis of rotation
        - In the sagittal plane: 42 degrees
        - In the transverse plane: 16 degrees
    - Functions like an oblique hinge
        - Pronation coupled with dorsiflexion, abduction, and eversion
        - Supination coupled with plantar flexion, adduction, and inversion
    - ROM
        - Pronation: 5 degrees
        - Supination: 20 degrees
        - Functional ROM: approximately 6 degrees
- Transverse tarsal joint (talus-navicular, calcaneal-cuboid)
    - Motion based on foot position
        - Two axes of rotation: talonavicular and calcaneocuboid
    - Eversion (early stance)
        - The joint axes are parallel.
        - ROM is allowed.
    - Inversion (late stance)
        - External rotation of the lower extremity causes the joint axes to intersect.
        - Motion is limited.
- Foot
    - Transmits 1.2 times body weight with walking
        - Three times body weight with running
    - Has three arches (Table 1.46)
        - Second metatarsal (Lisfranc) joint is "keylike."
            - Stabilizes second metatarsal

- Allows it to carry the most load with gait
- First metatarsal bears the most load during standing
- Expected life of Plastazote shoe insert in active adults is less than 1 month.
  - Fatigues rapidly in compression and shear
  - Should be replaced frequently or supported with other materials such as Spenco or PPT foam

□ Spine biomechanics

- Kinematics
  - ROM by anatomic segment (Table 1.47)
  - Analysis based on the functional unit
    - Motion segment: two vertebrae and the intervening soft tissues
  - Six degrees of freedom exist about all three axes.
  - Coupled motion
    - Simultaneous rotation, lateral bending, and flexion or extension
    - Especially axial rotation with lateral bending
  - Instant center of rotation within the disc
  - Normal sagittal alignment of the lumbar spine: 55–60 degrees of lordosis
    - The lordosis exists because of the disc spaces (not the vertebrae).
    - Most lordosis occurs between L4 and S1.
    - Loss of disc space height can cause loss of normal lumbar lordosis.
  - Iatrogenic flat back syndrome of the lumbar spine
    - Result of a distraction force
- Supporting structures
  - Anterior supporting structures
    - Anterior longitudinal ligament
    - Posterior longitudinal ligament
    - Vertebral disc
  - Posterior supporting structures
    - Intertransverse ligaments
    - Capsular ligaments and facets
    - Ligamentum flavum (yellow

ligament)
    - Halo vest—most effective device for controlling cervical motion
        - Because of pin purchase in the skull
- Apophyseal joints
    - Resist torsion during axial loading
        - Attached capsular ligaments resist flexion.
    - Guide the motion segment
    - Direction of motion determined by orientation of the facets of the apophyseal joint
        - Varies with each level
    - Cervical spine facets
        - Orientation: 45 degrees to the transverse plane
        - Parallel to the frontal plane
    - Thoracic spine facets
        - Orientation: 60 degrees to the transverse plane
        - Also 20 degrees to the frontal plane
    - Lumbar spine facets
        - Orientation: 90 degrees to the transverse plane
        - Also 45 degrees to the frontal plane
        - They progressively tilt up (transverse) and inward (frontal).
    - Cervical facetectomy of more than 50% causes loss of stability in flexion and torsion.
    - Torsional load resistance in the lumbar spine
        - Facets contribute 40%
        - Disc contributes 40%
        - Ligamentous structures contribute 20%
- Kinetics
    - Disc
        - Behaves viscoelastically
        - Demonstrates creep
            - Deforms with time
        - Demonstrates hysteresis
            - Absorbs energy with repeated axial loads
            - Later decreases in function

        - Compressive stresses highest in the nucleus pulposus
        - Tensile stresses highest in the annulus fibrosus
        - Stiffness increases with compressive load.
        - Higher loads increase deformation and creep rate.
        - Repeated torsional loading (shear forces)
            - Such repeated loading may separate the nucleus pulposus from the annulus and end plate.
            - Nuclear material may then be forced through an annular tear.
        - Loads increase with bending and torsional stresses.
        - After subtotal discectomy, extension is the most stable loading mode.
        - Disc pressures are lowest with lying supine, higher with standing, and highest with sitting.
        - Carrying loads
            - Disc pressures are lowest when the load is close to the body.
    - Vertebrae
        - Strength is related to bone mineral content and vertebrae size.
            - Increased in lumbar spine
        - Fatigue loading may lead to pars fractures.
        - Compression fractures occur at the end plate.

Table 1.48

Shoulder Biomechanics: Muscle Forces

Motion	Muscle Forces	Comments
Glenohumeral		
Abduction	Deltoid, supraspinatus	Cuff depresses head
Adduction	Latissimus dorsi, pectoralis major, teres major	
Forward flexion	Pectoralis major, deltoid (anterior), biceps	
Extension	Latissimus dorsi	
Internal rotation	Subscapularis, teres major	
External rotation	Infraspinatus, teres minor, deltoid (posterior)	
Scapular		
Rotation	Upper trapezius, levator scapulae (anterior), serratus anterior, lower trapezius	Works through a force couple
Adduction	Trapezius, rhomboid, latissimus dorsi	
Abduction	Serratus anterior, pectoralis minor	

- Vertebral body stiffness is decreased in osteoporosis.
    - Caused by loss of horizontal trabeculae
- Spinal arthrodesis is helpful
- Increasing implant stiffness
- Increases probability of successful fusion
- Increases likelihood of decreased bone mineral content of the bridged vertebrae

□ Shoulder biomechanics (Table 1.48)

- Kinematics
    - Scapular plane

            - Positioned 30 degrees anterior to the coronal plane
            - The preferred reference plane for ROM
        - Abduction requires external rotation of the humerus.
            - To prevent greater tuberosity impingement
            - With internal rotation contractures, abduction limited to 120 degrees
        - Abduction
            - Glenohumeral motion: 120 degrees
            - Scapulothoracic motion: 60 degrees
            - In ratio of 2:1
                - Varies over the first 30 degrees of motion
        - Scapulothoracic motion
            - Acromioclavicular joint movement during the early part
            - Sternoclavicular movement during the later portion
                - With clavicular rotation along the long axis
            - Surface joint motion in the glenohumeral joint is a combination of rotation, rolling, and translation.
    - Kinetics
        - Zero position
            - Abduction of 165 degrees in the scapular plane
            - Minimal deforming forces about the shoulder
            - Ideal position for reducing shoulder dislocations
                - Also for reducing "fractures with traction"
    - Stability
        - Limited about the glenohumeral joint
        - Humeral head surface area larger than glenoid area:
            - 48 × 45 mm versus 35 × 25 mm
        - Bony stability is limited

            - Relies on humeral head inclination (125 degrees) and retroversion (25 degrees)
            - Also relies on slight glenoid retrotilt
        - **Inferior glenohumeral ligament (anterior band)**
            - The most important static stabilizer
            - Superior and middle glenohumeral ligaments: secondary stabilizers to anterior humeral translation
        - Inferior subluxation prevented by negative intraarticular pressure
        - Rotator cuff muscles
            - Dynamic contribution to stability
        - Arthrodesis (see Fig. 1.63): 15–20 degrees of abduction, 20–25 degrees of forward flexion, 40–50 degrees of internal rotation
            - Excessive external rotation should be avoided
    - Other joints
        - Acromioclavicular joint
            - Scapular rotation through the conoid and trapezoid ligaments
            - Scapular motion through the joint itself
        - Sternoclavicular joint
            - Clavicular protraction/retraction in a transverse plane through the coracoclavicular ligament
            - Clavicular elevation and depression in the frontal plane
            - Also through the coracoclavicular ligament
            - Clavicular rotation around the longitudinal axis

□ Elbow biomechanics

- Functions
    - A component joint of the lever arm when the hand is positioned
    - Fulcrum for the forearm lever
    - Weight-bearing joint in patients using crutches
    - Activities of daily living
- Kinematics
    - Flexion and extension

        - 0–150 degrees
        - Functional ROM: 30 to 130 degrees
        - Axis of rotation: the center of the trochlea
    - Pronation and supination
        - Pronation: 80 degrees
        - Supination: 85 degrees
        - Functional pronation and supination: 50 degrees each
        - Axis: capitellum through radial head to ulnar head (forms a cone)
    - Carrying angle
        - Valgus angle at the elbow
        - For boys and men: 7 degrees; for girls and women: 13 degrees
        - Decreases with flexion
- Kinetics
    - Flexion is accomplished primarily by the brachialis and biceps.
    - Extension is accomplished by the triceps.
    - Pronation is accomplished by pronators (teres and quadratus).
    - Supination is accomplished by the biceps and supinator.
    - Static loads approach, and dynamic loads exceed, body weight.
- Stability
    - Provided partially by articular congruity

Table 1.49

Columns of the Wrist

Column	Function	Comments
Central	Flexion-extension	Distal carpal row and lunate (link)
Medial	Rotation	Triquetrum
Lateral	Mobile	Scaphoid

    - Three necessary and sufficient constraints for stability
        - Coronoid
        - Lateral (ulnar) collateral ligament (LCL)
        - Anterior band of the MCL

- Most important: anterior oblique fibers
- Stabilizes against both valgus angulation and distractional force at 90 degrees

- Most important secondary stabilizer against valgus stress: radial head
  - About 30% of valgus stability
  - Important at 0 to 30 degrees of flexion and pronation
- In extension, capsule is the primary restraint to distractional forces.
- Lateral stability is provided by LCL, anconeus, and joint capsule.
- Unilateral arthrodesis (see Fig. 1.63): 90 degrees of flexion
- Bilateral arthrodesis (see Fig. 1.63)
  - One elbow at 110 degrees of flexion for the hand to reach the mouth
  - Other at 65 degrees of flexion for perineal hygiene
- Arthrodesis is difficult to perform and (fortunately) rarely required.

- Forearm
  - Ulna transmits 17% of the axial load
  - Line of the center of rotation runs from radial head to distal ulna

□ Wrist and hand biomechanics

- Wrist
  - Part of an intercalated link system
  - Kinematics
    - Normal ROM
      - Flexion: 65 degrees
        - Functional: 10 degrees
      - Extension: 55 degrees
        - Functional: 35 degrees
      - Radial deviation: 15 degrees
        - Functional: 10 degrees

        - Ulnar deviation: 35 degrees
            - Functional: 15 degrees
    - Flexion and extension
        - Two-thirds radiocarpal
        - One-third intercarpal
    - Radial deviation
        - Primarily intercarpal movement
    - Ulnar deviation
        - Relies on radiocarpal and intercarpal motion
    - Instant center is usually the head of the capitate, but it varies.
- Columns of the wrist are listed in Table 1.49.
- Link system
    - A system of three links in a "chain"
        - Radius, lunate, and capitate
    - Less motion is required at each link.
        - However, it adds to instability of the chain.
    - Stability is enhanced by strong volar ligaments.
        - Also by the scaphoid, which bridges both carpal rows
- Relationships
    - Carpal collapse
        - Ratio of carpal height to third MC height: normally 0.54
    - Ulnar translation
        - Ratio of ulna-to-capitate length to third MC height
        - Normal is 0.30
    - Distal radius normally bears about 80% of distal radioulnar joint load.
    - Distal ulna bears 20%
        - Ulnar load bearing increases with ulnar

lengthening and decreases with ulnar shortening.

- Wrist arthrodesis is relatively common.
  - Dorsiflexion of 10–20 degrees is good for unilateral fusion (see Fig. 1.63).
- Bilateral fusion
  - Avoided if possible
  - If necessary, other wrist should be fused at 0–10 degrees of palmar flexion.

- Hand
  - Kinematics
    - ROM
      - Metacarpophalangeal (MCP) joint
        - Universal joint, 2 degrees of freedom
        - Flexion: 100 degrees
        - Abduction-adduction: 60 degrees
      - Proximal interphalangeal (PIP) joints
        - Flexion: 110 degrees
      - DIP joints
        - Flexion: 80 degrees
  - Arches
    - Two transverse arches
      - Proximal through carpus
      - Distal through metacarpal heads
    - Five longitudinal arches
      - Through each of the rays
  - Stability
    - MCP joint
      - Volar plate and the collateral ligaments

- Collateral ligaments: taut in flexion, lax in extension
- PIP and DIP joints
  - Rely more on joint congruity
  - Ratio of ligament surface to articular surface is large.
- Other concepts

Table 1.50

Recommended Positions of Flexion for Arthrodesis of the Joints of the Hand

Joint	Degrees of Flexion	Other Factors
MCP	20–30	
PIP	40–50	Less radial than ulnar
DIP	15–20	
Thumb CMC		
Thumb MCP	25	MC in opposition
Thumb IP	20	

- Hand pulleys prevent bowstringing and decrease tendon excursion.
  - Bowstringing increases moment arms.
- Sagittal bands allow MCP extension.
- With hyperextension of the MCP, the intrinsic muscles must function to produce PIP extension, because the extension tendon is lax.
- Normal grasp
  - For boys and men: 50 kg
  - For girls and women: 25 kg
  - Only 4 kg needed for daily function
- Normal pinch
  - For boys and men: 8 kg
  - For girls and women: 4 kg

        - Only 1 kg needed for daily activities
- Kinetics
    - Joint loading with pinch mostly in MCP
        - Because MCP joints have large surface area, however, contact pressures (joint load/contact area) are lower.
    - DIP joints have the most contact pressure.
        - Subsequently develop the most degenerative changes with time (Heberden nodes)
    - Grasping contact pressures are decreased, focused on MCP.
        - Patients with MCP arthritis often had occupations in which grasping was required.
    - Compressive loads occur at the thumb with pinching.
        - At interphalangeal joint: 3 kg
        - At MCP joint: 5 kg
        - At carpometacarpal (CMC) joint: 12 kg
            - An unstable joint
            - Frequently leads to degeneration
- Recommended positisions for arthrodesis of the hand are summarized in Table 1.50.

Testable Concepts

Section 1 Orthopaedic Tissues

I.Bone

- Haversian canals carry nerves and blood vessels longitudinally in bone, and Volkmann canals connect different haversian canals.
- Cellular biology:
    - Osteoblasts are derived from undifferentiated mesenchymal stem cells, and RUNX2 is the multifunctional transcription factor that directs this process.
    - Wnt/Beta-catenin (B-catenin) pathways are involved in osteoblast differentiation.
    - Sclerostin and Dkk-1 inhibit binding of the Wnt molecule to LRP5/6.
    - Inhibition of sclerostin or Dkk-1 will lead to increased bone mass.
    - BMPs work through SMAD to cause osteoblastic differentiation.
    - Osteoblasts produce type I collagen (i.e., bone), alkaline phosphatase, osteocalcin, bone sialoprotein, and RANKL.
    - Osteocytes are former osteoblasts surrounded by newly formed matrix. They are important for control of extracellular calcium and phosphorous concentration, and are less active in matrix production than are osteoblasts.
    - Osteoclasts are derived from hematopoietic cells in the macrophage lineage. RANKL is produced by osteoblasts, binds to immature osteoclasts, and stimulates differentiation into active, mature osteoclasts that result in an increase in bone resorption. OPG inhibits bone resorption by binding and inactivating RANKL.
    - Denosumab is a monoclonal antibody that targets and inhibits binding of RANKL to the RANK receptor, which is found on osteoclasts.
    - Osteoclasts bind to bone surfaces by means of integrins (vitronectin receptor), effectively sealing the space below, and then create a ruffled border and remove bone matrix by proteolytic digestion through the lysosomal enzyme cathepsin K.
    - Bisphosphonates directly inhibit osteoclastic bone resorption. Nitrogen-containing bisphosphonates are up to 1000-fold more potent than non–nitrogen-containing bisphosphonates. Bisphosphonates function by inhibiting farnesyl pyrophosphate synthase in the mevalonate pathway. They are associated with osteonecrosis of the jaw, and in animal models, they have reduced the rate of spinal fusion.
- Bone matrix is 60% inorganic (mineral) components and 40% organic components. Calcium hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ constitutes the majority of

the inorganic matrix. Type I collagen is 90% of the organic component, and osteocalcin is the most abundant noncollagenous protein in bone.

- Wolff's law: Remodeling occurs in response to mechanical stress. Hueter-Volkmann law: Compressive forces inhibit growth, whereas tension stimulates it.
- There are three major types of bone formation. In enchondral formation, bone replaces a cartilage model. Intramembranous formation occurs without a cartilage model; aggregates of undifferentiated mesenchymal differentiate into osteoblasts, which form bone. In appositional formation, osteoblasts lay down new bone on existing bone; the groove of Ranvier supplies the chondrocytes.
- There are three stages of fracture repair: inflammation, repair, and remodeling. Fracture healing type varies with treatment method. In closed treatment, healing occurs through periosteal bridging callus and interfragmentary enchondral ossification. In compression plate treatment, primarily cortical healing occurs.
- BMP-2 is used for acute open tibia fractures; BMP-7 is used for tibial nonunions. BMP-3 has no osteogenic activity.
- NSAIDs adversely affect healing of fractures as well as of lumbar spinal fusions. COX-2 activity is required for normal enchondral ossification during fracture healing.
- Bone grafts have three properties. Osteoconduction acts as a scaffold for bone growth; osteoinduction involves growth factors that stimulate bone formation; osteogenic grafts contain primitive mesenchymal cells, osteoblasts, and osteocytes.
- Calcium phosphate–based grafts are capable of osteooconduction and osteointegration. They have the highest compressive strength of any graft material. Calcium sulfate is osteoconductive but rapidly resorbed.
- The primary homeostatic regulators of serum calcium are PTH and $1,25(OH)_2D_3$. PTH results in increased serum Ca^{2+} level and decreased inorganic phosphate level.
- Bone mass peaks between 16 and 25 years of age. Physiologic bone loss affects trabecular bone more than cortical bone.
- Both urinary hydroxyproline and pyridinoline cross-links are elevated when there is bone resorption.
- Serum alkaline phosphatase increases when bone formation increases.
- The most common cause of hypercalcemia is malignancy. Initial treatment is with hydration, which causes a saline diuresis, along with loop diuretics.
- Renal osteodystrophy is a spectrum of disorders observed in chronic renal disease. The majority of cases are caused by phosphorous retention and secondary hyperparathyroidism.
- Rickets (in children) and osteomalacia (in adults) are caused by a failure of mineralization. In rickets, the width of the zone of provisional calcification is increased, which causes physeal widening and cupping.
- Premature arrest following growth plate injury is attributed to vascular invasion across the physis.

- Osteoporosis is a quantitative defect in bone. It is defined as a lumbar bone density of 2.5 or more standard deviations less than the peak bone mass of a healthy 25-year old (T-score).
- Loss of function of the *OPG* gene results in osteoporosis.
- Treatment of osteoporosis includes calcium supplements of 1000–1500 mg/day as well as bisphosphonates.
- Scurvy results from ascorbic acid deficiency, which causes a decrease in chondroitin sulfate synthesis and ultimately defective collagen growth and repair. Widening in the zone of provisional calcification is observed.
- Osteogenesis imperfecta is caused primarily by a mutation in genes responsible for metabolism and synthesis of collagen type I.

II. Cartilage and Joint

- Cartilage is viscoelastic (properties vary depending on rate of force application).
- Composed of water (75%), collagen (25% wet weight, 90%–95% is type II), and proteoglycans (10% wet weight)
- Collagen contributes to viscoelastic behavior in that it restrains "swelling" of aggrecan.
- Aggrecan is most common proteoglycan.
    - Increases osmotic pressure and is responsible for ECM's hydrophilic behavior
- Chondrocytes are only cell in cartilage.
    - BMP-2 and the transcriptional factor SOX-9 important in regulating differentiation and formation.
    - Have cilia that serve as mechanosensory organs or "antennae."
- Cartilage layers:
    - Zone 1 (superficial) has highest concentration of collagen and lowest of PG.
    - Zone 2 (middle or transition) has high levels of PG and water
    - Zone 3 (deep) has highest concentration of PG
    - Zone 4 (calcified cartilage) contains type X collagen
- Growth factors:
    - IL-1 stimulates MMP, COX-2, and nitric oxide synthetase, which degrades cartilage
    - TGF-β stimulates synthesis of ECM and decreased activity of IL-1 and MMPs
- Changes with aging:
    - Fewer chondrocytes but larger
    - Decreased chondroitin but increased keratin
    - Smaller PG molecules (less able to hold water)
    - Increased advanced glycosylation end products
    - Increased stiffness (modulus of elasticity)

- Changes with arthritis:
    - Decreased keratin but increased chondroitin/keratan ratio
    - Increased water content and permeability initially followed by decreased water content in later stages
    - Decreased stiffness (modulus of elasticity)
    - Osteophyte formation due to pathologic activation of endochondral ossification by periarticular chondrocytes through Indian hedgehog (Ihh) mechanism
- Lubricin is a mucinous glycoprotein that binds to hyaluronic acid and contributes to boundary lubrication.
- Major mode of lubrication in joints is elastohydrodynamic (lubricant pressure causes elastic deformation of the opposing surfaces which increases conformity).
- Rheumatoid arthritis:
    - Rheumatoid factor is antibody (IgM) against the Fc portion of IgG
    - Anti-CCP test more sensitive and specific, and presence of antibodies linked to aggressive disease
    - DMARDs:
    - Target TNF-α: etanercept, infliximab, adalimumab
    - Target IL-1: anakinra
    - Target CD20: rituximab
    - Risks of opportunistic infection and lymphoma
- Crystalline arthropathies:
    - Gout: monosodium urate (strongly negatively birefringent, needle-shaped crystals)
    - Pseudogout: calcium pyrophosphate dehydrate (CPP) (weakly positive birefringent, rhomboid-shaped crystals)

III. Muscle

- A-band represents thick filaments composed of myosin.
- I-band represents thin filaments composed of actin.
- Z-disk represents terminus of sarcomere.
- Motor unit is composed of the α-motoneuron and the myofibers it innervates.
- Contraction:
    - ACh diffuses across the synaptic cleft and binds to postsynaptic receptors on sarcolemma, which begin depolarization.
    - Myasthenia gravis is due to IgG antibodies to the AcH receptor. Manifests initially as ptosis and diplopia. Weakness worse with use.
    - Botulinum A reduces spasticity by blocking presynaptic acetylcholine release.
- Following muscle injury, TGF-β stimulates proliferation of myofibroblasts and increases fibrosis.
- Delayed-onset muscle soreness more common after eccentric exercises and may

be associated with changes in I-band.

IV.Tendon

- Composed of water (50%–60%), collagen (75% dry weight, 95% is type I), PG, and elastin
- Elastin is a highly elastic protein than is responsible for "toe region" of stress-strain curve.
- Decorin is most predominant PG, regulates fibril diameter, and inhibits TGF-β1.
- Sheathed tendons have vincula (extensions of synovium), which carry blood supply.
- Following injury, the inflammatory stage is weakest stage of repair and is characterized by production of collagen type III.

V.Ligament

- Similar in composition to tendon but (1) more water, (2) less total collagen but more type III, and (3) higher PG content.
- Following injury, healing ligament demonstrates increased collagen fibers but fewer mature cross-links at 1 year.
- Like tendons, ligaments have direct or indirect (Sharpey fibers) insertions.

VI.Neural Tissue and Intervertebral Disc

- Myelin sheath composed of galactocerebroside and speeds wave propagation (thicker sheath increases speed).
- Action potential created when neurotransmitters cross synapse and trigger voltage-gated Na^+ channels.
- Intervertebral disc:
    - Nucleus pulposus derived from notochord and has a high concentration of proteoglycan
    - Annulus fibrosis derived from mesoderm
    - Avascular; nutrients and fluid diffuse from vertebral end plates
- Early degenerative disc disease is an irreversible process, with IL-1β stimulating the release of MMPs, NO, IL-6, and PGE_2.
- Aging disc has decreased water content as a result of fewer large PGs.
    - Fibronectin cleavage and fragmentation associated with degeneration

Section 2 Orthopaedic Biology

I.Cellular and Molecular Biology

- Antibodies against nuclear content (ANAs) are implicated in several conditions,

including scleroderma (scl-70) and CREST syndrome.
- Alterations in ploidy occur during mitosis and gametogenesis, resulting in conditions such as trisomy-21.
- Marfan syndrome and malignant hyperthermia are examples of disorders with autosomal dominant inheritance.
- Duchenne muscular dystrophy is an example of a disorder with X-linked recessive inheritance.
- Fluorescent in situ hybridization is used to examine chromosomes for translocations predictable of diseases, including:
    - t(X;18): synovial sarcoma
    - t(11;22): in Ewing sarcoma
    - t(12;22): in clear cell sarcoma
- Bacterial LPS is recognized by TLRs on innate immune system cells.
- Adaptive immunity is conferred with the production of antibodies.
- Cell-mediated hypersensitivity (type IV) causes reaction to orthopaedic implants.

II. Infection and Microbiology

- Roughly 80% of orthopaedic infections are due to *Staphylococcus.*
- CA-MRSA at-risk groups: athletes, IV drug abusers, homeless persons, military recruits, prisoners
- C-reactive protein is the most sensitive monitor of the course of infection; it has a short half-life and dissipates about 1 week after effective treatment.
- Necrotizing fasciitis is most commonly polymicrobial and associated with diabetes.
    - Requires early débridement/amputation above level of infection.
- Only 100 bacteria are required to cause infection in the presence of a foreign object; fibronectin increases adhesion, and glycocalyx-biofilm-slime-polysaccharide capsule inhibits phagocytosis.
- Three basic mechanisms of antibiotic resistance have been identified: avoidance, decreased susceptibility, and inactivation. Biofilm formation is an example of avoidance; the biofilm creates a physical barrier.
- Superantigens like TSS toxin-1 trigger cytokine release from T cells.
- Smoking leads to two to four times more infections/osteomyelitis.
- Hyperglycemia impairs wound healing and decreases ability to fight infection.
- Lyme arthritis can be treated effectively with oral antibiotics. Adults can be given amoxicillin, doxycycline, or cefuroxime for 4 weeks.
- *Clostridium tetani* produces an exotoxin leading to tetanospasm. Td vaccine is recommended every 10 years.
- Sequestrum is the dead bone nidus with surrounding granulation tissue. Involucrum is periosteal new bone formation.
- MRI is the best method to show early osteomyelitis but may overestimate extent of disease.

- *Kingella kingae* can be difficult to culture; PCR should be considered in the toddler with a septic knee.
- *Staphylococcus epidermidis* is the most common organism in implant-associated infections.
- Antibiotic therapy according to Gustilo classification of open fractures:
    - Gustilo I and II: first-generation cephalosporins the treatment of choice
    - Gustilo IIIA: first-generation cephalosporin plus an aminoglycoside
    - Gustilo IIIB (grossly contaminated): first-generation cephalosporin plus aminoglycoside plus penicillin
- Antibiotics:
    - Aminoglycosides inhibit translation through irreversible binding of the 30S ribosomal subunit, inhibiting translation of proteins.
    - Cephalosporins inhibit cell-wall production by preventing peptidoglycan cross-linkage.
    - Glycopeptides, such as vancomycin, inhibit cell-wall production by interfering with the addition of cell-wall subunits.
    - Rifamycin inhibits DNA-dependent RNA polymerase F and displays excellent biofilm penetration. Bacteria develop rapid resistance to rifampin used as monotherapy.
    - Macrolides, like erythromycin, bind the 50S ribosomal subunits.
    - Fluoroquinolones, such as ciprofloxacin, inhibit DNA gyrase.
    - Beta-lactam antibiotics, like penicillin, work by inhibiting peptidoglycan synthesis by binding to the bacterial cell membrane surface penicillin-binding proteins.

Section 3 Perioperative and Orthopaedic Medicine

I.Thromboprophylaxis

- Virchow triad: endothelial damage, stasis or decreased blood flow, and hypercoagulability.
- Aspirin irreversibly binds and inactivates COX enzyme in platelets, reducing thromboxane A_2.
- Warfarin can be reversed with fresh frozen plasma and vitamin K.
- Heparin and low-molecular-weight heparin act through ATIII and can be reversed by protamine sulfate.
- Rivaroxaban is a direct factor Xa inhibitor.
- Lactate is an indirect marker of tissue hyperperfusion and serves as best measure of resuscitation.

II.Perioperative Disease and Comorbidities

- Ratio of 1:1:1 blood product resuscitation is superior to saline fluid.

- Fat embolism syndrome classical triad = petechial rash, neurologic symptoms, respiratory decline.
- Malignant hyperthermia is autosomal dominantly inherited defect in ryanodine receptor.
    - Caused by an uncontrolled release of calcium
    - Triggered by volatile anesthetics (and succinylcholine)
    - Early sign is increasing end-tidal CO_2
    - Treatment is 100% O_2 and dantrolene (stabilizes sarcoplasmic reticulum).

Section 4 Other Basic Principles

I.Imaging and Special Studies

- Increased radiation exposure associated with:
    - Imaging of larger body parts
    - Positioning the extremity closer to the x-source
    - Use of large C-arm rather than mini C-arm
- 3.0 T MRI has 9 times greater proton energy than 1.5T.

II.Biomaterials and Biomechanics

- Work is the product of force and the displacement it causes (Joule).
- Energy is the ability to perform work.
    - Potential energy is stored
    - Kinetic energy is energy caused by motion: $1/2\ mv^2$.
- Stress is the internal resistance of body to a load (force/area).
- Strain is relative measure of deformation = change in length/original length (no units).
- Young's modulus of elasticity (E) = stress/strain.
    - Unique for every material
    - High E to low E: ceramic, cobalt chrome, stainless steel, titanium, cortical bone, PMMA, polyethelene, cancellous bone, tendon/ligament, cartilage
- Viscoelastic materials have a stress-strain behavior that is time/rate dependent.
- Isotropic materials have mechanical properties that are the same for all directions loaded (golf ball).
- Anisotropic materials have mechanical properties that vary with the direction of the applied load (bone is stronger in axial load than with bending moment).
- Corrosion:
    - Galvanic corrosion occurs when dissimilar metals are in direct contact (cobalt chrome and stainless steel).
    - Crevice corrosion occurs in fatigue cracks with low oxygen tension.
    - Fretting corrosion comes from small movements abrading the outside

layer.
    - Stress corrosion occurs in areas with high stress gradients.
- Joint arthrodesis:
    - Hip: 25–30 degrees of flexion; 0 degrees of abduction/rotation
    - Knee: 0–7 degrees of valgus; 10–15 degrees of flexion
    - Ankle: 5 degrees of hindfoot valgus; 5–10 degrees of external rotation; neutral dorsiflexion
    - Shoulder: 15–20 degrees of abduction; 20–25 of forward flexion; 40 degrees of internal rotation
    - Elbow: 90 degrees of flexion if unilateral; if bilateral, one at 65 degrees and one at 110 degrees
    - Wrist: 10–20 degrees of dorsiflexion; if bilateral, then the opposite should be in 10 degrees of palmarflexion.

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CHAPTER 2

Anatomy

F. Winston Gwathmey Jr.

Introduction

Overview

- **Osteology: 206 bones in the human skeleton: 80 in the axial skeleton and 126 in the appendicular skeleton**
  - Ossification
    - Intramembranous (direct laying down of bone without a cartilage model [skull]) or enchondral (with a cartilage

precursor [most bones])

- Enchondral growth begins in the diaphyses of long bones at primary ossification centers, most of which are present at birth.
  - Secondary ossification centers usually develop at proximal or distal ends of bones and are important for growth.
  - Frequently the site of pediatric physeal fractures

- **Arthrology: joints are commonly classified into three types on the basis of their freedom of movement.**
  - Synarthroses: joining of two bony elements with no motion during maturity (e.g., skull sutures)
  - Amphiarthroses: have hyaline cartilage and intervening discs with limited motion (e.g., symphysis pubis)
  - Diarthroses: characterized by hyaline cartilage, synovial membranes, capsules, and ligaments
- **Myology: classification based on the arrangement of muscle fibers**
  - Parallel (e.g., rhomboids)
  - Fusiform (e.g., biceps brachii)
  - Oblique (with tendinous interdigitation): further classified as pennate, bipennate, multipennate
  - Triangular (e.g., pectoralis minor)
  - Spiral (e.g., latissimus dorsi)
- **Nerves**
  - Peripheral nerves
    - Originate from the ventral rami of spinal nerves and are distributed via several plexuses (cervical, brachial, lumbosacral)
    - **The mnemonic "SAME" can be used to help understand the function of nerves: *s*ensory = *a*fferent; *m*otor = *e*fferent.**
    - Efferent (motor) fibers carry impulses from the central nervous system (CNS) to muscles.
    - Afferent (sensory) fibers carry information toward the CNS.
  - Autonomic nerves
    - Control visceral structures
    - Consist of parasympathetic (craniosacral) and sympathetic (thoracolumbar) divisions
      - Preganglionic neurons of parasympathetic nerves
        - Arise in the nuclei of cranial nerves III, VII, IX, and X and in the S2, S3, and S4 segments of the spinal cord
        - Synapse in peripheral ganglia
      - Preganglionic neurons in the sympathetic system

- Located in the spinal cord (T1–L3)
- Synapse in chain ganglia adjacent to spine and collateral ganglia along major abdominal blood vessels

- **Vessels: arteries, veins, and lymphatic vessels**

Upper Extremity

Shoulder

- **Osteology**
  - Scapula
    - Spans second through seventh ribs and serves as an attachment for 17 muscles
    - Anteverted on chest wall approximately 30 degrees relative to the body
    - Glenoid retroverted approximately 5 degrees relative to scapular body
    - Os acromiale: incomplete fusion of secondary ossification centers, most commonly between mesoacromion and metaacromion
    - Coracoid: attachments to coracoid include coracoacromial ligament, coracoclavicular ligaments (conoid [medial] and trapezoid [lateral]), conjoined tendon (coracobrachialis and short head of biceps), and pectoralis minor.
    - **Suprascapular notch: suprascapular artery passes superior to superior transverse scapular ligament and suprascapular nerve passes inferior to ligament through notch (mnemonic: "Army over Navy" for artery over nerve).**
    - Spinoglenoid notch: both the artery and nerve inferior to the inferior transverse scapular ligament
    - **Coracoacromial ligament contributes to anterosuperior stability in rotator cuff deficiency and should be preserved with irreparable cuff tears to prevent anterosuperior escape.**
      - Acromial branch of the thoracoacromial artery runs on medial aspect of the coracoacromial ligament.
  - Clavicle
    - First bone in the body to ossify (at 5 weeks' gestation) and last to fuse (medial epiphysis at 25 years of age)
    - Fracture of clavicle is the most common musculoskeletal birth injury.
  - Proximal humerus
    - Humeral head retroverted 30 degrees relative to transepicondylar axis of humerus
      - Head height approximately 5.6 cm above superior border of pectoralis major tendon (important for arthroplasty)

- Anatomic neck (directly below humeral head) attachment for the shoulder capsule
- Surgical neck more distal and more often involved in fractures
- Transverse humeral ligament important stabilizer of the biceps tendon

▪ **Arthrology: one major articulation (glenohumeral joint) and two minor articulations (sternoclavicular, acromioclavicular)**

- □ Glenohumeral joint (Fig. 2.1): ball and socket; greatest joint range of motion in body; motion is at the expense of stability, which is provided by static and dynamic restraints
    - Static restraints: articular anatomy, glenoid labrum, glenohumeral ligaments, capsule, and negative intraarticular pressure
    - Dynamic stabilizers: rotator cuff and biceps tendon; scapulothoracic mechanics contribute to stability
    - Important glenohumeral stabilizers summarized in Table 2.1
    - Fibrocartilaginous glenoid labrum deepens socket 50% and provides bumper to translation.
        - Labral anatomic variants include sublabral foramen (anterosuperior) and Buford complex (absence of anterosuperior labrum and cordlike middle glenohumeral ligament).
            - **Use caution repairing anterosuperior labral variant—may cause loss of external rotation.**
- □ Sternoclavicular joint (Fig. 2.2)
    - Double gliding with an articular disc
    - Only true joint connecting upper extremity with axial skeleton

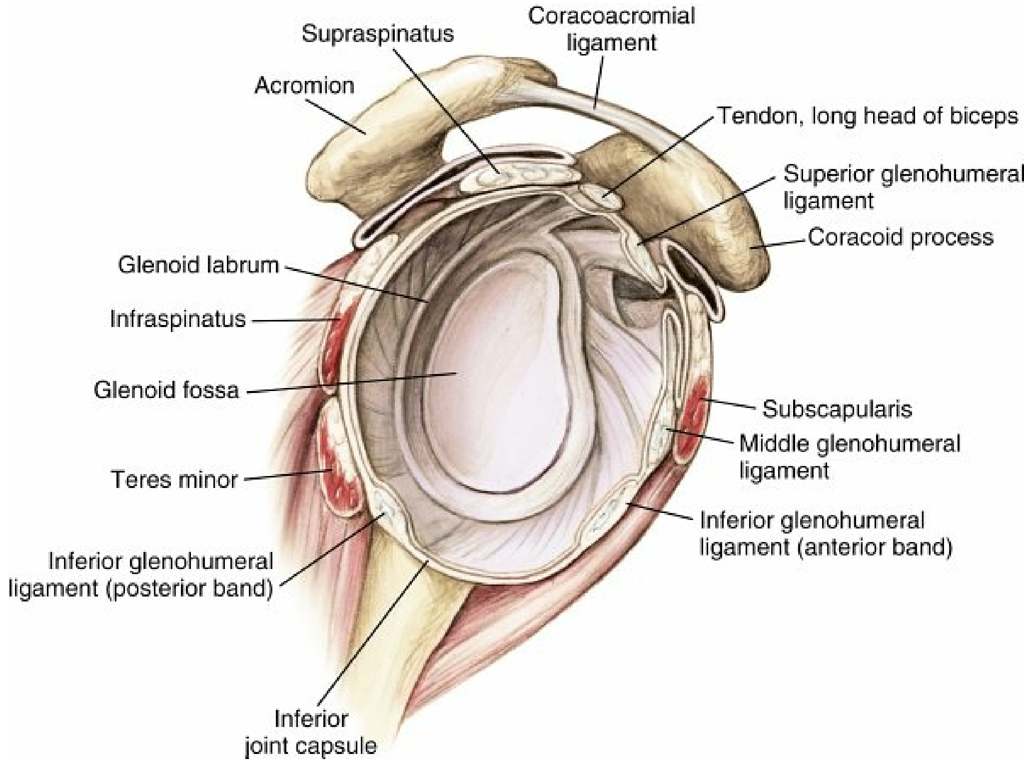


FIG. 2.1 Glenohumeral joint.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figure SA-4.

- Posterior sternoclavicular ligament strongest and primary restraint to anteroposterior instability
- Rotates 30 degrees with shoulder motion

□ Acromioclavicular (AC) joint
- Plane/gliding joint with a fibrocartilaginous disc
- Ligaments (see Fig. 2.2):
    - AC ligaments: prevent anteroposterior displacement
    - Coracoclavicular ligaments: prevent superior displacement of distal clavicle
        - Trapezoid (anterolateral): approximately 25 mm from AC joint
        - Conoid (posteromedial and stronger): approximately 45 mm from AC joint
- When the arm is maximally elevated, about 5 to 8 degrees of rotation are possible at the AC joint, although the clavicle rotates approximately 40 to 50 degrees.

Table 2.1

Glenohumeral Stabilizers

Structure	Function
Glenoid labrum	Increases surface area, deepens socket, static stabilizer
Coracohumeral ligament	Restrains inferior translation and external rotation of adducted arm
Superior glenohumeral ligament	Restrains external rotation and inferior translation of adducted or slightly abducted arm
Middle glenohumeral ligament (absent in up to 30% of shoulders)	Restrains anterior translation with arm abducted to 45 degrees
Inferior glenohumeral ligament, anterior band	Restrains anterior and inferior translation with arm externally rotated and abducted to 90 degrees (position of apprehension)
Inferior glenohumeral ligament, posterior band	Restrains posterior and inferior translation with arm internally rotated and abducted to 90 degrees

- □ Scapulothoracic joint
  - Though not a true joint, this attachment allows scapular movement against the posterior rib cage and contributes to glenohumeral joint positioning and mechanics.
  - Fixed primarily by the scapular muscular attachments
  - Positions the glenoid for glenohumeral motion. Glenohumeral motion in comparison with scapulothoracic motion is in a 2:1 ratio.
- □ Muscles of the shoulder girdle are shown in Fig. 2.3 and outlined in Table 2.2. Rotator cuff: supraspinatus, infraspinatus, teres minor, subscapularis
  - Function: depress and stabilize the humeral head against the glenoid; force-couple larger shoulder muscles to maintain humeral head center of rotation
- □ Shoulder internal rotators (pectoralis major, latissimus dorsi, teres major, and subscapularis) are stronger than external rotators (teres minor and infraspinatus), which is why posterior shoulder dislocations may occur with electric shock and seizures.
- □ Three important (and testable) spaces formed by muscles around the posteromedial shoulder: quadrangular space, triangular space, and triangular interval (Fig. 2.4, Table 2.3)
  - Triangular interval is inferior to quadrangular space.
    - Mnemonic: triangular interv*al* is dist*al*

Arm

- **Osteology**
  - Humerus
    - Posterior spiral groove (for radial nerve) adjacent to the deltoid tuberosity that runs obliquely from proximal medial to distal lateral
    - Trochlea: medial spool-shaped structure; articulates with olecranon of the ulna
    - Capitellum: lateral globe-shaped structure; opposes radial head
    - Articular surface of distal humerus has 7-degree valgus tilt relative to shaft (carrying angle of elbow).

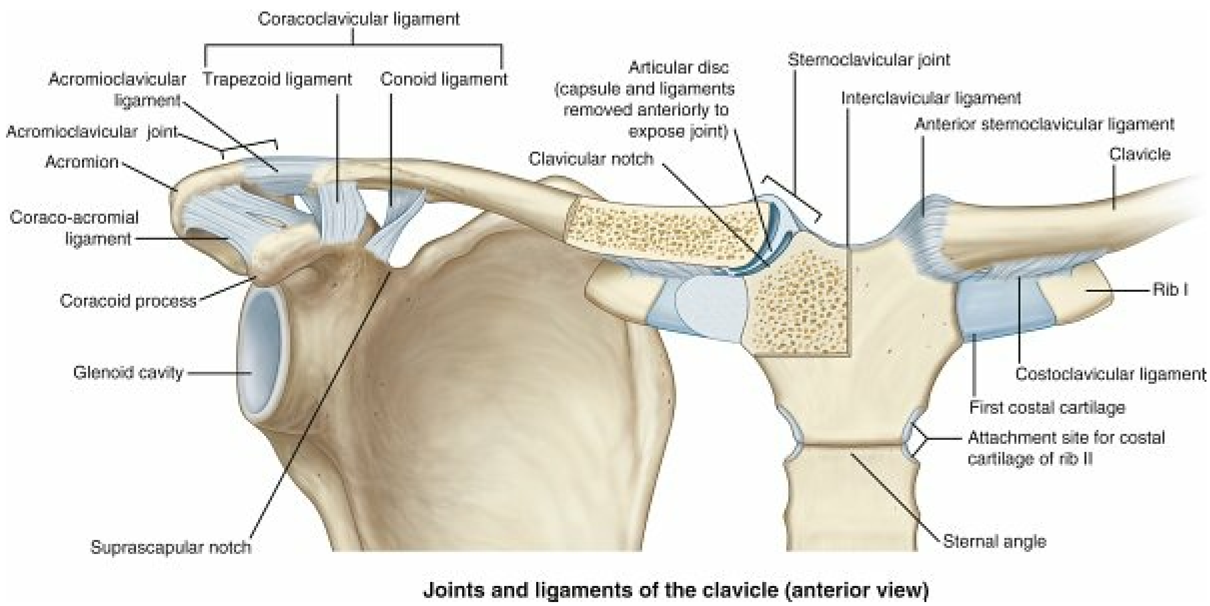


FIG. 2.2 Joints and ligaments of the clavicle (anterior view).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

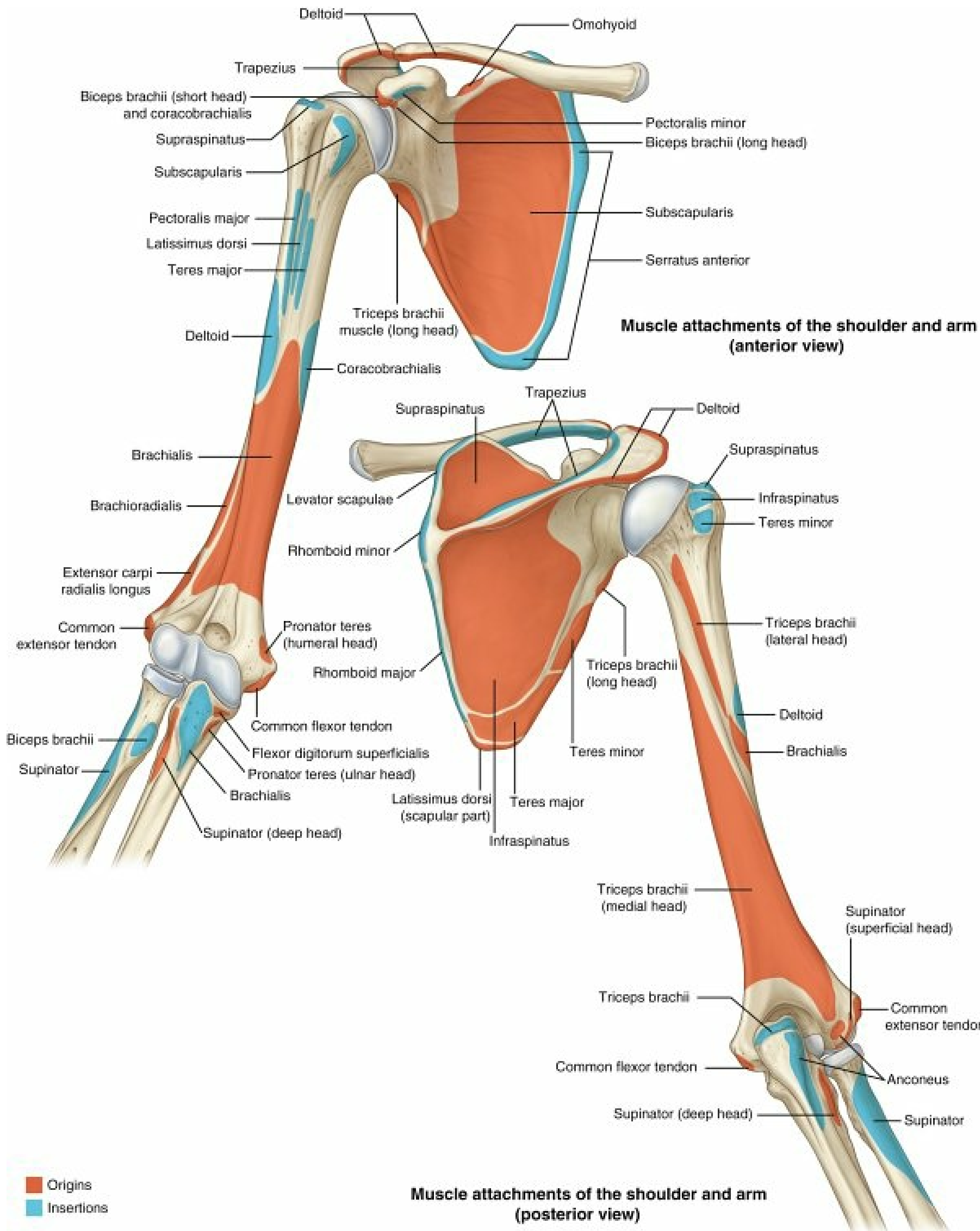


FIG. 2.3 Muscle attachments of the shoulder and arm (anterior and posterior views). From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.2

Muscles of the Shoulder Girdle

Muscle	Origin	Insertion	Action	Innervation
Trapezius	SP C7–T12	Clavicle, scapula	Rotating scapula	Cranial nerve XI

		(acromion, SP)		
Latissimus dorsi	SP T6–S5, ilium	Humerus (ITG)	Extending, adducting, internally rotating humerus	Thoracodorsal nerve
Rhomboid major	SP T2–T5	Scapula (medial border)	Adducting scapula	Dorsal scapular nerve
Rhomboid minor	SP C7–T1	Scapula (medial spine)	Adducting scapula	Dorsal scapular nerve
Levator scapulae	Transverse process C1–4	Scapula (superior medial)	Elevating, rotating scapula	C3, C4 nerves
Pectoralis major	Sternum, ribs, clavicle	Humerus (lateral ITG)	Adducting, internally rotating arm	Medial and lateral pectoral nerves
Pectoralis minor	Ribs 3–5	Scapula (coracoid)	Protracting scapula	Medial pectoral nerve
Subclavius	Rib 1	Inferior clavicle	Depressing clavicle	Upper trunk nerves
Serratus anterior	Ribs 1–9	Scapula (ventral medial)	Preventing winging	Long thoracic nerve
Deltoid	Lateral clavicle, scapula	Humerus (deltoid tuberosity)	Abducting arm	Axillary nerve
Teres major	Inferior scapula	Humerus (medial ITG)	Adducting, internally rotating, extending arm	Lower subscapular nerve
Subscapularis	Ventral scapula	Humerus (lesser tuberosity)	Internally rotating arm, providing anterior stability	Upper and lower subscapular nerves
Supraspinatus	Superior scapula	Humerus (GT)	Abducting and externally rotating arm, providing	Suprascapular nerve

			stability	
Infraspinatus	Dorsal scapula	Humerus (GT)	Providing stability, externally rotating arm	Suprascapular nerve
Teres minor	Scapula (dorsolateral)	Humerus (GT)	Providing stability, externally rotating arm	Axillary nerve

GT, Greater tuberosity; *ITG,* intertubercular groove; *SP,* spinous process.

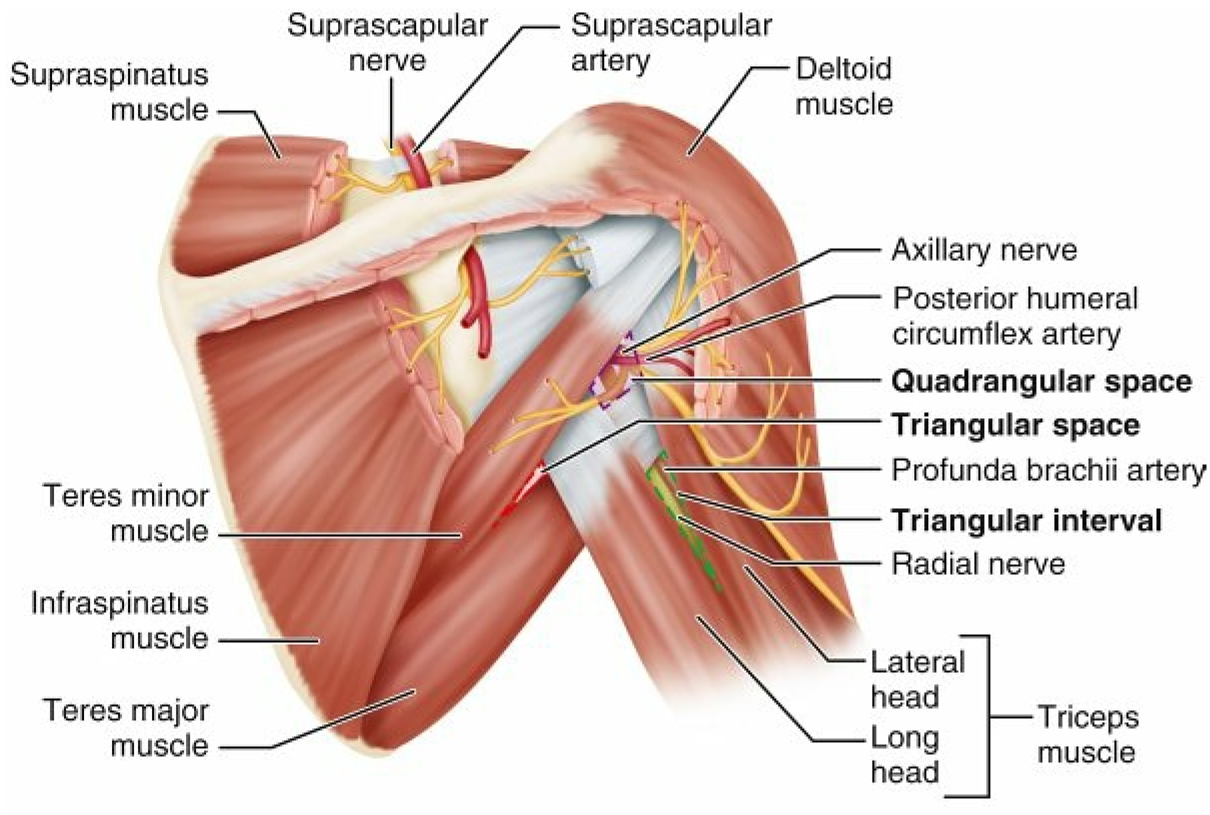


FIG. 2.4 Borders of the key spaces and intervals around the shoulder, including the suprascapular nerve course as well as the quadrangular space and triangular space/interval.

Table 2.3

Shoulder Spaces

Space	Borders	Nerve	Artery
Quadrangular (quadrilateral) space	Superior: lower border of teres minor Inferior: upper border of teres major Medial: long head of triceps Lateral: surgical neck of humerus	Axillary	Posterior humeral circumflex
Triangular space	Superior: lower border of teres minor Inferior: upper border of teres major Lateral: long head of triceps		Circumflex scapular
Triangular interval	Superior: lower border of teres major Medial: long head of triceps Lateral: shaft of humerus	Radial	Profunda brachii

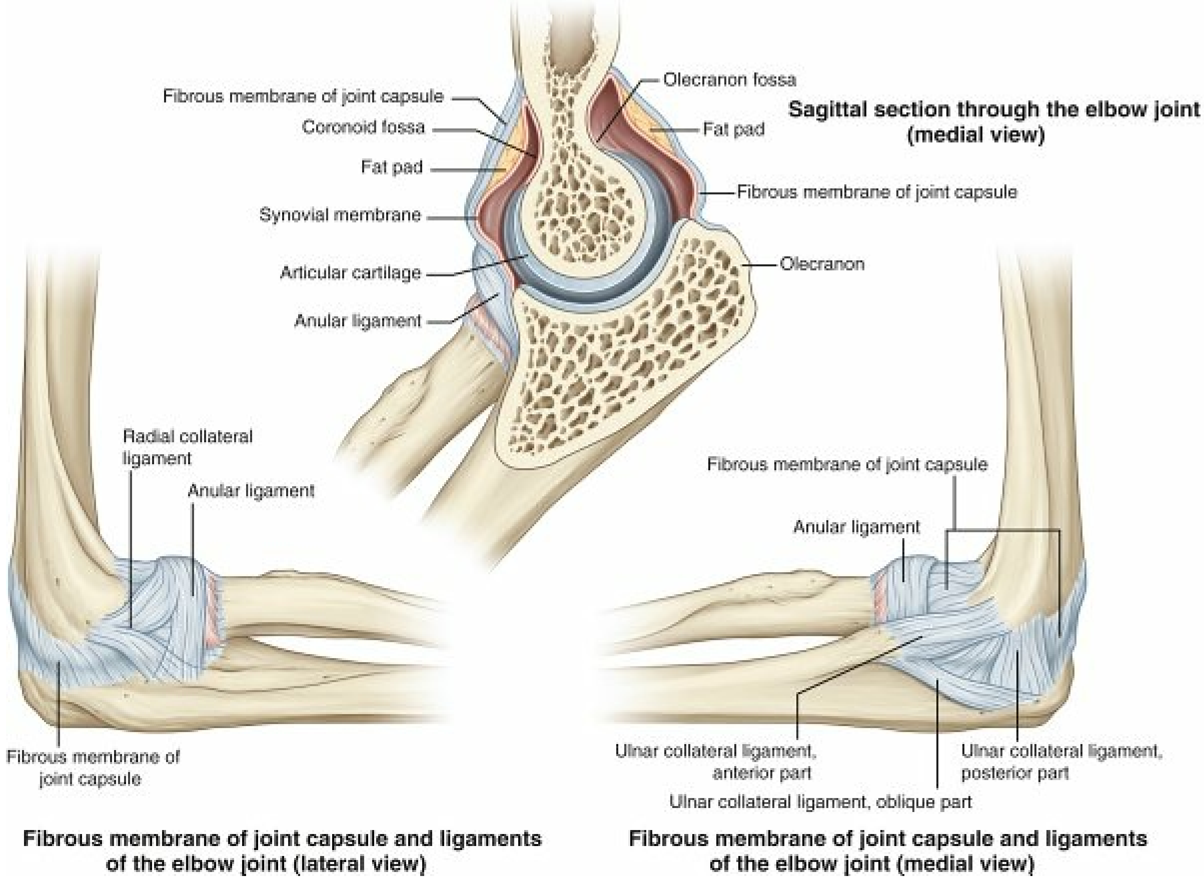


FIG. 2.5 Elbow joint including fibrous membranes of joint capsule and ligaments.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.4

Elbow Ligaments

Ligament	Components	Comment(S)
Medial or ulnar collateral	Anterior band	• Anteroinferior portion of the medial humeral epicondyle to sublime tubercle (18 mm distal to coronoid tip) • Strongest elbow ligament and primary restraint to valgus stress • Taut from 60 degrees of flexion to full extension • Reconstructed in UCL reconstruction (Tommy John surgery)
	Posterior band	• Taut from 60 to 120 degrees of flexion • Greatest change in length from flexion to extension
	Transverse band	• Cooper ligament
Lateral collateral	Lateral ulnar collateral ligament	• Lateral humeral epicondyle to supinator crest • Deficiency results in posterolateral rotator instability
	Anular ligament, quadrate (anular ligament to radial neck), and oblique cord	

- **Arthrology**
  - Elbow: hinge (ulnohumeral articulation) and pivot joint (radiocapitellar articulation)
    - **Radial head should line up with capitellum at all arm positions on all radiographic views.**
    - Tensile forces at medial elbow, compressive forces at lateral elbow
    - Capsuloligamentous structures of elbow are a key source of testable material (Fig. 2.5).
      - Capsule allows maximum distension at approximately 70 to 80 degrees of flexion (patients with effusion most comfortable in this position).
      - Anterior capsule attaches at a point approximately 6 mm distal to the tip of the

coronoid.

- Coronoid tip is an intraarticular structure that is visualized during elbow arthroscopy.
- Elbow ligaments (Table 2.4)
  - Medial or ulnar collateral ligament primary valgus stabilizer
  - Lateral ulnar collateral ligament posterolateral stabilizer
  - Osborne's ligament stabilizes ulnar nerve in cubital tunnel.
  - Ligament of Struthers: variant anatomy arising from supracondylar process to attach to medial epicondyle; potential site of median nerve compression

Table 2.5

Muscles of the Arm/Elbow

Muscle	Origin	Insertion	Action	Innervation
Coracobrachialis	Coracoid	Midhumerus (medial)	Flexion, adduction	Musculocutaneous
Biceps brachii	Coracoid (short head) Supraglenoid (long head)	Radial tuberosity	Supination, flexion	Musculocutaneous
Brachialis	Anterior humerus	Ulnar tuberosity (anterior)	Flexing forearm	Musculocutaneous radial
Triceps brachii	Infraglenoid (long head) Posterior humerus (lateral head) Posterior humerus (medial head)	Olecranon	Extending forearm	Radial

- **Muscles of the arm/elbow (** Table 2.5)
  - Brachialis strongest elbow flexor and attaches to the coronoid 11 mm

distal to the tip

- Biceps brachii inserts at ulnar margin radial tuberosity (long head proximal, short head distal); powerful supinator of forearm
- Primary elbow extensor (triceps) inserts on olecranon process.
- Mobile wad: brachioradialis, extensor carpi radialis longus (ECRL), extensor carpi radialis brevis (ECRB)
- Flexor-pronator mass: pronator teres, flexor carpi radialis, palmaris longus, flexor carpi ulnaris (FCU), flexor digitorum superficialis (FDS)

Forearm

- **Osteology**
  - Ulna
    - Proximally: two curved processes, the olecranon and the coronoid processes, with an intervening trochlear notch
    - Distally, the ulna tapers and ends in a lateral head and a medial styloid process.
  - Radius
    - Proximally: head with a central fovea, neck, and proximal medial radial tuberosity (for insertion of biceps tendon)
    - Gradual bend (convex laterally) and increase in size distally
      - Restoration of the radial bow (and length) is critical in the fixation of radial shaft fractures to maintain arc of pronation and supination.
    - Distally, the radius is composed of the carpal articular surface, an ulnar notch, a dorsal tubercle (Lister tubercle, which is at the level of the scapholunate joint), and a lateral styloid process.
- **Arthrology: proximally includes the elbow joint and distally includes the wrist joint**
  - **Radius and ulna connected by oblique interosseous membrane/ligament (disrupted in Essex-Lopresti injury), which transmits axial load from radius at wrist to ulna at elbow**
- **Muscles (** Fig. 2.6, Table 2.6): arranged according to both location and function
  - Volar flexors (superficial and deep) (Fig. 2.7)
  - Dorsal extensors (superficial and deep) (see Fig. 2.7)

Wrist and Hand

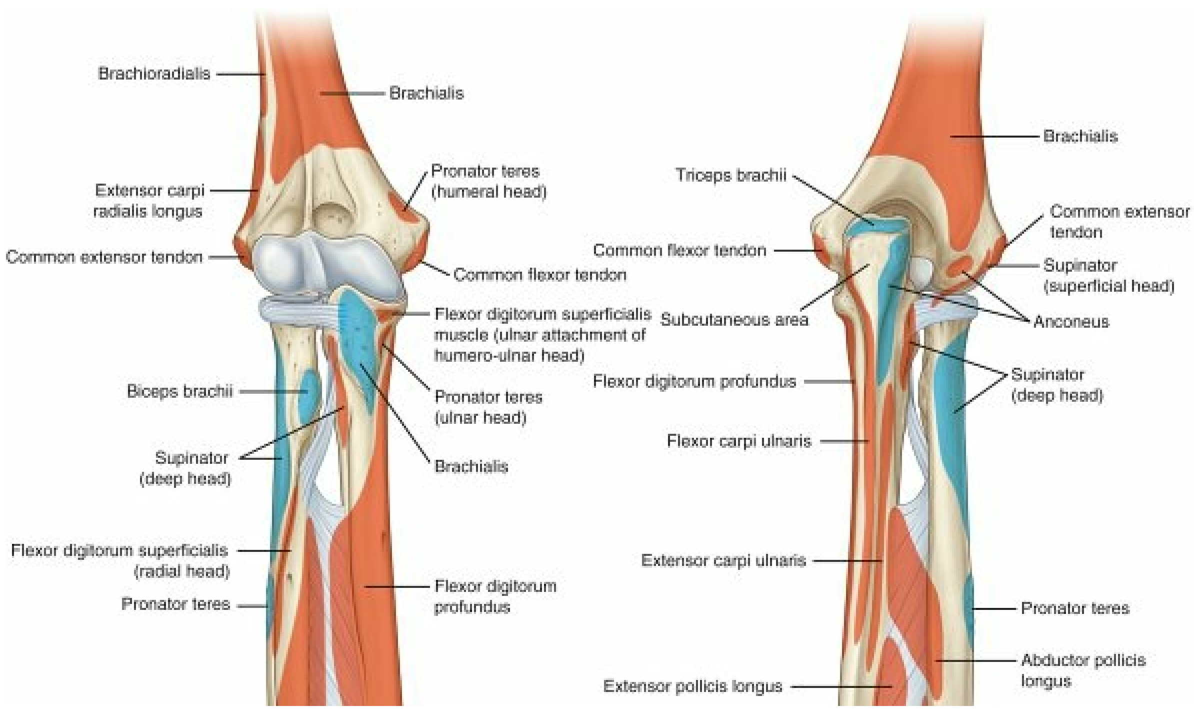
- **Osteology (** Fig. 2.8)
  - Carpal bones

        - **Ossification begins at the capitate (usually present at 1 year of age) and proceeds in a counterclockwise direction, according to posteroanterior radiographs of the right hand**.
        - Several key features are important to recognize in the individual carpal bones (Table 2.7).
    - Metacarpals
        - Several characteristics allow identification of individual metacarpals (Table 2.8).
    - Phalanges
- **Arthrology**
    - Distal radioulnar joint (DRUJ) articulation (most stable in supination)
    - Radiocarpal (wrist) joint
        - Ellipsoid shape involving distal radius and the scaphoid, lunate, and triquetrum
        - Located at the level of the crease of proximal wrist flexion
        - Ligaments (Table 2.9; see Fig. 2.8)
            - Extrinsic ligaments bridge carpal bones to radius or metacarpals (e.g., radio-scapho-capitate); intrinsic ligaments attach carpal bones together (e.g., scapholunate).
            - Palmar/volar radiocarpal ligaments are the strongest supporting structures.
            - **Space of Poirier: central weak area in floor of carpal tunnel; implicated in volar dislocation of lunate in perilunate dislocation**
            - Ligament of Testut (radioscapholunate ligament) functions as a neurovascular conduit.
        - Triangular fibrocartilage complex (TFCC) (Fig. 2.9, Table 2.10): vascular supply from periphery (central portion avascular)
    - Intercarpal joints
        - Proximal row
            - Scaphoid linked to the lunate (via the scapholunate ligament), which is linked to the triquetrum (via the lunotriquetral ligament)
            - Flexes with radial deviation and extends with ulnar deviation
                - SL ligament injury: dorsal intercalated segmental instability (DISI)
                - LT ligament injury: volar intercalated segmental instability (VISI)
            - Dorsal intercarpal ligaments are stronger.

- Distal row
    - Dorsal and palmar intercarpal ligaments connect trapezium with trapezoid, trapezoid with capitate, and capitate with hamate.
    - Interosseous ligaments are much thicker in the distal row, connecting capitate and hamate (strongest), capitate and trapezoid, and trapezium and trapezoid (weakest).

□ Midcarpal joint

- Transverse articulations between proximal and distal rows are reinforced by palmar and dorsal intercarpal ligaments and carpal collateral ligaments.
- Radial ligament is stronger.



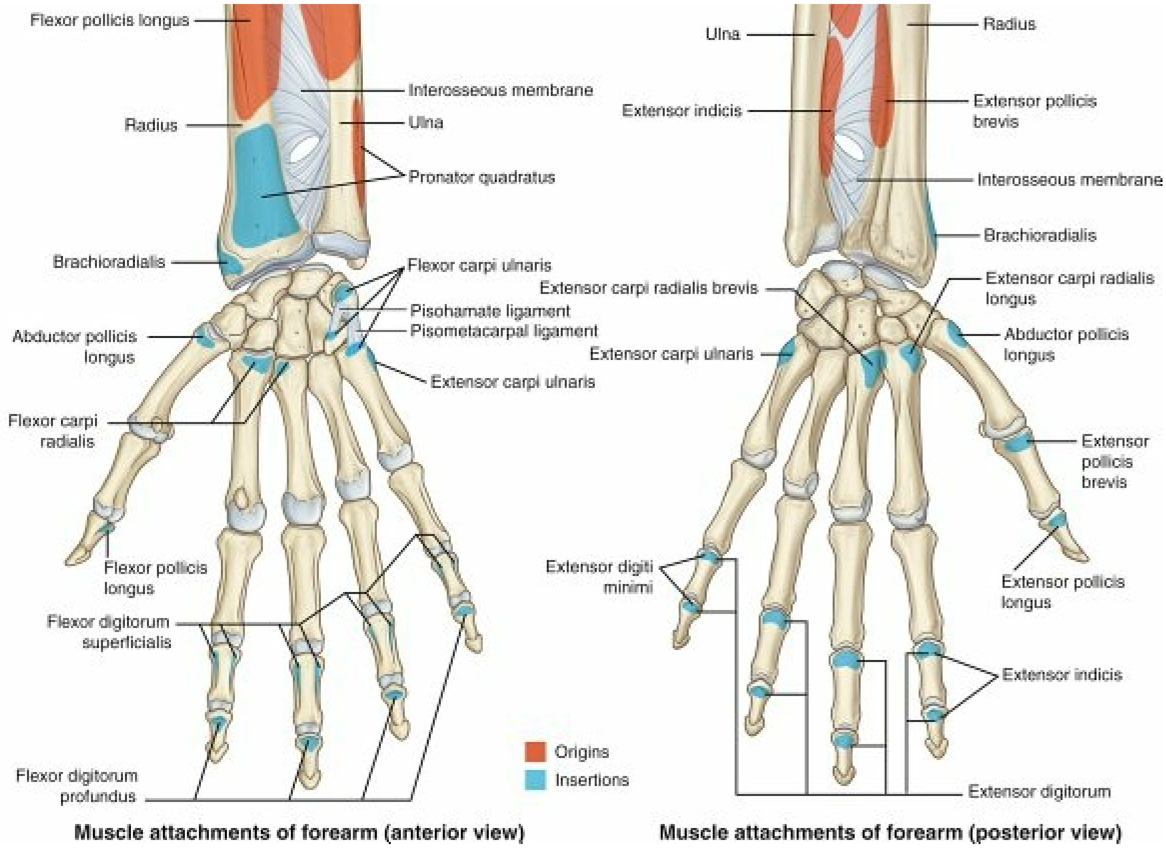


FIG. 2.6 Muscle attachments of the forearm (anterior and posterior views).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.6

Muscles of Forearm

Muscle	Origin	Insertion	Action	Innervation
Superficial Flexors				
Pronator teres	Medial epicondyle and coronoid	Midlateral radius	Pronating, flexing forearm	Median nerve
Flexor carpi radialis	Medial epicondyle	Second and third metacarpal bases	Flexing wrist	Median nerve
Palmaris longus	Medial epicondyle	Palmar aponeurosis	Flexing wrist	Median nerve
Flexor carpi ulnaris	Medial epicondyle and posterior ulna	Pisiform	Flexing wrist	Ulnar nerve
Flexor digitorum superficialis	Medial epicondyle, proximal anterior ulna,	Base of middle phalanges	Flexing PIP joint	Median nerve

	and anterior radius			
Deep Flexors				
Flexor digitorum profundus	Anterior and medial ulna	Base of distal phalanges	Flexing DIP joint	Median–anterior interosseous/ulnar nerves
Flexor pollicis longus	Anterior and lateral radius	Base of distal phalanges	Flexing IP joint, thumb	Median–anterior interosseous nerve
Pronator quadratus	Distal ulna	Volar radius	Pronating hand	Median–anterior interosseous nerve
Superficial Extensors				
Brachioradialis	Lateral supracondylar humerus	Lateral distal radius	Flexing forearm	Radial nerve
Extensor carpi radialis longus	Lateral supracondylar humerus	Second metacarpal base	Extending wrist	Radial nerve
Extensor carpi radialis brevis	Lateral epicondyle of humerus	Third metacarpal base	Extending wrist	Radial nerve
Anconeus	Lateral epicondyle of humerus	Proximal dorsal ulna	Extending forearm	Radial nerve
Extensor digitorum	Lateral epicondyle of humerus	Extensor aponeurosis	Extending digits	Radial–posterior interosseous nerve
Extensor digiti minimi	Common extensor tendon	Small finger extensor expansion over proximal phalanx	Extending small finger	Radial–posterior interosseous nerve
Extensor carpi ulnaris	Lateral epicondyle of humerus	Fifth metacarpal base	Extending/adducting hand	Radial–posterior interosseous nerve
Deep Extensors				
Supinator	Lateral epicondyle of humerus, ulna	Dorsolateral radius	Supinating forearm	Radial–posterior interosseous nerve
Abductor	Dorsal	First	Abducting/extending	Radial–posterior

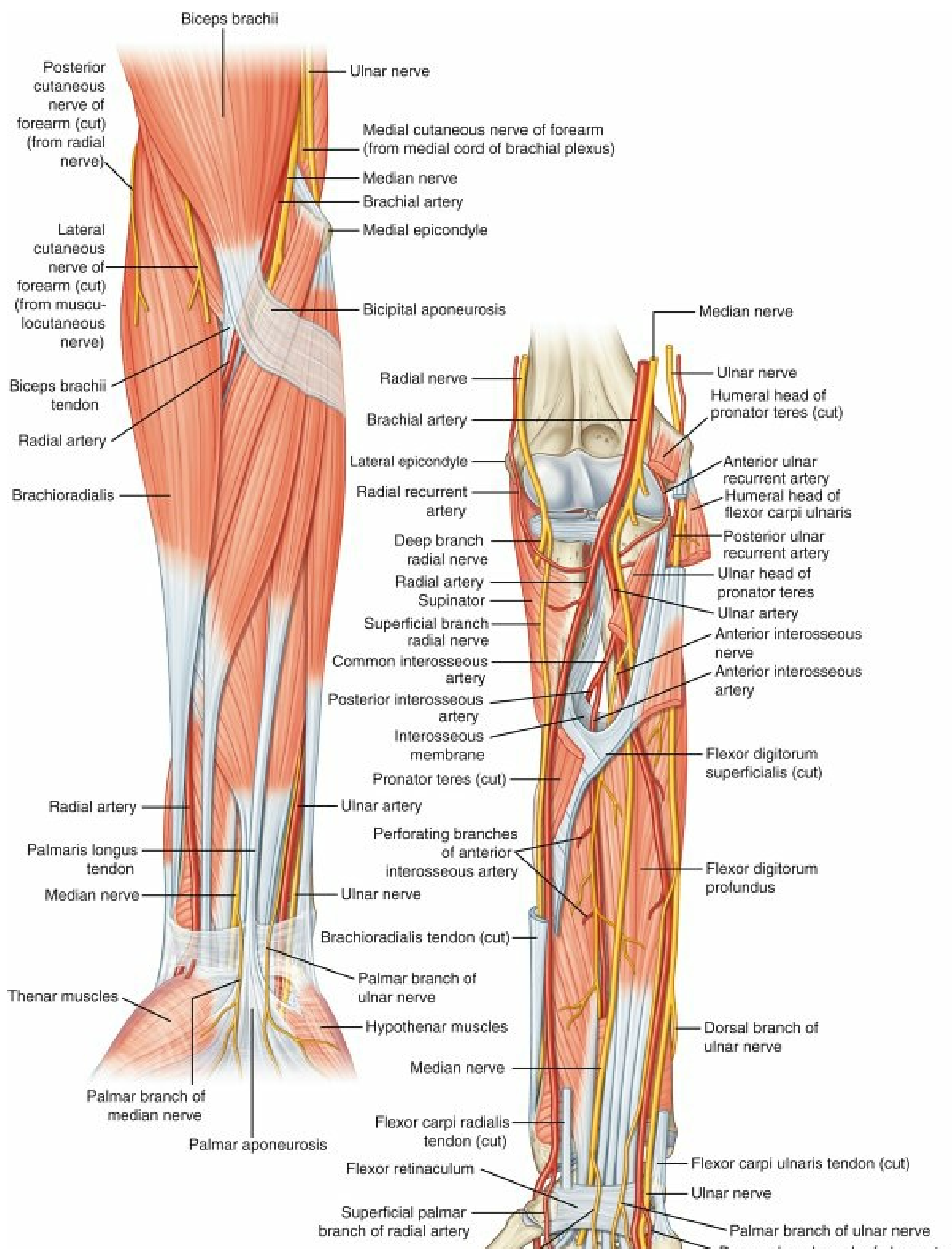
pollicis longus	ulna/radius	metacarpal base	thumb	interosseous nerve
Extensor pollicis brevis	Dorsal radius	Thumb proximal phalanx base	Extending thumb MCP joint	Radial–posterior interosseous nerve
Extensor pollicis longus	Dorsolateral ulna	Thumb dorsal phalanx base	Extending thumb IP joint	Radial–posterior interosseous nerve
Extensor indicis proprius	Dorsolateral ulna	Index finger extensor apparatus (ulnarly)	Extending index finger	Radial–posterior interosseous nerve

- Carpometacarpal (CMC) joints
  - Thumb CMC joint
    - Highly mobile saddle-shaped joint
    - Supported by a capsule and radial, palmar, and dorsal CMC ligaments
  - Finger CMC joints
    - Gliding joints with capsules, dorsal CMC ligaments (strongest), palmar CMC ligaments, and interosseous CMC ligaments
- Metacarpophalangeal (MCP) joints
  - Palmar (volar plate), collateral, and deep transverse metacarpal ligaments
  - Cam mechanism (collateral ligaments tighten with MCP joint flexion)
- Interphalangeal (IP) joints
  - Hinge joints with capsules and obliquely oriented collateral ligaments

▪ **Muscles of the hand (** Fig. 2.10, Table 2.11)

- Extensor tendon anatomy
  - Extensor compartments of wrist: formed by the extensor retinaculum over dorsal wrist (Fig. 2.11, Table 2.12)
    - Anatomic snuffbox is bordered by tendons of the first and third dorsal wrist compartments. Extensor pollicis brevis (EPB) tendon serves as the radial snuffbox border, extensor pollicis longus (EPL) tendon as the ulnar border.
  - Extensor mechanism anatomy/intrinsic apparatus
    - Complex arrangement of structures that surround digits (Fig. 2.12, Table 2.13)
- Flexor tendon anatomy

- Carpal tunnel (Fig. 2.13)
    - Borders of the carpal tunnel listed in Table 2.14
    - Transverse carpal ligament (TCL): attaches radially to the scaphoid tuberosity and trapezial ridge and ulnarly to the hook of the hamate and pisiform
        - Divided in carpal tunnel release
    - Contains the median nerve and nine tendons (one flexor pollicis longus [FPL], four FDS, and four flexor digitorum profundus [FDP])
    - **FDS to the middle and ring fingers are volar to FDS to index and small fingers.**
    - Decreases in volume with wrist flexion



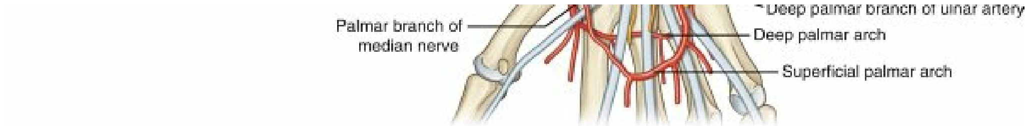


FIG. 2.7 Volar flexors (superficial and deep).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

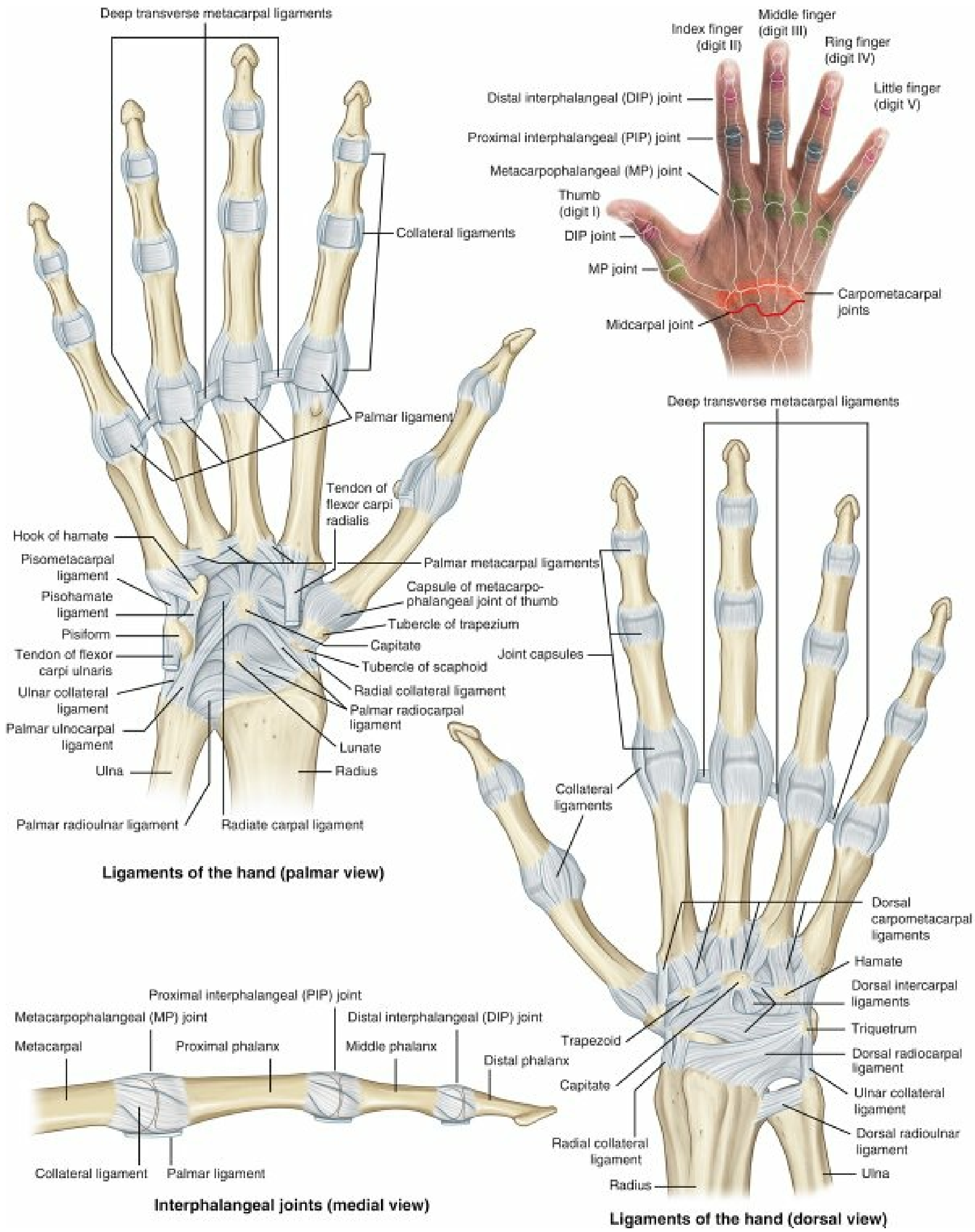


FIG. 2.8 Ligaments of the hand and interphalangeal joints.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.7

Carpal Bone Features

Carpal Bone	Distinctive Features	NoteS
Scaphoid	Tubercle (TCL, APB), waist, proximal and distal poles	• 75% covered by articular cartilage • Retrograde blood supply from dorsal carpal branch of radial artery
Lunate	Half moon shaped	• Kienböck disease
Triquetrum	Pyramid shaped	
Pisiform	Spheroidal (TCL, FCU)	• In FCU tendon
Trapezium	FCR groove, tubercle (opponens, APB, FPB, TCL)	• May be excised to treat thumb CMC arthritis
Trapezoid	Wedge shaped	
Capitate	Largest bone, central location	
Hamate	Hook (TCL)	• Radial border of Guyon canal • Deep motor branch of ulnar nerve under hook

APB, Abductor pollicis brevis; *FPB*, flexor pollicis brevis.

Table 2.8

Metacarpal Bone Features

Metacarpal	Distinctive Features
I (thumb)	Short, stout; base is saddle shaped
II (index)	Longest, largest base; medial at base
III (middle)	Styloid process
IV (ring)	Small quadrilateral base, narrow shaft
V (small)	Tubercle at base (extensor carpi ulnaris)

Table 2.9

Extrinsic Ligaments of the Wrist

Dorsal	
Dorsal intercarpal (DIC)	Dorsal support to translation of midcarpal joint
Dorsal radiocarpal (DRC)	aka radiotriquetral Controls ulnar translation
Volar	
Radioscaphocapitate (RSC)	Supports scaphoid waist
Long radiolunate (LRL)	Strong tether to lunate displacement
Radioscapholunate (RSL)	Ligament of Testut (neurovascular conduit)
Short radiolunate (SRL)	Prevents dorsal lunate dislocation

Table 2.10

Triangular Fibrocartilage Complex

Component	Origin	Insertion
Dorsal and volar radioulnar ligament	Ulnar radius	Caput ulnae
Articular disc	Radius/ulna	Triquetrum
Prestyloid recess	Disc	Meniscus homologue
Meniscus homologue	Ulna/disc	Triquetrum/ulnar collateral ligament
Ulnar collateral ligament	Ulna	Fifth metacarpal

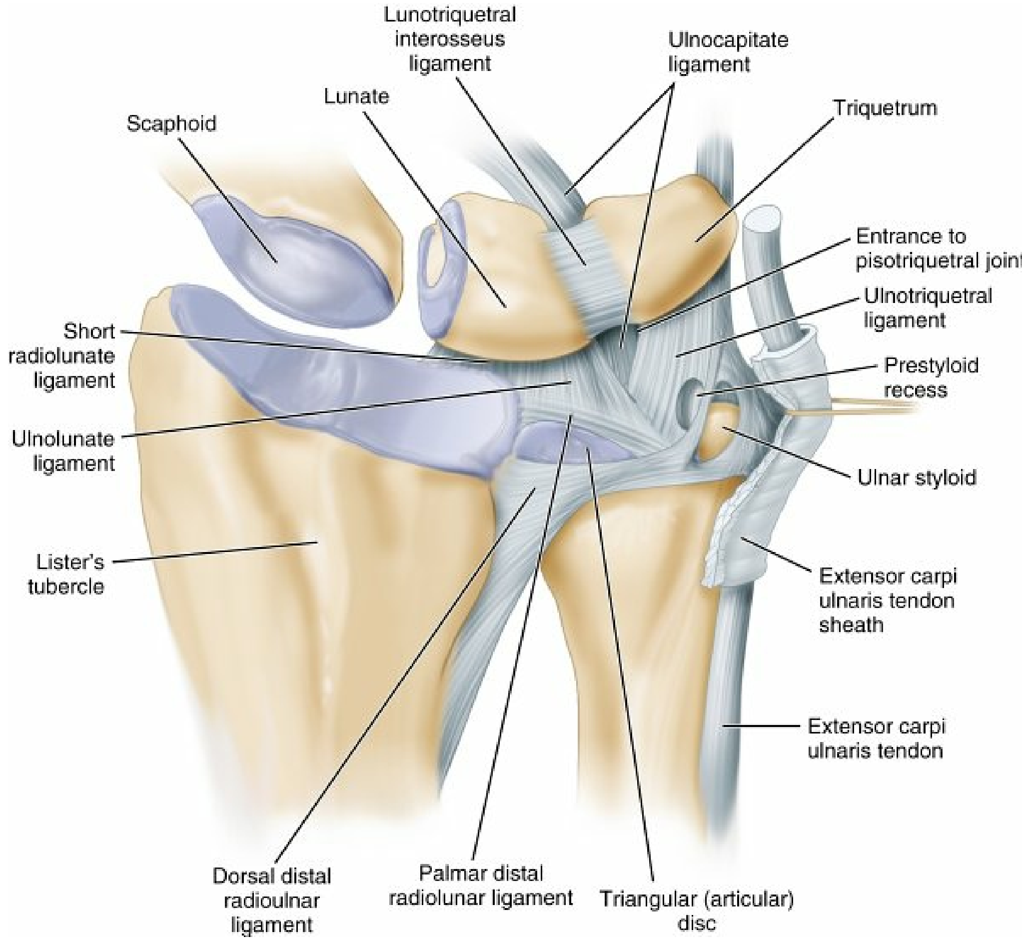


FIG. 2.9 Triangular fibrocartilage complex.

From Miller MD, Thompson SR, editors: *DeLee and Drez's orthopaedic sports medicine: principles and practice,* ed 4, Philadelphia, 2014, Saunders.

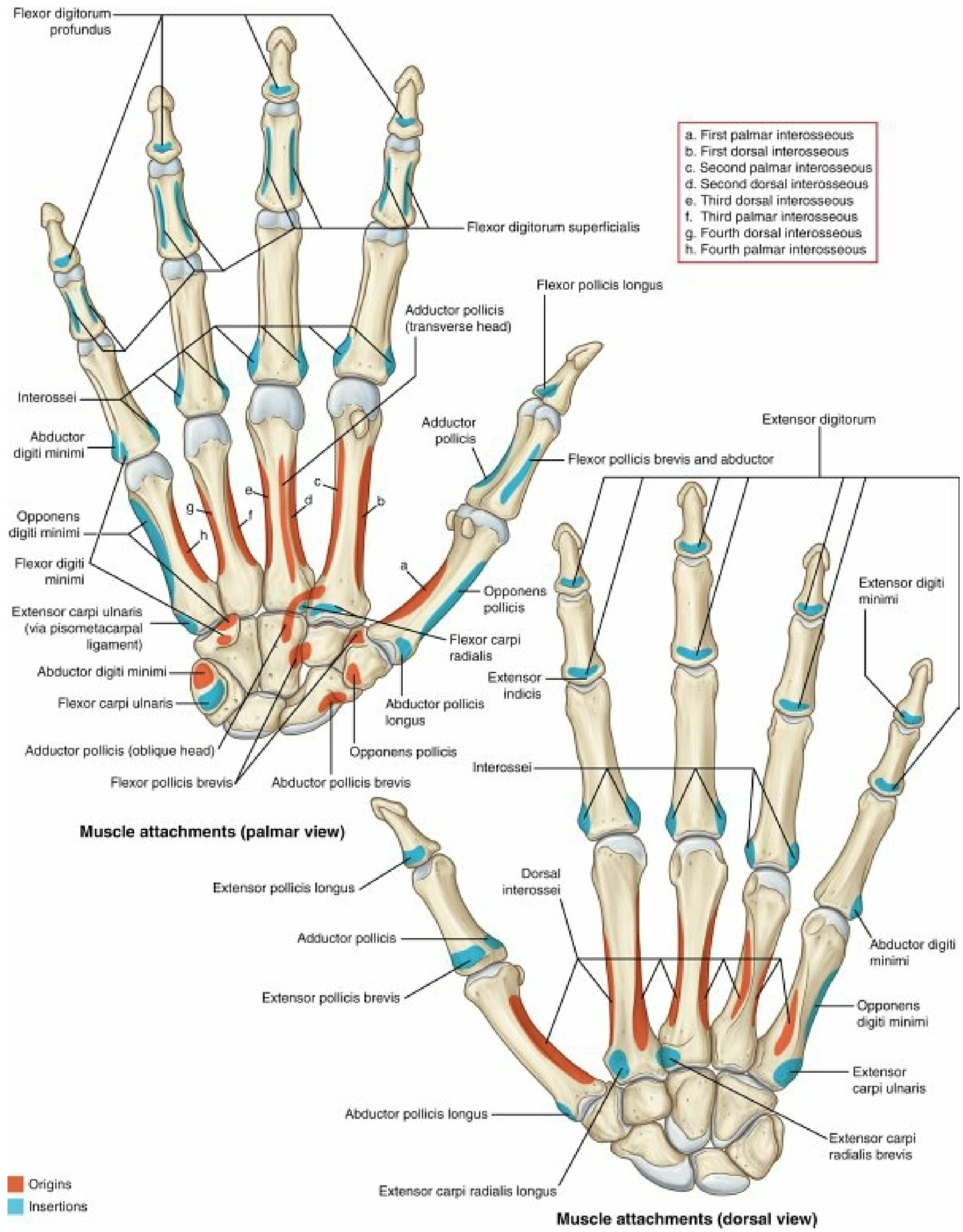


FIG. 2.10 Muscle attachments (planar and dorsal views).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.11

Muscles of the Hand

Muscle	Origin	Insertion	Action	Innervation
Thenar Muscles				
Abductor pollicis brevis	Scaphoid, trapezoid	Base of proximal phalanx, radial side	Abducting thumb	Median nerve
Opponens pollicis	Trapezium	Thumb metacarpal	Abducting, flexing, rotating (medially)	Median nerve
Flexor pollicis brevis	Trapezium, capitate	Base of proximal phalanx, radial side	Flexing MCP joint	Median, ulnar nerves
Adductor pollicis	Capitate, second and third metacarpals	Base of proximal phalanx, ulnar side	Adducting thumb	Ulnar nerve
Hypothenar Muscles				
Palmaris brevis	TCL, palmar aponeurosis	Ulnar palm	Retracting skin	Ulnar nerve
Abductor digiti minimi	Pisiform	Base of proximal phalanx, ulnar side	Abducting small finger	Ulnar nerve
Flexor digiti minimi brevis	Hamate, TCL	Base of proximal phalanx, ulnar side	Flexing MCP joint	Ulnar nerve
Opponens digiti minimi	Hamate, TCL	Small-finger metacarpal	Abducting, flexing, rotating (laterally)	Ulnar nerve
Intrinsic Muscles				
Lumbrical	Flexor digitorum profundus	Lateral bands (radial)	Extending PIP joint	Median, ulnar nerves
Dorsal interosseous	Adjacent metacarpals	Proximal phalanx base/extensor apparatus	Abducting, flexing MCP joint	Ulnar nerve
Volar interosseous	Adjacent metacarpals	Proximal phalanx base/extensor apparatus	Adducting, flexing MCP joint	Ulnar nerve

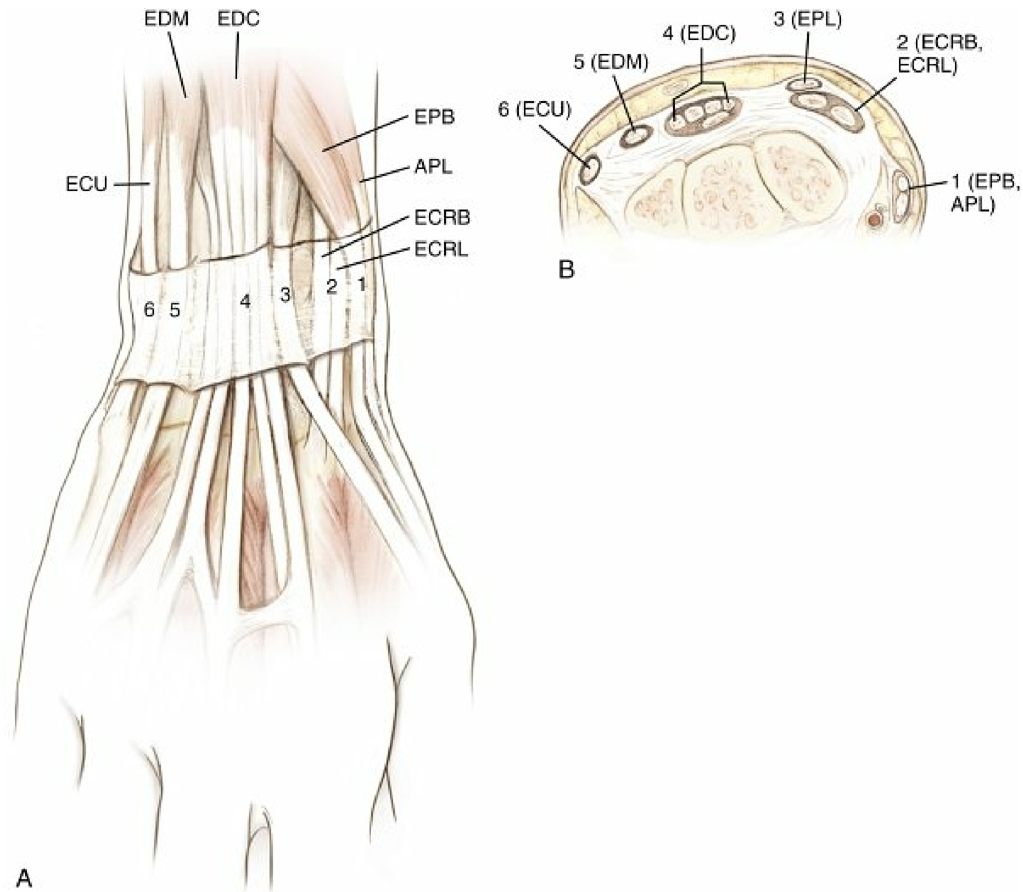


FIG. 2.11 Extensor compartments of the wrist (1 to 6) (see Table 2.12). *APL,* Abductor pollicis longus; *ECRB,* extensor carpi radialis brevis; *ECRL,* extensor carpi radialis longus; *ECU,* extensor carpi ulnaris; *EDC,* extensor digitorum communis; *EDM,* extensor digiti minimi; *EPB,* extensor pollicis brevis; *EPL,* extensor pollicis longus. Modified from Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figure HW-6.

- Guyon canal
- Contains ulnar nerve and artery
    - Borders: flexor retinaculum (deep), volar carpal ligament (superficial), pisiform (ulnar/proximal), hook of hamate (radial/distal)
- Flexor tendon sheath (Fig. 2.14)
    - Covers flexor tendons, protecting and nourishing tendons (vincula)
    - Five anular pulleys (A1–5) with three intervening cruciate attachments (C1–3)

Table 2.12

Extensor Compartments of Wrist

CompartMent	Contents	NOTES	Pathologic CONDITIO
I	Abductor pollicis longus	• EPB tendon ulnar to APL tendon	De Quervain tenosyno

	(APL), extensor pollicis brevis (EPB)	• APL frequently has multiple tendon slips, which should be addressed during release for de Quervain tenosynovitis).	
II	Extensor carpi radialis longus (ECRL), brevis	• ECRL radial to ECRB • EPL tendon ulnar to ECRB tendon at the wrist level.	Extensor ten (intersect syndrom
III	Extensor pollicis longus (EPL)	• Ulnar to Lister tubercle • Tested by placing patient's palm flat on table and lifting thumb.	Rupture Lister tuber (after fractu Drumme tendi of the
IV	Extensor digitorum communis (EDC), extensor indicis proprius (EIP)	• EIP ulnar to index EDC • EIP most distal muscle belly • Small EDC present in only 25% • Sensory PIN in floor	Extensor tenosyno
V	Extensor digiti minimi (EDM)	• EDM ulnar to small EDC	Rupture (rheumat arthritis: Vaughn-Jackson syndrom
VI	Extensor carpi ulnaris (ECU)	• ECU subsheath part of TFCC	Snapping at styloid

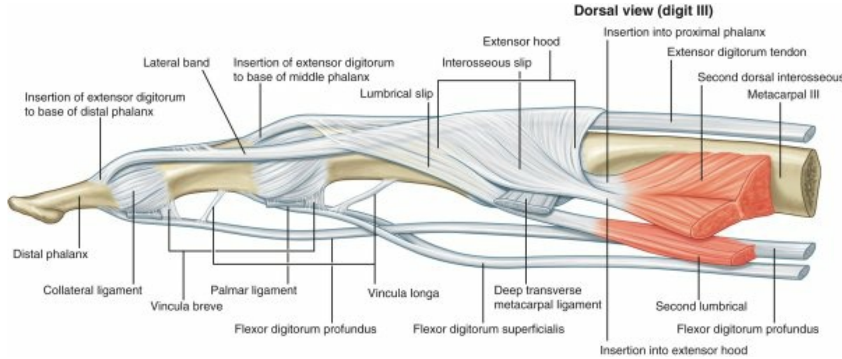


FIG. 2.12 Extensor apparatus.
From Drake RL et al, editors: *Gray's atlas of anatomy*, ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.13

Extensor Mechanism of Hand

STRUCTURE	ATTACHMENTS	SIGNIFICANCE
Sagittal bands	Covers MCP joint	Allows MCP extension
Transverse (sagittal)	Volar plate fibers	Allows MCP flexion (interossei)
Lateral bands	Covers PIP joint	Allows PIP extension (lumbrical muscles)
Oblique retinacular ligament (Landsmeer)	A4 pulley, terminal tendon	Allows DIP extension (passive)

- A2 and A4 pulleys originate from bone, whereas A1, A3, and A5 pulleys originate from the palmar plates of the metacarpal, proximal IP (PIP), and distal IP (DIP) joints.
- A2 pulley, overlying the proximal phalanx, is the most critical to function, followed by A4, which covers the middle phalanx.
- A1 pulley is involved in trigger digits.

▪ **Nerves of the upper extremity**

□ Brachial plexus (Fig. 2.15)

- Formed from the ventral primary rami of C5 to T1
- Exits neck between the anterior and middle scalene muscles
- Dorsal rami of C5 to T1 innervate the dorsal neck musculature and skin.
- From proximal to distal: roots, trunks, divisions, cords, and branches (mnemonic: "*R*eal *T*exans *d*rink *c*old *b*eer").
    - Five roots (C5–T1), although contributions from C4 (pre-fixed) and T2 (post-fixed) can be small

    - Dorsal scapular nerve (C5): to levator scapula, rhomboid major/minor
    - Long thoracic nerve (C5–7): to serratus anterior
- Three trunks (upper, middle, lower)
    - Suprascapular nerve (upper trunk, C5, 6)
    - Nerve to subclavius (upper trunk, C5, 6)

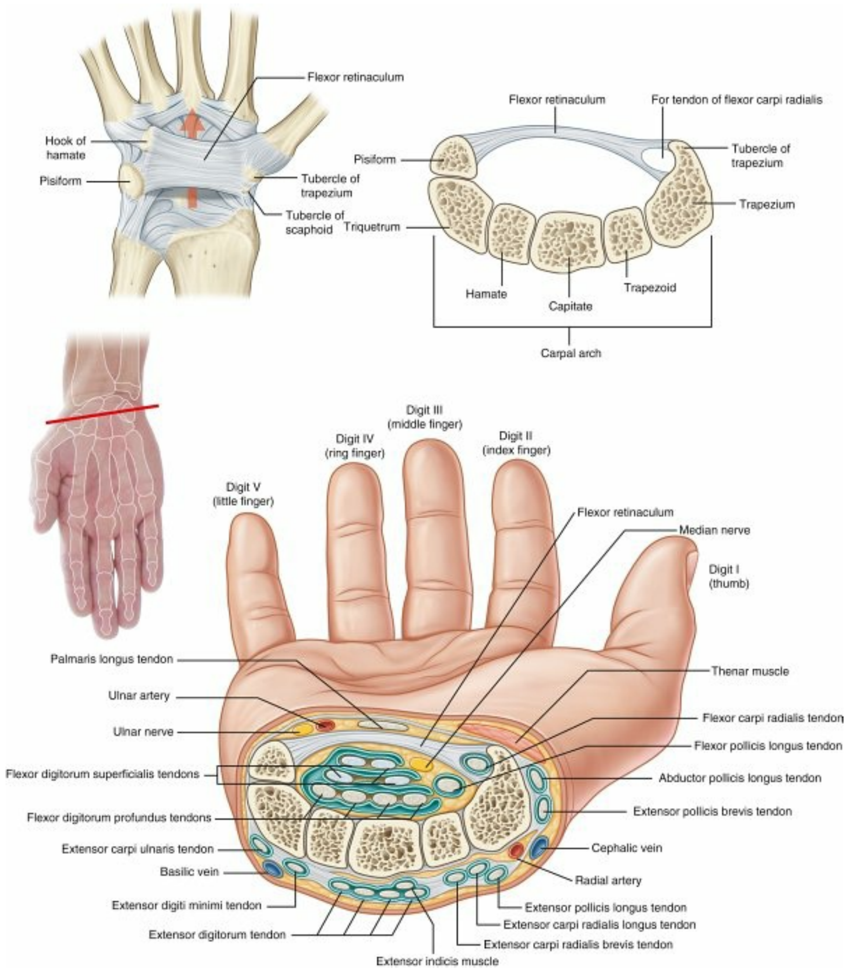


FIG. 2.13 Anatomy of the carpal tunnel.
From Drake RL et al, editors: *Gray's atlas of anatomy*, ed 2, Philadelphia, 2015, Churchill Livingstone.

- Six divisions (anterior and posterior; two limbs from each trunk)
    - No terminal branches at this level
- Three cords (lateral, medial, and posterior) named for their anatomic relationship to the axillary artery (Table 2.15)

Table 2.14

Carpal Tunnel Borders

BORDER	STRUCTURES
Roof	Transverse carpal ligament
Floor	Carpal bones
Radial	Scaphoid tubercle/trapezium
Ulnar	Hook of hamate

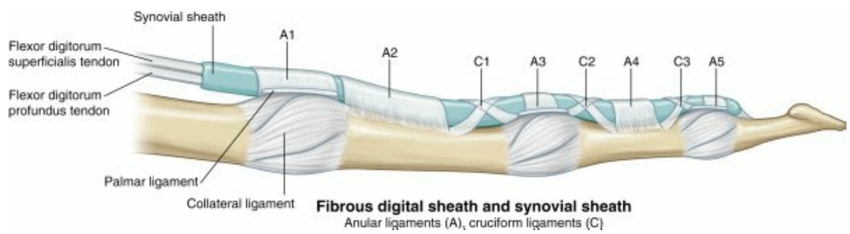


FIG. 2.14 Flexor tendon sheath.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

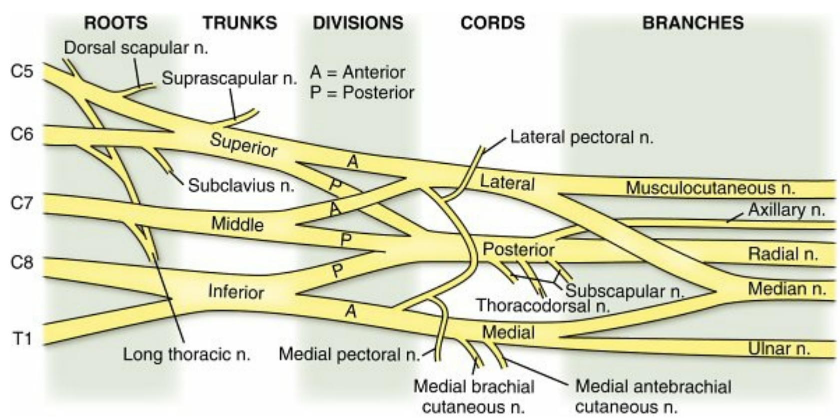


FIG. 2.15 Brachial plexus.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figure SA-7.

- Main terminal branches (musculocutaneous, axillary, radial, median, ulnar)
- Other terminal branches
    - Lateral cord
        - Lateral pectoral nerve (C5–7): to pectoralis major
    - Posterior cord
        - Upper subscapular nerve (C5, 6): to

subscapularis
            - Lower subscapular nerve (C5, 6): to subscapularis, teres major
            - Thoracodorsal nerve (C6–8): to latissimus dorsi
        - Medial cord
            - Medial pectoral nerve (C8, T1): to pectoralis minor/major
            - Medial brachial cutaneous nerve (T1)
            - Medial antebrachial cutaneous nerve (C8, T1)
        - **All minor medial and lateral cord branches have *medial* or *lateral* in their names. Posterior cord branches do not.**
    - Preclavicular branches (from roots and upper trunk)
        - Dorsal scapular nerve
        - Long thoracic nerve
        - Suprascapular nerve
        - Nerve to the subclavius
    - **Innervation of all rotator cuff muscles is derived from C5 and C6 of the brachial plexus (** Table 2.16).
- □ Brachial plexus injury
    - Preganglionic brachial plexus injuries
        - Proximal to dorsal root ganglion: CNS injury with little potential for recovery
        - Preclavicular nerve involvement
            - Medial scapular winging (long thoracic nerve to serratus anterior), rhomboid paralysis (dorsal scapular nerve), Horner syndrome (disruption of stellate ganglion/sympathetic chain at C8, T1), rotator cuff dysfunction (suprascapular nerve to

supraspinatus/infraspinatus), latissimus dorsi paralysis (thoracodorsal nerve), elevated hemidiaphragm (phrenic nerve)
        - Nerve conduction study: absent motor but intact sensory conduction
    - Postganglionic brachial plexus injuries
        - Less preclavicular nerve involvement (no scapular winging, rhomboid paralysis, etc.)
        - Characteristic obstetric brachial plexus palsies (Table 2.17)
- Scapular winging
    - Medial winging: long thoracic nerve (C5–7) injury leading to serratus anterior dysfunction
        - Superior elevation with the scapula translated medially and the inferior angle rotated medially
    - Lateral winging: spinal accessory nerve (cranial nerve XI) injury leading to trapezius dysfunction
        - Shoulder depression with the scapula translated laterally and the inferior angle rotated laterally because of the unopposed pull of the serratus anterior
        - **Usually a history of ipsilateral neck surgery (i.e., thyroidectomy)**
- Major brachial plexus branches (Table 2.18)
    - Suprascapular nerve (upper trunk, C5, 6)

Table 2.15

Brachial Plexus

BRANCH	ORIGIN	ROOTS	MOTOR INNERVATION	SENSORY INNERVATION
Dorsal scapular	C5 root	C5	Rhomboid major, rhomboid minor	
Long thoracic	C–7 roots	C5–7	Serratus anterior	
Suprascapular	Superior trunk	C5, 6	Supraspinatus, infraspinatus	
Nerve to subclavius	Superior trunk	C5, 6	Subclavius	
Lateral pectoral	Lateral cord	C5–7	Pectoralis major	
Upper subscapular	Posterior cord	C5, 6	Subscapularis	

Lower subscapular	Posterior cord	C5, 6	Subscapularis, teres major	
Thoracodorsal	Posterior cord	C6–8	Latissimus dorsi	
Medial pectoral	Medial cord	C8, T1	Pectoralis major, pectoralis minor	
Medial brachial cutaneous	Medial cord	C8, T1		Medial arm
Medial antebrachial cutaneous	Medial cord	C8, T1		Medial forearm
Musculocutaneous	Lateral cord	C5–7	All muscles in the anterior compartment of the arm	Lateral forearm
Axillary	Posterior cord	C5, 6	Deltoid, teres minor	Lateral shoulder
Radial	Posterior cord	C5–T1	All muscles in the posterior compartments of arm and forearm	Posterior arm/forearm, dorsum of radial hand
Median	Medial/lateral cords	C5–T1	All muscles in the anterior compartment of the forearm (except FCU and ulnar FDP), opponens pollicis, FPB, APB, and two lateral lumbrical muscles	Radial 3½ digits, radial palm
Ulnar	Medial cord	C8, T1	FCU, ulnar FDP, all intrinsic muscles of the hand (except opponens pollicis, FPB, APB, and two lateral	Ulnar 1½ digits, ulnar palm/wrist

			lumbricals)	

Table 2.16

Rotator Cuff Muscle Innervation

Muscles Innervated	Nerves
External Rotators	
Supraspinatus	Suprascapular nerve (C5, 6)
Infraspinatus	Suprascapular nerve (C5, 6)
Teres minor	Axillary nerve (C5, 6)
Internal Rotator	
Subscapularis	Upper (C5) and lower (C5, 6) subscapular nerves

Table 2.17

Obstetric Brachial Plexus Palsies

Palsy Type	Roots	Deficit	Prognosis
Erb-Duchenne	C5, 6	Weakness of deltoid, rotator cuff, elbow flexors, and wrist and hand extensors “Waiter’s tip”	Best
Klumpke	C8, T1	Weakness of wrist flexors and intrinsic apparatus, Horner syndrome	Poor
Total plexus	C5–T1	Flaccid arm	Worst

Table 2.18

Major Brachial Plexus Branches

Nerves	Muscles Innervated
Musculocutaneous (lateral cord)	Coracobrachialis, biceps, brachialis
Axillary (posterior cord)	Deltoid, teres minor
Radial Nerve	
Radial (posterior cord)	Triceps, brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis
Posterior interosseous	Supinator, extensor carpi ulnaris, extensor digitorum, extensor digiti minimi, abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, extensor indicis proprius
Median Nerve	
Median (medial and lateral cord)	Pronator teres, flexor carpi radialis, palmaris longus, flexor digitorum superficialis, abductor pollicis brevis, superficial head of flexor pollicis brevis, opponens pollicis, first and second lumbrical muscles
Anterior interosseous	Flexor digitorum profundus (first and second), flexor pollicis longus, pronator quadratus
Ulnar Nerve	
Ulnar (medial cord)	Flexor carpi ulnaris, flexor digitorum profundus (third and fourth), pollicis brevis, abductor digiti minimi, opponens digiti minimi, flexor digiti minimi, third and fourth lumbrical muscles, interossei, adductor pollicis, deep head of flexor pollicis brevis

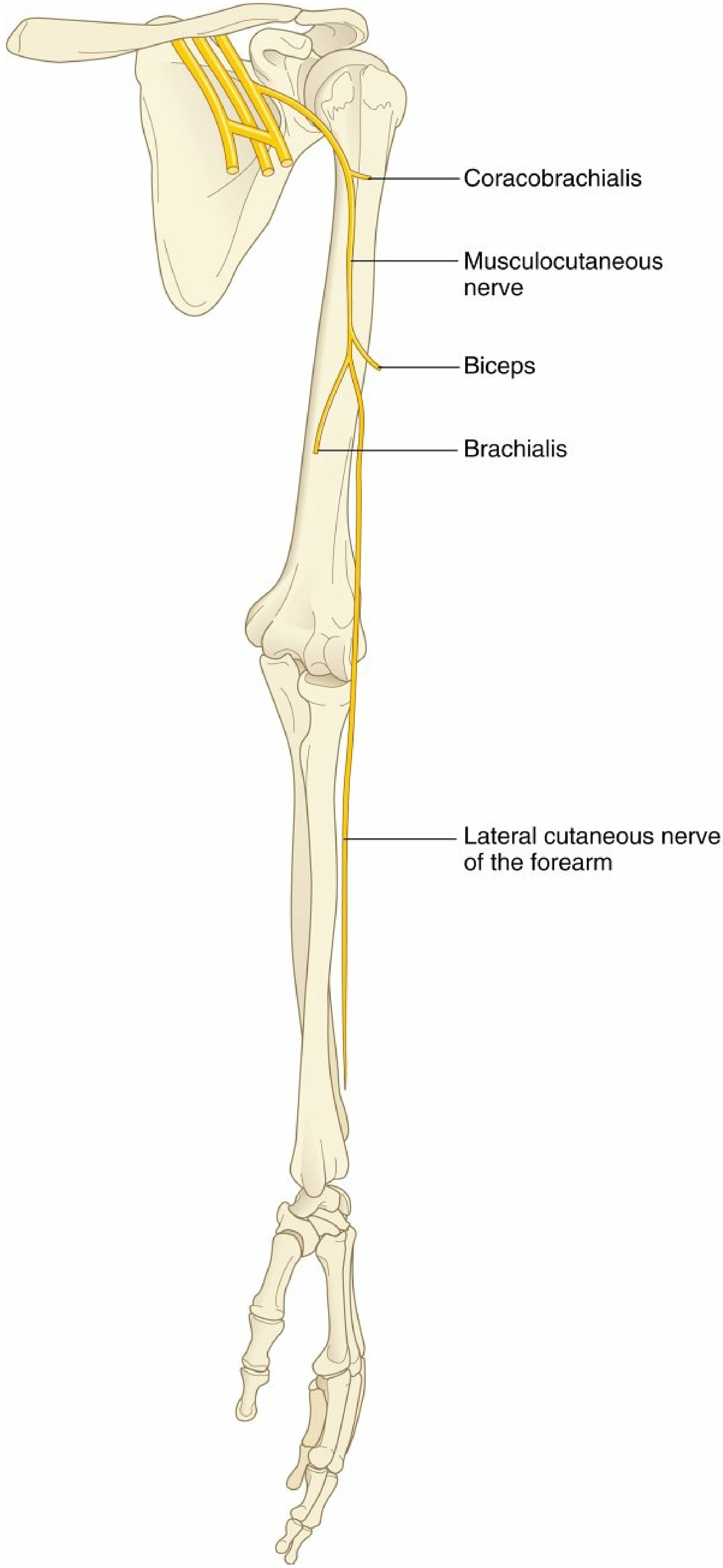
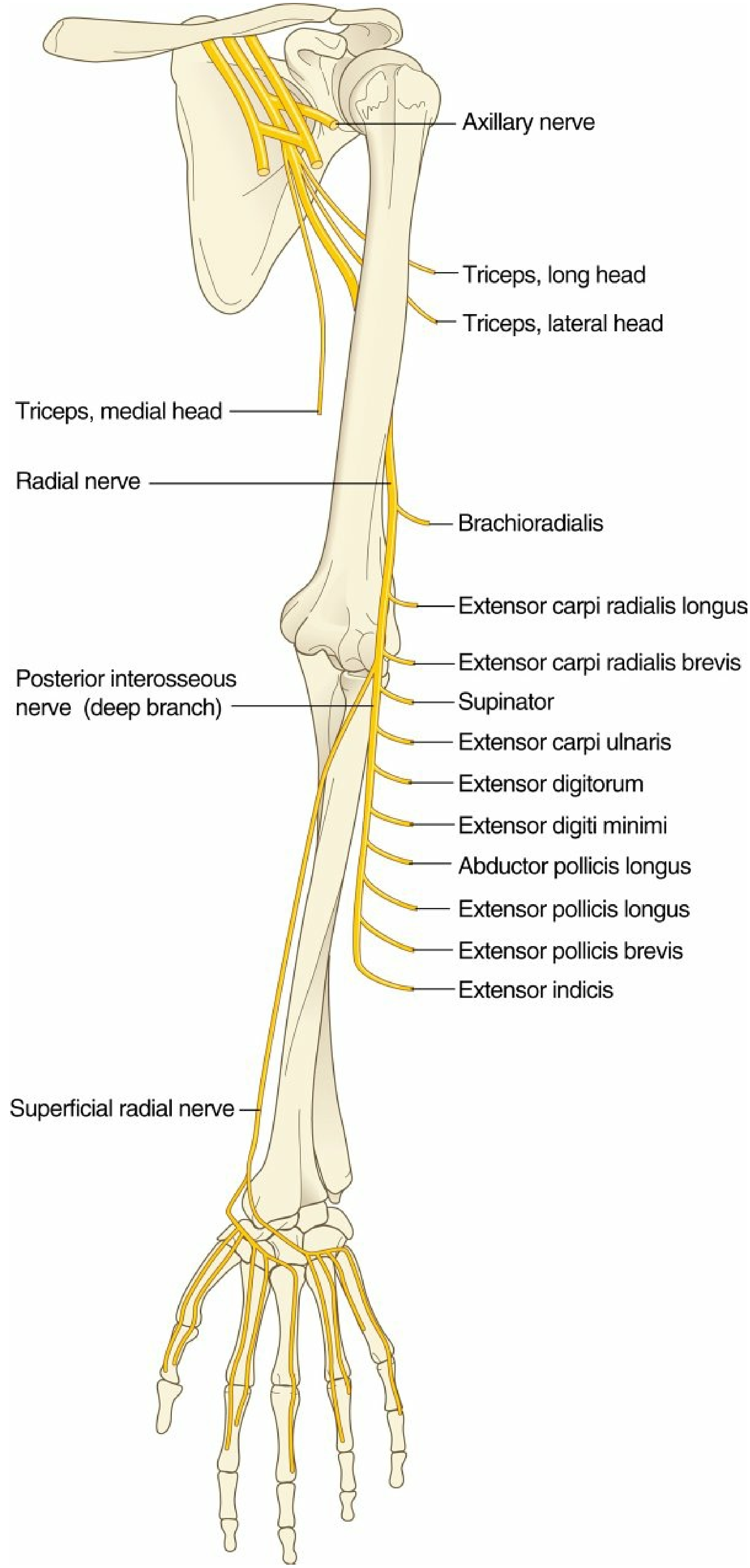

Coracobrachialis
Musculocutaneous nerve
Biceps
Brachialis
Lateral cutaneous nerve of the forearm

FIG. 2.16 Nerves in shoulder and arm (lateral cord).
From Drake RL et al, editors: *Gray's atlas of anatomy*, ed 2, Philadelphia, 2015, Churchill Livingstone.

    - Passes through scapular notch beneath superior transverse scapular ligament, sending a branch to the supraspinatus before traveling through the spinoglenoid notch to innervate the infraspinatus
- Musculocutaneous nerve (lateral cord, C5–7) (Fig. 2.16)
    - Pierces the coracobrachialis 5 to 8 cm distal to the coracoid
    - Branches supply the coracobrachialis, biceps, and brachialis.
    - Gives off a sensory branch to the elbow joint before it becomes the lateral antebrachial cutaneous nerve of the forearm, which is located deep to the cephalic vein



Axillary nerve
Triceps, long head
Triceps, lateral head
Triceps, medial head
Radial nerve
Brachioradialis
Extensor carpi radialis longus
Extensor carpi radialis brevis
Posterior interosseous nerve (deep branch)
Supinator
Extensor carpi ulnaris
Extensor digitorum
Extensor digiti minimi
Abductor pollicis longus
Extensor pollicis longus
Extensor pollicis brevis
Extensor indicis
Superficial radial nerve

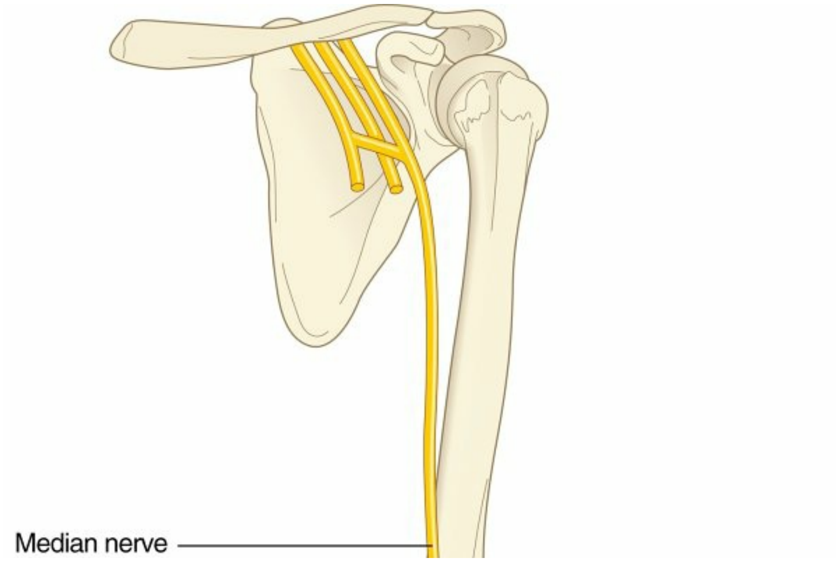
FIG. 2.17 Nerves in shoulder and arm (posterior cord).
From Drake RL et al, editors: *Gray's atlas of anatomy*, ed 2, Philadelphia, 2015, Churchill Livingstone.

- Axillary nerve (posterior cord, C5, 6)
    - **Passes anterior to subscapularis muscle and inferior to shoulder capsule, traveling from anterior to posterior through quadrangular space**
    - Anterior branch supplying deltoid and skin over lateral shoulder passes around humerus in deep deltoid fascia approximately 5–7 cm distal to acromion.
    - Posterior branch supplies teres minor and posterior deltoid.
- Radial nerve (posterior cord, C5–T1) (Fig. 2.17)
    - Passes through triangular interval and then spirals around the humerus (medial to lateral) in the spiral groove. Approximately 20 cm from medial epicondyle and 14 cm from lateral epicondyle
    - Emerges on the lateral side of the arm after piercing the lateral intermuscular septum approximately 7.5 cm above the trochlea between the brachialis and brachioradialis anterior to the lateral epicondyle (where it supplies the anconeus muscle)
    - Passes anterior to the lateral epicondyle between the brachialis and brachioradialis and divides into the superficial and deep (posterior interosseous nerve [PIN]) branches approximately 1–3 cm distal to lateral epicondyle
        - **PIN splits the supinator and supplies all of the extensor muscles except the mobile wad (brachioradialis, ECRB, ECRL).**
            - Terminal sensory branch to dorsal wrist joint in floor of fourth extensor compartment
        - **Superficial branch of the radial nerve emerges through antebrachial fascia approximately 6–9 cm proximal to the radial styloid. Runs between the brachioradialis and ERCL to supply**

sensation to the dorsal radial surface distal forearm and hand.

- Median nerve (medial and lateral cords, C5–T1) (Fig. 2.18)
    - Accompanies brachial artery in the arm, crossing it during its course (lateral to medial) approximately 15 cm from the medial epicondyle
    - Supplies some branches to the elbow joint but has no branches in the arm itself
    - Medial to brachial artery and superficial to brachialis muscle as it passes
    - In forearm, the median nerve splits the two heads of the pronator teres and then runs between the FDS and FDP. Supplies all the superficial flexor muscles of the forearm except the FCU.
    - **Anterior interosseous nerve branches 4 cm distal to elbow and runs between the FPL and FDP; supplies all the deep flexors except the ulnar half of the FDP. Terminates in the pronator quadratus (PQ).**
    - Palmar cutaneous branch arises approximately 6 cm proximal to radial styloid and passes superficial to the flexor retinaculum to innervate the thenar skin.
    - Median nerve passes through the carpal tunnel between FDS and flexor carpi radialis (FCR) to supply the radial lumbricals, thenar musculature via a deep recurrent branch, and sensation to the volar aspect of thumb, index, long, and radial half of the ring fingers.
- Ulnar nerve (medial cord, C8, T1) (Fig. 2.19)
    - Posteromedial to brachial artery in upper arm and then passes posterior to the medial intermuscular septum at the arcade of Struthers (8–10 cm from medial epicondyle)
    - Crosses elbow posterior to medial epicondyle at elbow through the cubital tunnel
    - Cubital tunnel: Osborne ligament (roof), medial collateral ligament (MCL) (floor)
    - No branches in arm, but supplies articular branch to elbow joint
    - **Enters the forearm between the two heads of the FCU (humeral and ulnar)**
    - Runs between the FCU and FDP, innervating the

ulnar half of this muscle (FDP to ring and small fingers)



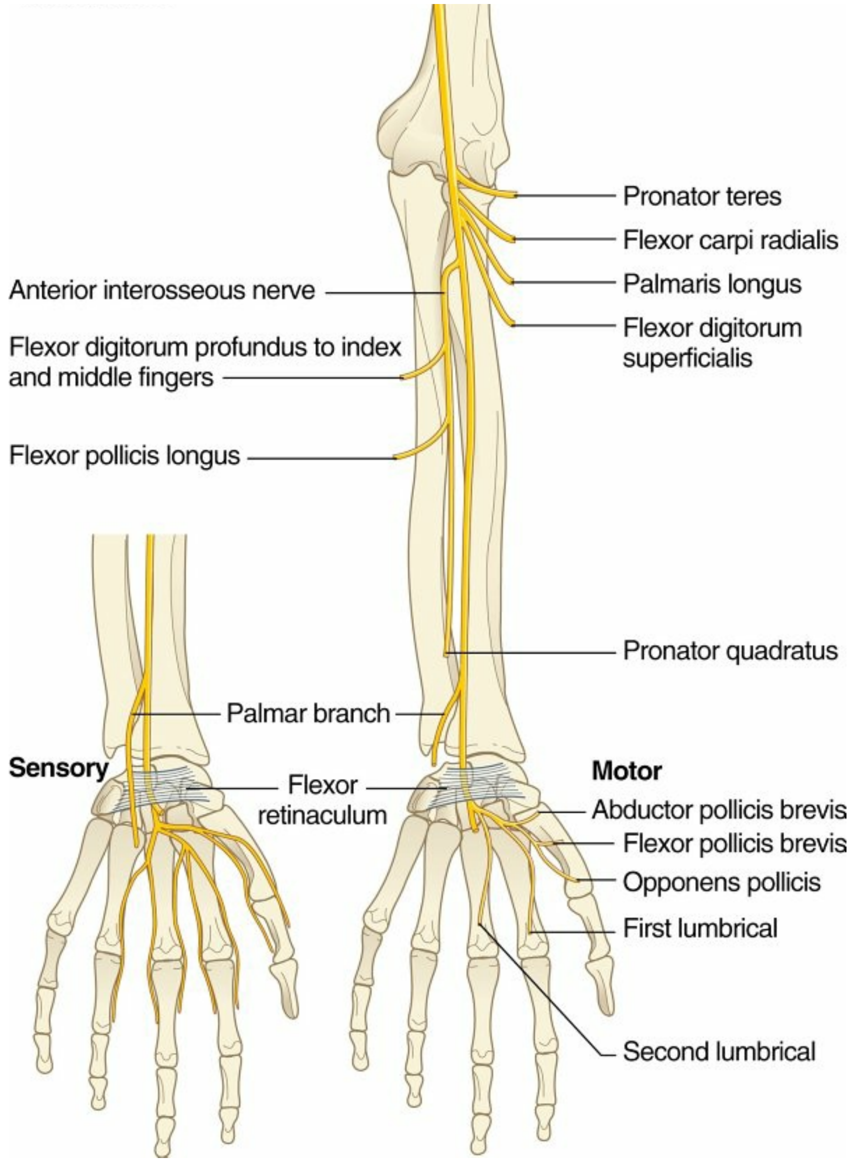


FIG. 2.18 Nerves in shoulder and arm (medial and lateral cords).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

- Runs radial to FCU at distal forearm and wrist
- Dorsal cutaneous nerve branches approximately 7 cm proximal to ulnar styloid and provides sensation to dorsoulnar forearm and wrist.
- Ulnar nerve enters hand superficial to TCL through Guyon canal. Divides into a superficial sensory branch and a deep motor branch.
    - Deep branch travels around the hook of the hamate between the abductor digiti minimi and flexor digiti minimi brevis, providing motor innervation to intrinsic muscles of hand.
    - Sensory branch supplies ulnar half of the ring and the small fingers.

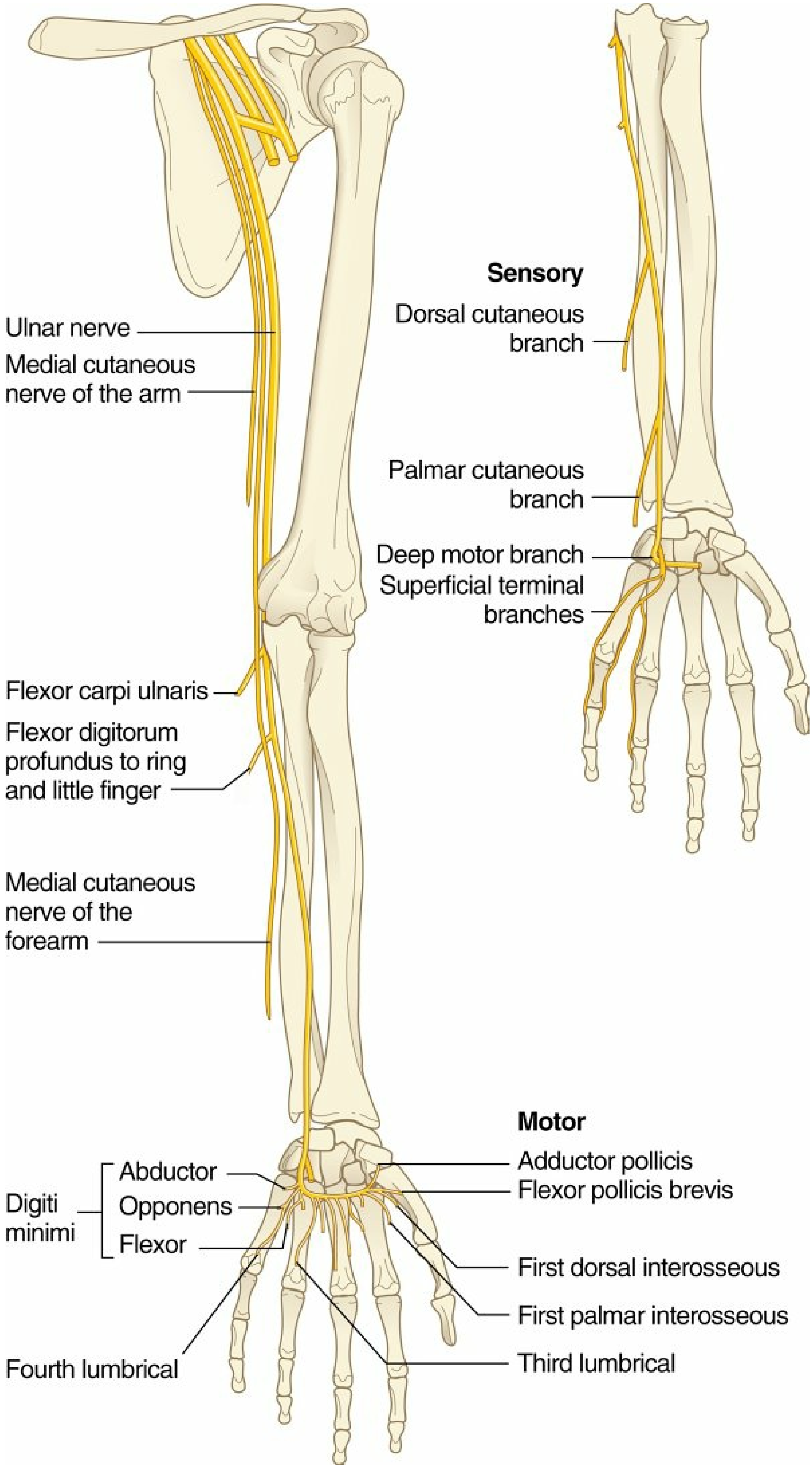

Sensory
Dorsal cutaneous branch
Palmar cutaneous branch
Deep motor branch
Superficial terminal branches
Ulnar nerve
Medial cutaneous nerve of the arm
Flexor carpi ulnaris
Flexor digitorum profundus to ring and little finger
Medial cutaneous nerve of the forearm
Motor
Digiti minimi
Abductor
Opponens
Flexor
Adductor pollicis
Flexor pollicis brevis
First dorsal interosseous
First palmar interosseous
Third lumbrical
Fourth lumbrical

FIG. 2.19 Nerve regions in shoulder and arm. (From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.)

- □ Cutaneous innervation to upper extremity (Figs. 2.20 through 2.22)
  - Supraclavicular nerve (C3 and C4) supplies the upper shoulder.
  - Axillary nerve supplies the shoulder joint and the overlying skin.
  - Medial, lateral, and dorsal brachial cutaneous nerves supply the balance of cutaneous innervation of the arm.
  - Lateral antebrachial cutaneous nerve: continuation of the musculocutaneous nerve that passes lateral to the cephalic vein after emerging laterally from between the biceps and brachialis at the elbow
  - Medial antebrachial cutaneous nerve: a branch from the medial cord of the brachial plexus
  - Posterior antebrachial cutaneous nerve: a branch of the radial nerve given off in the arm
  - Sensation to thumb
    - Provided by five branches: lateral antebrachial cutaneous nerve, superficial and dorsal digital branches of the radial nerve, and digital and palmar branches of the median nerve

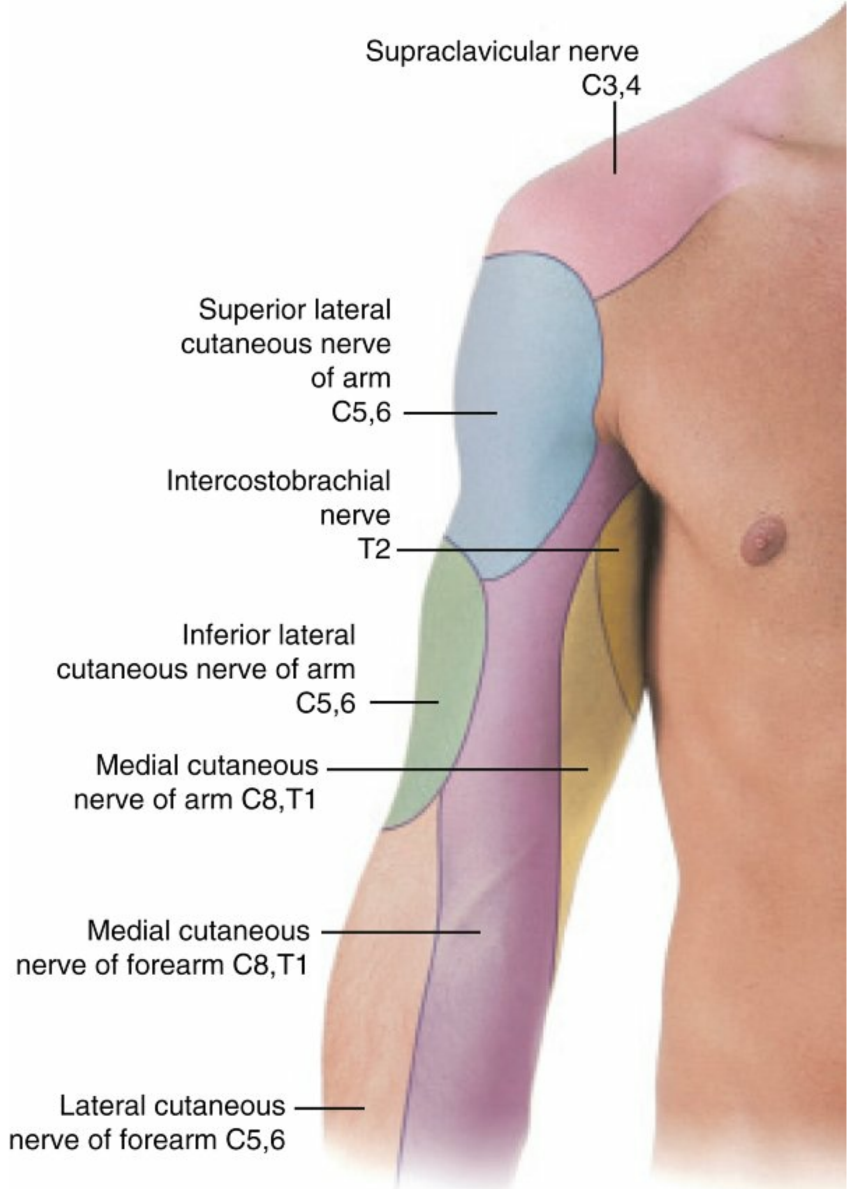


FIG. 2.20 Nerve regions in arm and hand.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

- Neuroanatomic relationships in the forearm are outlined in Table 2.19

□ Compressive neuropathies of the upper extremity are covered in the hand chapter.

▪ **Vascularity of the upper extremity** (Figs. 2.23 and 2.24)

□ Subclavian artery

- Left subclavian artery arises directly from the aorta; right subclavian artery arises from the brachiocephalic trunk.
- Emerges between anterior and middle scalene muscles and becomes the axillary artery at outer border of the first rib

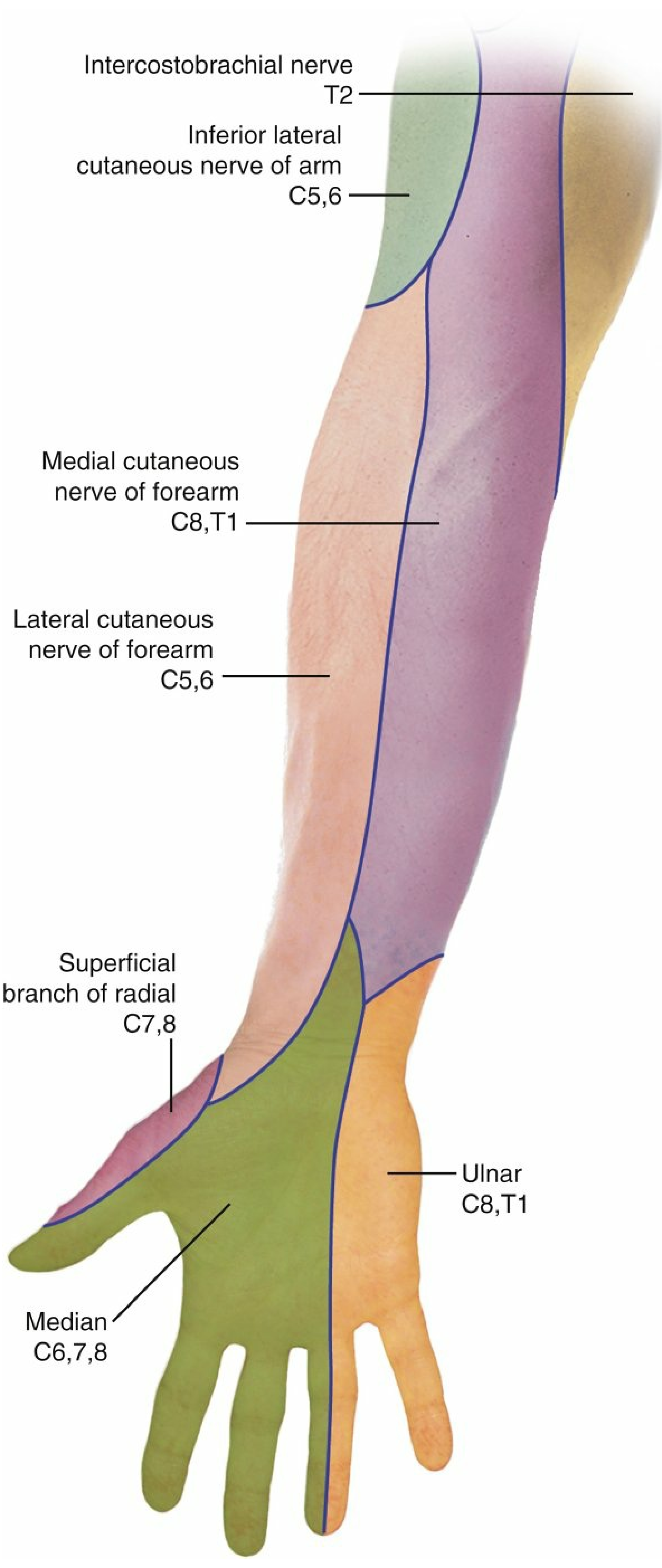
□ Axillary artery

- Divided into three parts on the basis of its physical relationship to pectoralis minor muscle (first part is medial to it, second is under it, and third is lateral to it)

- **Each part of the artery has as many branches as the number of that part (e.g., the second part has two branches: thoracoacromial and lateral thoracic)** (Table 2.20).
- Third part, at the origin of the anterior and posterior humeral circumflex arteries, is the most vulnerable to traumatic vascular injury.

□ Brachial artery

- Originates at the lower border of the tendon of the teres major and runs with the median nerve in the medial arm anterior to the intermuscular septum



Intercostobrachial nerve
T2
Inferior lateral
cutaneous nerve of arm
C5,6
Medial cutaneous
nerve of forearm
C8,T1
Lateral cutaneous
nerve of forearm
C5,6
Superficial
branch of radial
C7,8
Ulnar
C8,T1
Median
C6,7,8

FIG. 2.21 Nerve regions in arm and hand (anterior view). (From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.)

Table 2.19

Neuroanatomic Relationships in Forearm

Nerve	Relationship
Radial	Between brachialis and brachioradialis
Posterior interosseous	Splits supinator
Superficial radial	Between brachioradialis and extensor carpi radialis longus
Median	Medial to brachial artery at elbow
Anterior interosseous	Splits pronator teres and runs between flexor digitorum superficialis and flexor digitorum profundus Between flexor pollicis longus and flexor digitorum profundus
Ulnar	Between flexor carpi ulnaris and flexor digitorum profundus

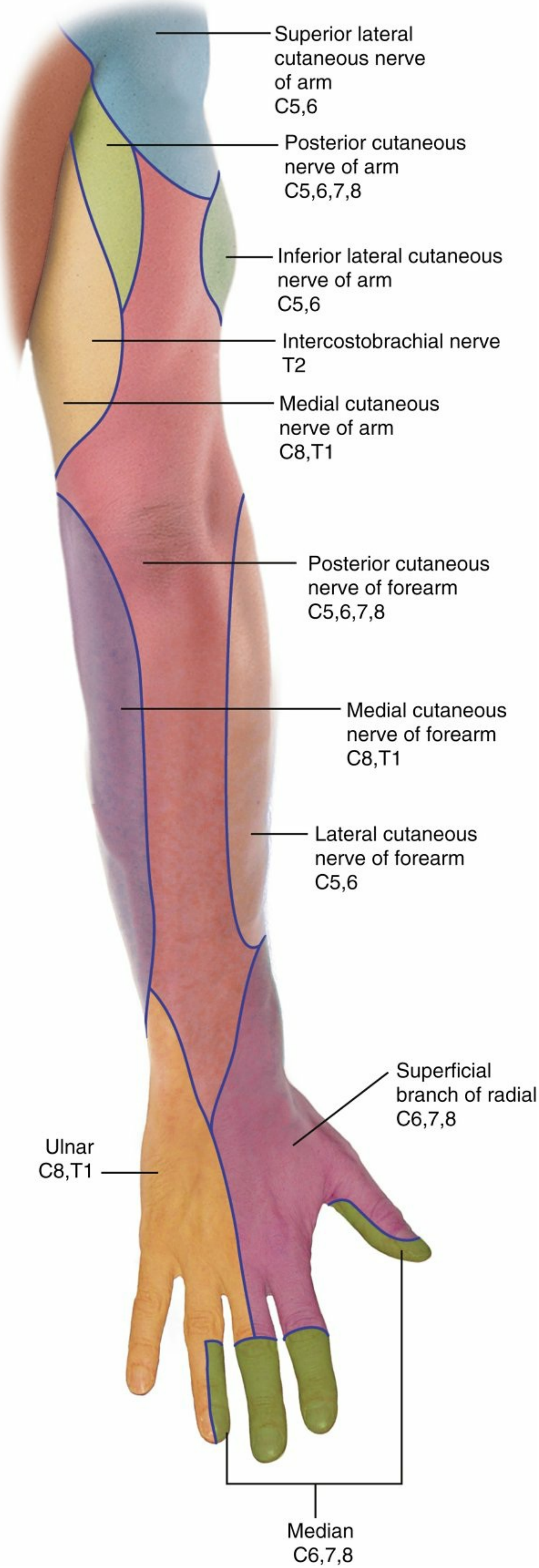

Superior lateral cutaneous nerve of arm C5,6
Posterior cutaneous nerve of arm C5,6,7,8
Inferior lateral cutaneous nerve of arm C5,6
Intercostobrachial nerve T2
Medial cutaneous nerve of arm C8,T1
Posterior cutaneous nerve of forearm C5,6,7,8
Medial cutaneous nerve of forearm C8,T1
Lateral cutaneous nerve of forearm C5,6
Superficial branch of radial C6,7,8
Ulnar C8,T1
Median C6,7,8

FIG. 2.22 Nerve regions in arm and hand (posterior view).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

- Deep muscular branch (also known as the *profunda brachii*) accompanies the radial nerve posteriorly in the triangular interval).
- Radial collateral and superior/inferior ulnar collateral branches around the elbow
- Supratrochlear branch is least flexible branch.
- Enters antecubital fossa (bordered by the two epicondyles, the brachioradialis laterally, and the pronator teres medially), passing anterior to brachialis and supinator muscles
- Divides at the level of the radial neck into the radial and ulnar arteries (Table 2.21)

□ Radial artery

- Initially runs on the pronator teres, deep to the brachioradialis
- Continues to the wrist between this muscle and the FCR
- Forearm branches include the recurrent radial (which anastomoses with radial collateral artery) and muscular branches.
- At the wrist, the radial artery reaches the dorsum of the carpus by passing between the FCR and the abductor pollicis longus (APL) and EPB tendons (snuffbox).
- Before that, it gives off a superficial palmar branch that communicates with the superficial arch (ulnar artery).
- It forms the deep palmar arch in the hand.

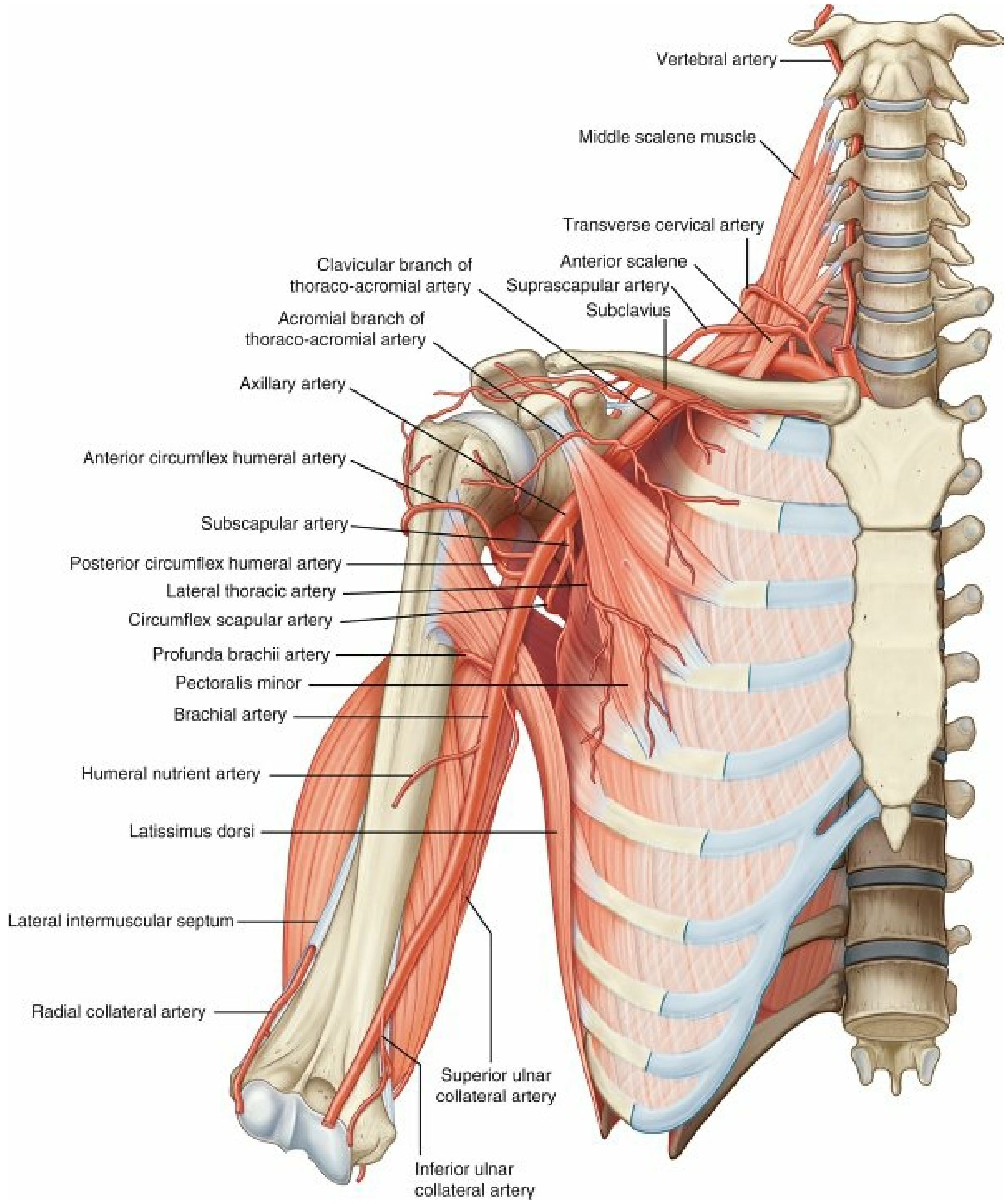


FIG. 2.23 Arteries of the shoulder and arm.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

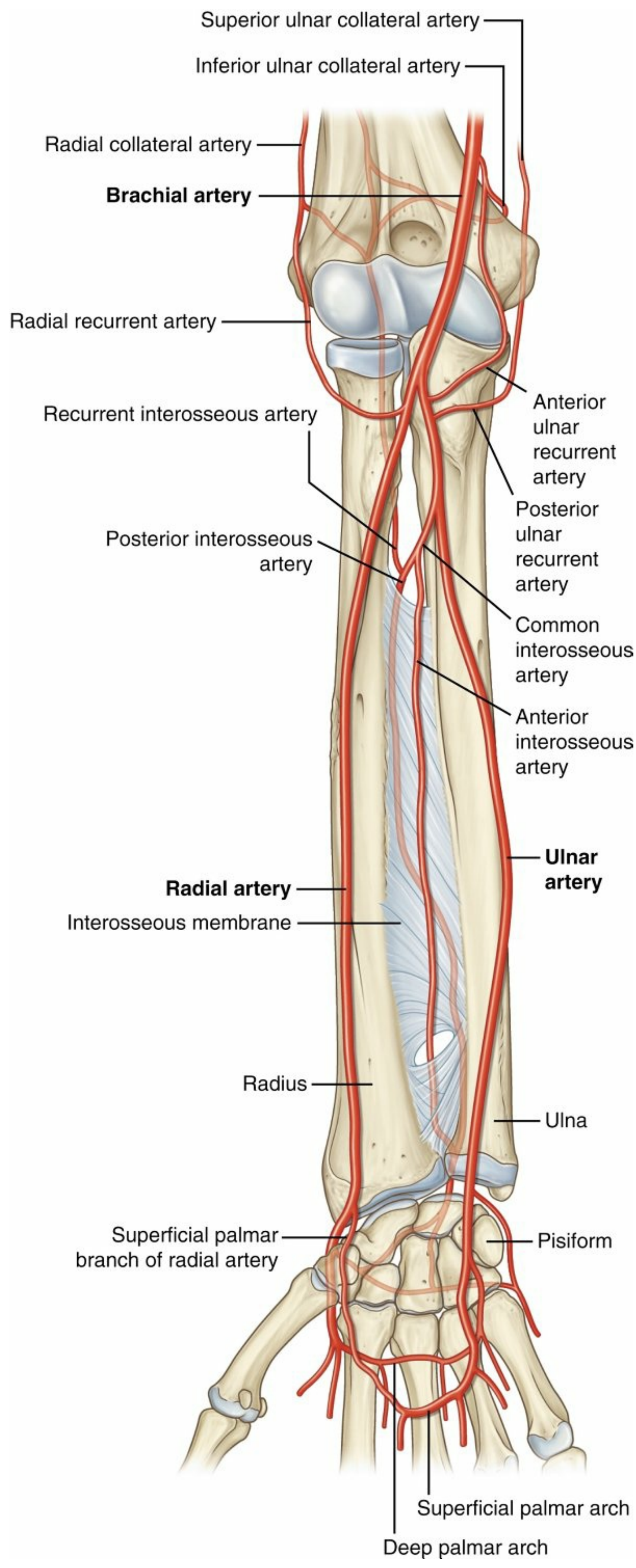

Superior ulnar collateral artery
Inferior ulnar collateral artery
Radial collateral artery
Brachial artery
Radial recurrent artery
Recurrent interosseous artery
Anterior ulnar recurrent artery
Posterior ulnar recurrent artery
Posterior interosseous artery
Common interosseous artery
Anterior interosseous artery
Ulnar artery
Radial artery
Interosseous membrane
Radius
Ulna
Superficial palmar branch of radial artery
Pisiform
Superficial palmar arch
Deep palmar arch

FIG. 2.24 Arteries of the forearm.
From Drake RL et al, editors: *Gray's atlas of anatomy*, ed 2, Philadelphia, 2015, Churchill Livingstone.

- The dorsal carpal branch of the radial artery enters the scaphoid dorsally and distally.

□ Ulnar artery: larger of the two branches
- Covered by the superficial flexors proximally (between FDS and FDP)
- Distally the artery lies on the FDP between the tendons of the FCU and FDS.

Table 2.20

Parts of the Axillary Artery

Part	Branch	Course
I	Supreme thoracic	Medial to serratus anterior and pectoral muscles
II	Thoracoacromial	Four branches: deltoid, acromial, pectoralis, clavicular
	Lateral thoracic	Descends to serratus anterior
III	Subscapular	Two branches: thoracodorsal and circumflex scapular (triangular space)
	Anterior humeral circumflex	Blood supply to humeral head: arcuate artery lateral to bicipital groove
	Posterior humeral circumflex	Branch in the quadrangular space accompanying axillary nerve

Table 2.21

Vascular Relationships in Forearm

Artery	Relationship
Radial	On pronator teres deep to brachioradialis Enters wrist between brachioradialis and flexor carpi radialis
Ulnar	Proximally between FDS and FDP Distally on FDP between FCU and FDS

- Forearm branches include the anterior and posterior recurrent ulnar (which anastomose with inferior and superior ulnar collateral arteries, respectively), the common interosseous (with anterior and posterior branches), and several muscular and nutrient arteries.
- At the wrist, ulnar artery lies on the TCL.
- Gives off a deep palmar branch (which anastomoses with the deep arch) and then forms the superficial palmar arch

▪ **Digital arteries arise from superficial palmar arch and run dorsal to digital nerves.**

- **Approaches to the upper extremity (** Table 2.22)
  - Surgical approaches to the shoulder (Fig. 2.25)
    - Anterior (deltopectoral) approach (Fig. 2.26)
      - Interval: deltoid (axillary nerve) and pectoralis major (medial and lateral pectoral nerves); can be extended distally along lateral border of biceps into anterolateral approach to humerus
      - Dissection
        - Interval marked by cephalic vein. Develop plane between deltoid and pectoralis major to expose the clavipectoral fascia. Cephalic vein is mobilized either laterally or medially according to surgeon preference.
        - Incise clavipectoral fascia lateral to the conjoint tendon to expose the subscapularis and proximal humerus. Retract deltoid laterally. Shoulder abduction relaxes deltoid to improve access.
        - For access to shoulder joint, subscapularis may be divided longitudinally, detached from the lesser tuberosity, or taken off with a lesser tuberosity osteotomy.
        - A leash of three vessels (one artery and the superior and inferior venae comitantes) marks the lower border of the subscapularis.
        - Anterior shoulder capsule closely associated with subscapularis tendon
        - Layers of the anterior shoulder are summarized in Table 2.23.

Table 2.22

Upper Extremity Approaches

Approach	Superficial Interval (Nerve)	Deep Interval (Nerve)	Stru
Shoulder			
Anterior (deltopectoral)	Deltoid (axillary) *and* pectoralis major (medial/lateral		C M

	pectoral)		A
Lateral (deltoid-splitting)	Split deltoid (axillary)		Axill
Posterior	Split deltoid (axillary)	Infraspinatus (suprascapular) *and* teres minor (axillary)	A P S
Humerus			
Anterolateral (proximal)	Deltoid (axillary) *and* pectoralis major (medial/lateral pectoral)		C M
Anterolateral (middle/distal)	Lateral to biceps (musculocutaneous)	Split brachialis (radial and musculocutaneous)	C M
Anterolateral (distal)	Brachialis (musculocutaneous) *and* brachioradialis (radial)		R L
Posterior (triceps-splitting)	Lateral and long heads of triceps (distal to branching of radial nerve)	Split medial (deep) head of triceps (radial)	R U
Posterior (triceps-slide)	Triceps (radial) *and* medial intermuscular septum		R U
Elbow			
Anterior (antecubital fossa)	Biceps (musculocutaneous) *and* brachioradialis (radial)	Pronator teres (median) *and* supinator (PIN)	C B L B R M S P
Medial (Hotchkiss)	Brachialis (musculocutaneous) *and* triceps (radial) or pronator teres (median)	Split or elevation of flexor-pronator mass (median)	U M
Lateral (Kaplan)	ECRB (radial/PIN) *and* EDC (PIN)		P L

Posterolateral (Kocher)	Anconeus (radial) *and* ECU (PIN)		P L
Posterior	Multiple options (olecranon osteotomy, triceps-sparing [Bryan-Morrey], triceps splitting) but none with a true internervous plane		U R
Forearm			
Anterior (Henry)	Brachioradialis (radial) *and* pronator teres/FCR (median)		P R R S
Posterior (Thompson)	ECRB (radial/PIN) *and* EDC/EPL (PIN)		PIN
Posterior ulna	ECU (radial) *and* FCU (ulnar)		U U
Wrist			
Dorsal	Third and fourth extensor compartments (no internervous plane)		PIN
Volar (distal Henry)	Median nerve *and* radial artery		M R
Carpal tunnel	Median nerve *and* ulnar nerve	Transverse carpal ligament	Med m P

AHCA, Anterior humeral circumflex artery; *LABCN,* lateral antebrachial cutaneous nerve; *MABCN,* medial antebrachial cutaneous nerve; *PCB,* palmar cutaneous branch of median nerve; *PHCA,* posterior humeral circumflex artery; *SBRN,* superficial branch of radial nerve.

- Risks
  - Musculocutaneous nerve
    - Penetrates posterior aspect of conjoint tendon approximately 5–8 cm distal to coracoid (may be more proximal in 30% of

shoulders)
    - Protect by keeping dissection lateral to conjoint tendon and avoiding vigorous medial retraction.
- Axillary nerve
    - Passes anterior to posterior through quadrangular space just inferior to the shoulder capsule
    - Shoulder adduction and external rotation reduce tension on the nerve.
- Subscapularis failure
    - Subscapularis should be securely repaired during closing.
    - Protect subscapularis repair postoperatively with passive external rotation restrictions.

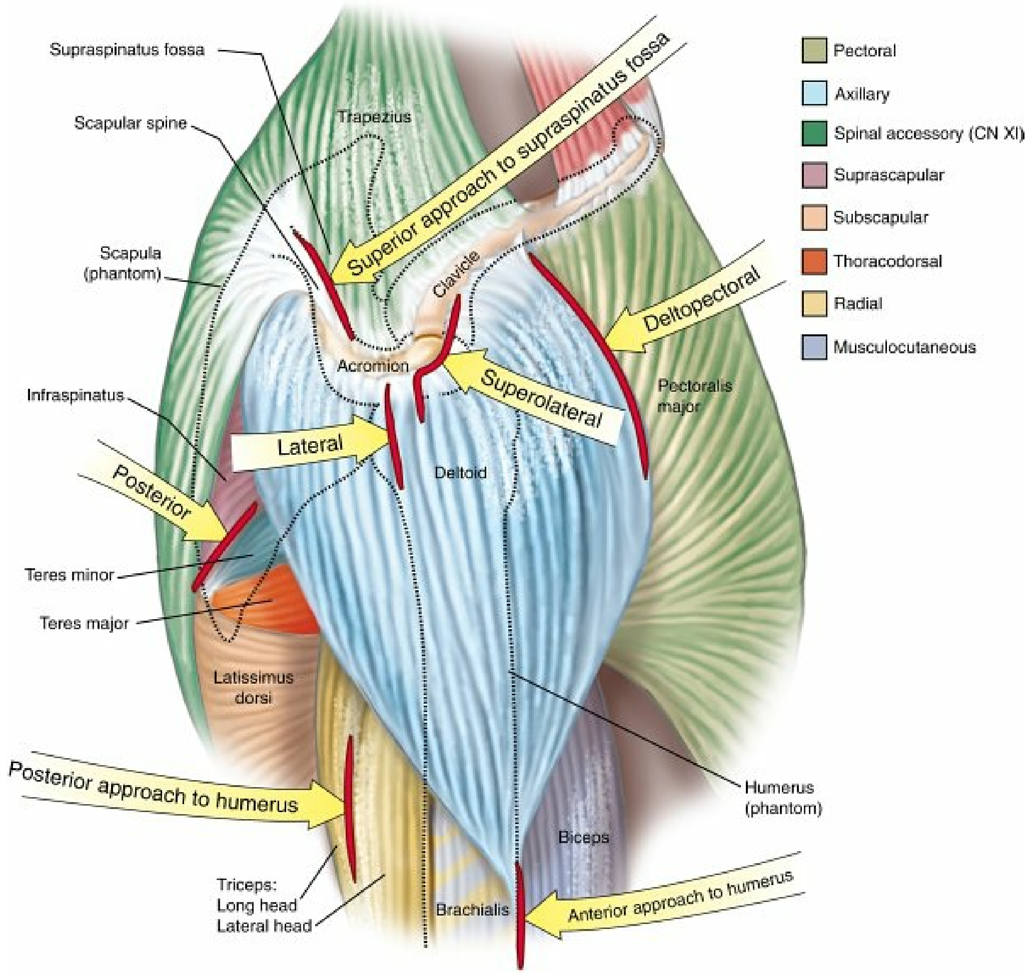


FIG. 2.25 Surgical intervals. Internervous planes for approaches to the shoulder and arm.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 2-11.

- Lateral (deltoid-splitting) approach
  - Interval: none; often split is made through the anterior raphe.
  - Dissection
    - Either split the deltoid muscle or detach it subperiosteally from the acromion.
    - Supraspinatus tendon is exposed, which allows for repairs of the rotator cuff.
  - Risks
    - Axillary nerve
      - Courses from posterior to anterior around shoulder in deep fascia of deltoid approximately 5–7 cm distal to acromion
      - Place a stich at the

inferior border of the muscle split so it will not accidentally propagate distally during the procedure.

- Posterior approach
  - Interval: infraspinatus (suprascapular nerve) and teres minor (axillary nerve)
  - Dissection
    - Split the posterior deltoid, thereby exposing the interval between the infraspinatus and teres minor.
    - Posterior capsule lies immediately deep to the interval.
  - Risks
    - **Quadrangular space (axillary nerve and posterior humeral circumflex artery): keep dissection above the teres minor**.
    - Suprascapular nerve may be damaged with excessive medial retraction of infraspinatus.

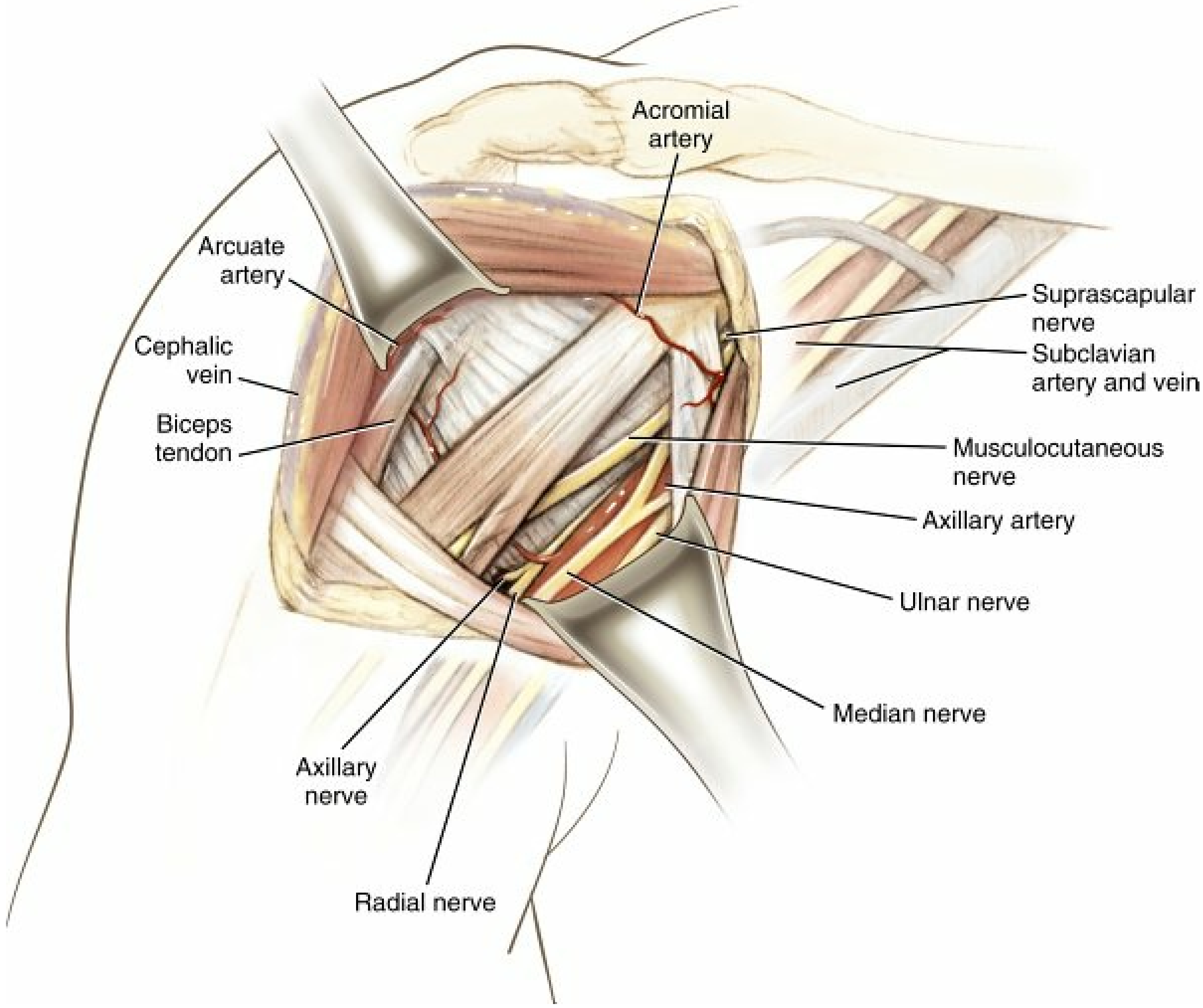


FIG. 2.26 Anterior (Henry) surgical approach to the shoulder.
From Miller MD et al: *Orthopaedic surgical approaches*, Philadelphia, 2008, Saunders, Figure SA-12.

Table 2.23

Layers of Shoulder

Layer	Structures
I	Deltoid, pectoralis major, trapezius
II	Clavipectoral fascia, conjoined tendon, short head of biceps, and coracobrachialis
III	Deep layer of subdeltoid bursa, rotator cuff muscles (*s*upraspinatus, *i*nfraspinatus, *t*eres minor, *s*ubscapularis [mnemonic: "SITS"])
IV	Glenohumeral joint capsule, coracohumeral ligament

- □ Surgical approaches to the humerus
    - Anterolateral approach
        - Interval: deltoid (axillary nerve) and pectoralis major (medial and lateral pectoral nerves) and along lateral biceps proximally, between the fibers of the brachialis (radial and musculocutaneous nerves) midhumerus, and between the brachialis (radial and

musculocutaneous nerves) and brachioradialis (radial nerve) distally

- Dissection
  - Proximal approach
    - Interval marked by the cephalic vein. Retract the pectoralis major medially and the deltoid laterally.
    - Anterior circumflex humeral vessels may need to be ligated.
  - Middle approach
    - Split the brachialis fibers longitudinally (dual innervation).
    - Alternatively, the humerus may be exposed between the brachialis and biceps, but this approach is not extensile distally.
  - Distal approach
    - Retract the brachialis muscle medially and the brachioradialis laterally.
    - May be extended distally to the forearm when combined with a volar Henry approach
- Risks
  - Radial and axillary nerves are at risk for injury mainly because of forceful retraction. Radial nerve can also be injured by screw penetration or retraction compression as it courses within the spiral groove.
  - For distal exposure, be wary of the lateral antebrachial cutaneous nerve entering the field (coursing medially to lateral under the biceps tendon) and the radial nerve (traveling under

the brachioradialis muscle).

- Posterior approach to the humerus
    - Interval: none
    - Dissection
        - Triceps-splitting
            - Superficial approach: dissect between lateral and long heads of the triceps (triceps-splitting).
            - Deep approach: split the medial head of the triceps (triceps-splitting).
        - Lateral triceps slide
            - Mobilize the entire triceps complex medially by dissecting the lateral head off the lateral intermuscular septum.

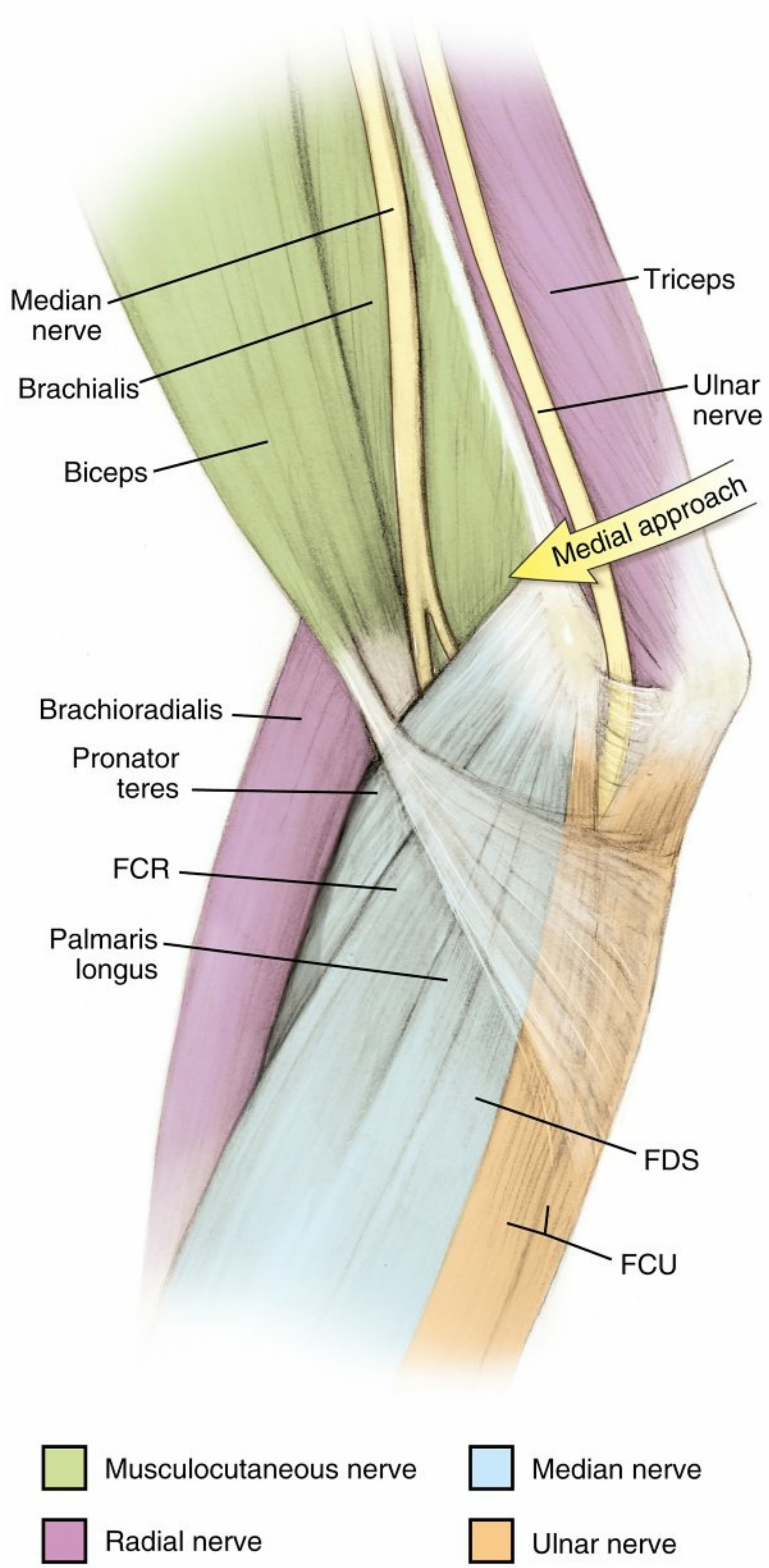


FIG. 2.27 Internervous planes for medial approaches to the elbow.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figures 3-8 and 3-9.

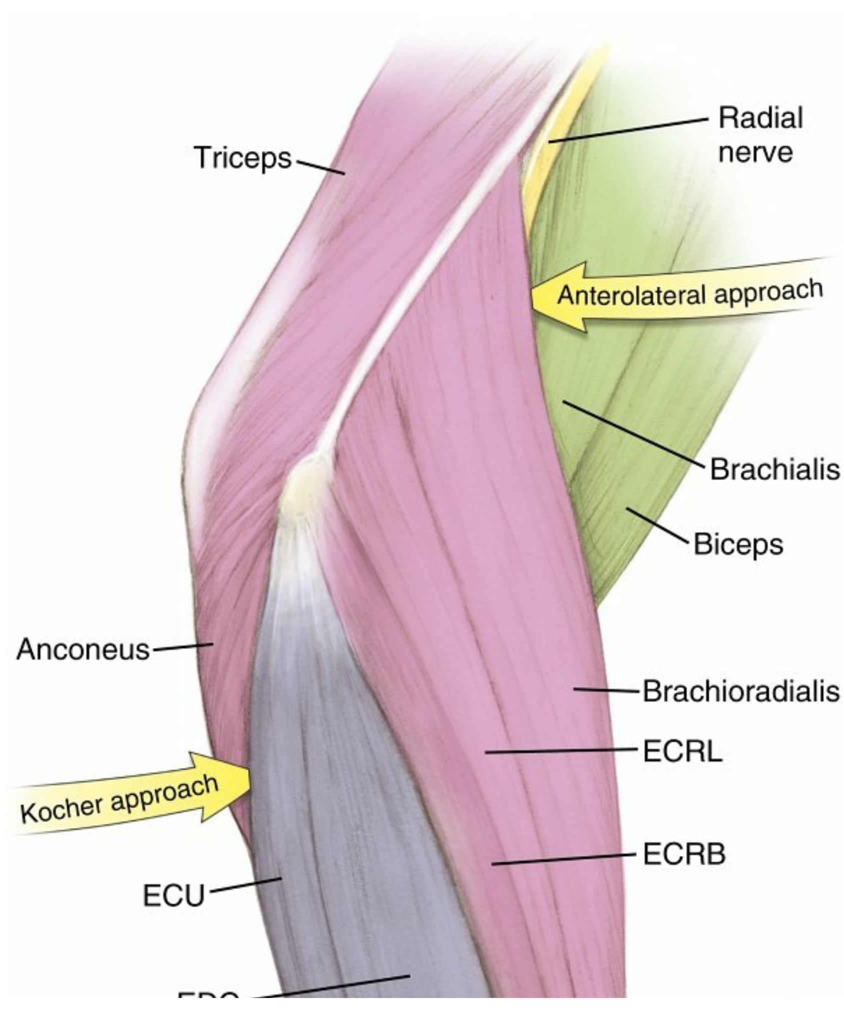
- Risks
    - Radial nerve: limits proximal extension of approach

- Identify and protect the radial nerve as it passes from medial to lateral in the proximal part of the exposure.
- With the triceps-splitting approach, access to posterior humerus can be increased from 55% to 76% by mobilizing the radial nerve.

- Ulnar nerve: jeopardized unless subperiosteal dissection of the humerus is performed meticulously
- Axillary nerve: seen in the proximal exposure of the lateral triceps slide

□ Surgical approaches to the elbow (Figs. 2.27 and 2.28)

- Anterior approach to the antecubital fossa
  - Interval: biceps, brachioradialis, and pronator teres (Fig. 2.29)



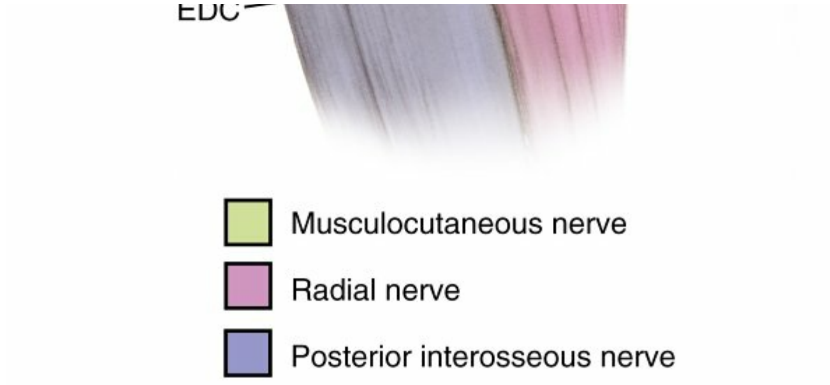


FIG. 2.28 Internervous planes for lateral approaches to the elbow.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figures 3-8 and 3-9.

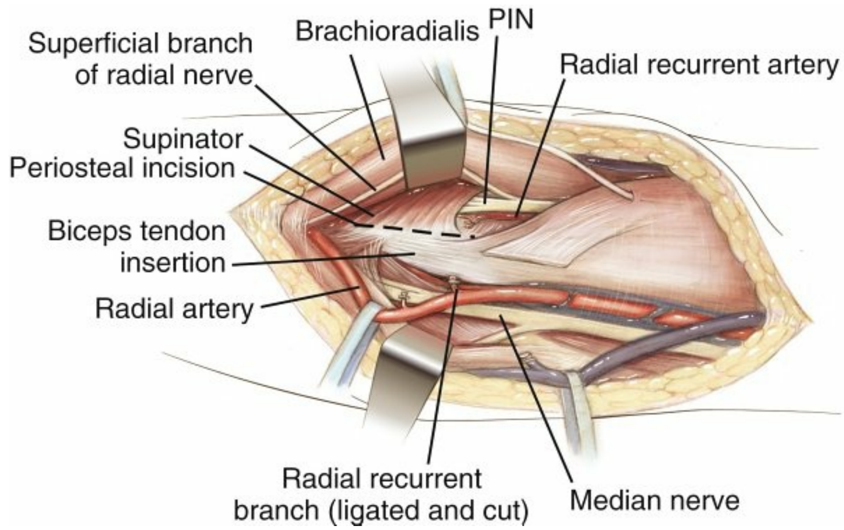


FIG. 2.29 Anterior approach to the elbow.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 3-19.

- Dissection
  - Curved incision from medial border of biceps transversely across the flexion crease and distally along radial border of brachioradialis
    - Avoid 90-degree angle across flexion crease.
  - Brachioradialis retracted laterally, pronator teres retracted medially
  - Dissect supinator from radius to expose elbow capsule and anterior radius.

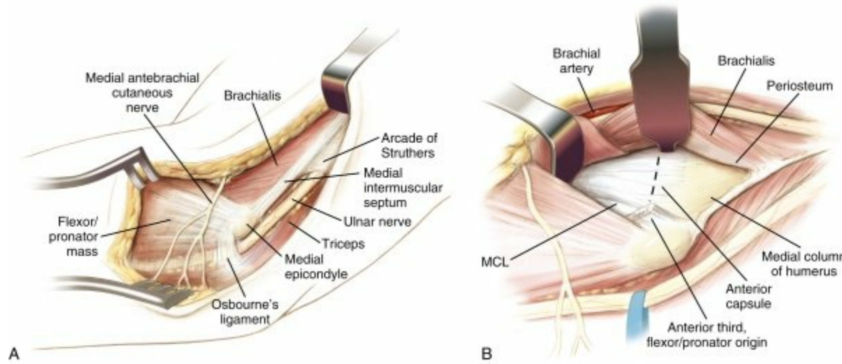


FIG. 2.30 Medial approach to the elbow. (A) Superficial exposure. (B) Deep exposure.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures EF-23 and EF-26.

    - Risks
        - Multiple veins, including cephalic and basilic vein, anastomose in antecubital fossa.
        - Lateral antebrachial cutaneous nerve emerges from beneath the biceps tendon.
        - Brachial artery lies directly deep to biceps aponeurosis.
        - Recurrent branches of radial artery
        - Median nerve most medial major neurovascular structure in antecubital fossa
        - **PIN (supinate forearm to protect)**
- Medial approach to the elbow (Hotchkiss) (Fig. 2.30)
    - Interval: between the brachialis (musculocutaneous nerve) and triceps (radial nerve) proximally and between the brachialis and pronator teres (median nerve) distally
    - Dissection: incise anterior third of the flexor pronator mass to reach the anterior elbow capsule.
    - Risks
        - Medial antebrachial cutaneous nerves cross field and must be protected.
        - Ulnar nerve
- Lateral (Kaplan) approach to the elbow
    - Interval: between the ECRB (radial/PIN) and extensor digitorum communis (EDC) (PIN) (Note: uses the same muscular interval as the more distal dorsal Thompson approach.)
    - Dissection: split the anular ligament while

remaining anterior to the LUCL. Pronate the arm to move the PIN anteriorly and radially.
    - Risks: PIN, lateral ulnar collateral ligament (LUCL)
- Posterolateral (Kocher) approach to the elbow (Fig. 2.31)
    - Interval: between the anconeus (radial nerve) and the origin of the main extensor (extensor carpi ulnaris [ECU], PIN)
    - Dissection: pronate the arm to move the PIN anteriorly and radially, and approach the radial head through the proximal supinator fibers.
    - **Risks: extending this approach distal to anular ligament increases risk for injury to PIN.**
- Proximal extension of lateral approach
    - Interval: along lateral intercondylar ridge, between triceps and ECRL (brachioradialis nerve)
    - Dissection: subperiosteally expose the anterior humerus and lateral column.
    - Risks: retractor placed under brachialis anteriorly to protect radial nerve, distally limited by PIN
- Posterior approach to the elbow
    - Interval: none
    - Dissection
        - Olecranon osteotomy: predrill the olecranon osteotomy (best done with a chevron cut 2 cm distal to the tip), and protect the ulnar nerve (Fig. 2.32).
        - Triceps-sparing (Bryan-Morrey): elevate the triceps insertion subperiosteally off the olecranon and retract laterally. Repair triceps mechanism with transosseous sutures.
        - Triceps splitting: in an alternative approach, split the triceps and leave the olecranon intact.
        - Paratricipital (triceps slide): triceps is elevated off the medial and lateral intermuscular septa so the tendon may be mobilized in either direction to access the humerus. The triceps insertion is undisturbed.

- Risks:
  - Ulnar nerve can be injured with dissection or excessive retraction.
  - Radial nerve limits the proximal extension along the humerus.
  - Do not divide triceps transversely in the triceps-sparing approach.

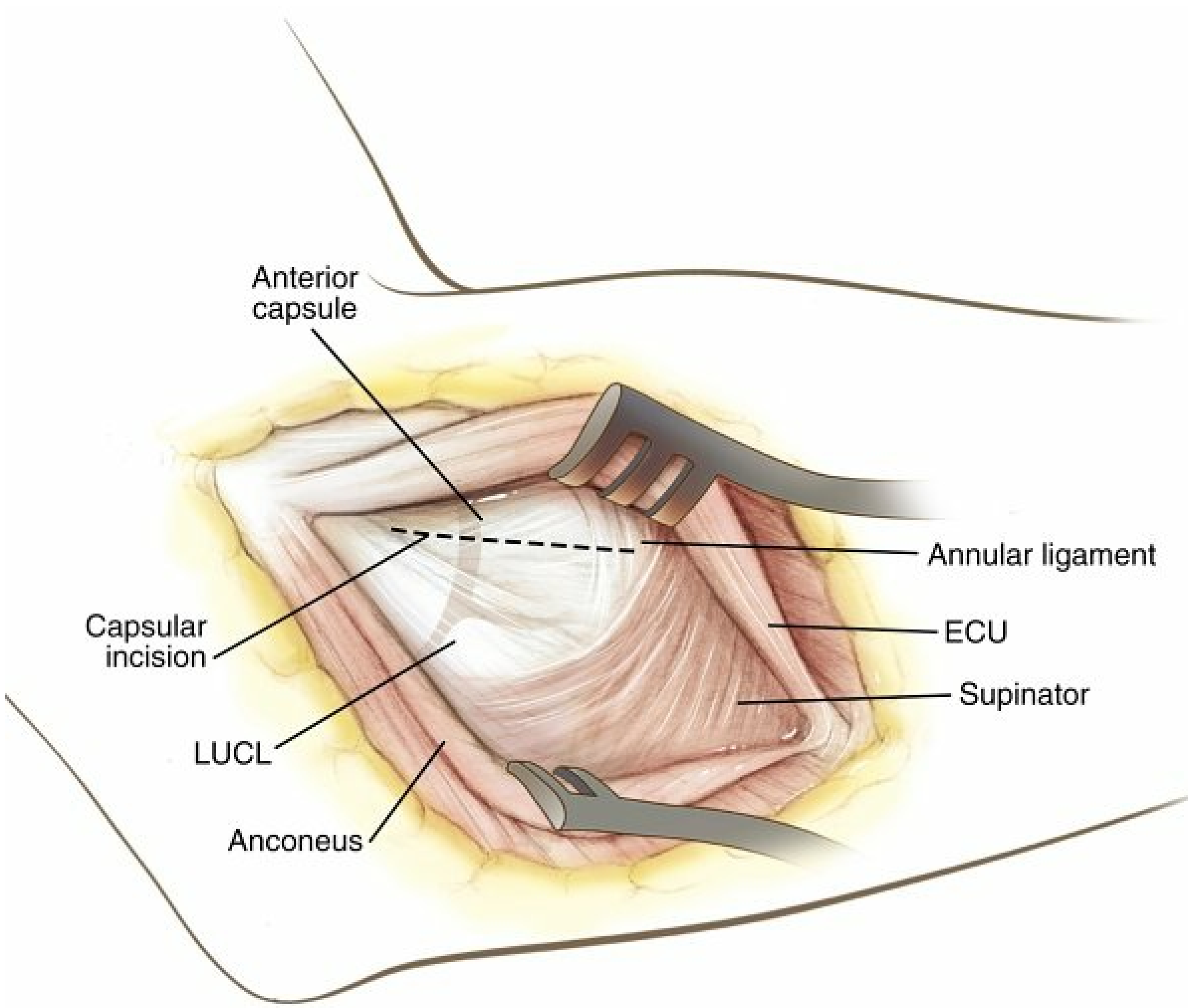


FIG. 2.31 Posterolateral approach to the elbow.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figure EF-32.

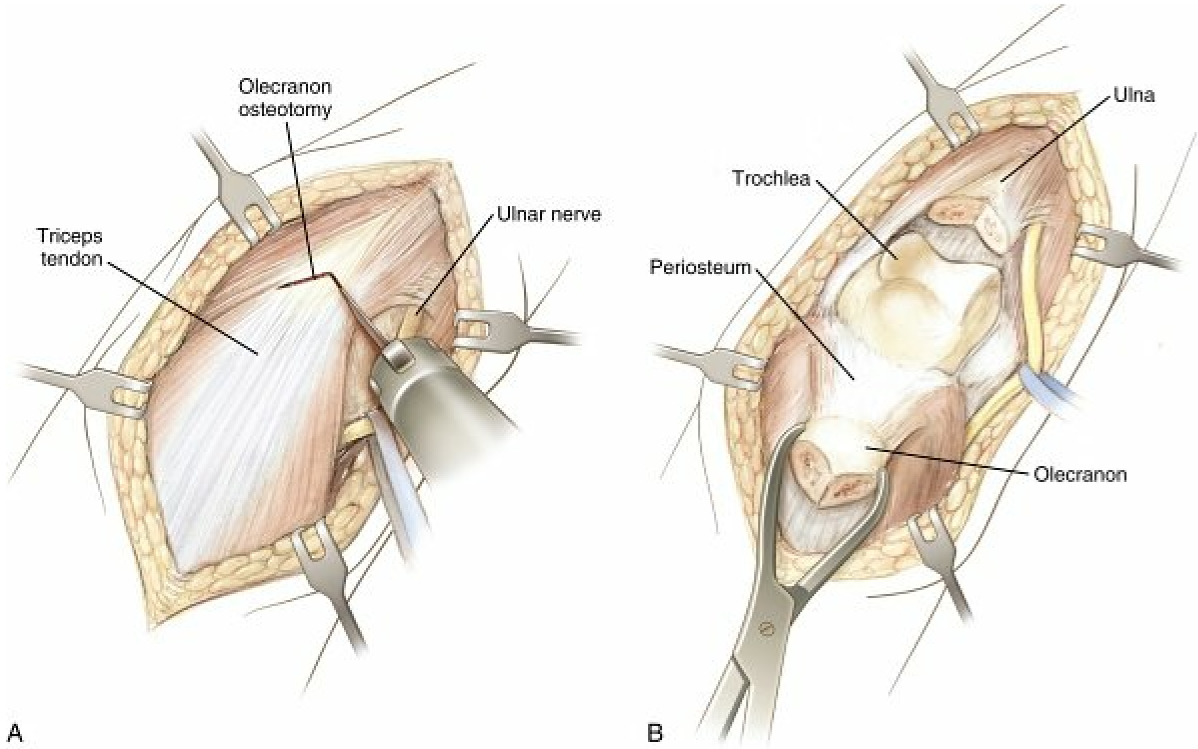
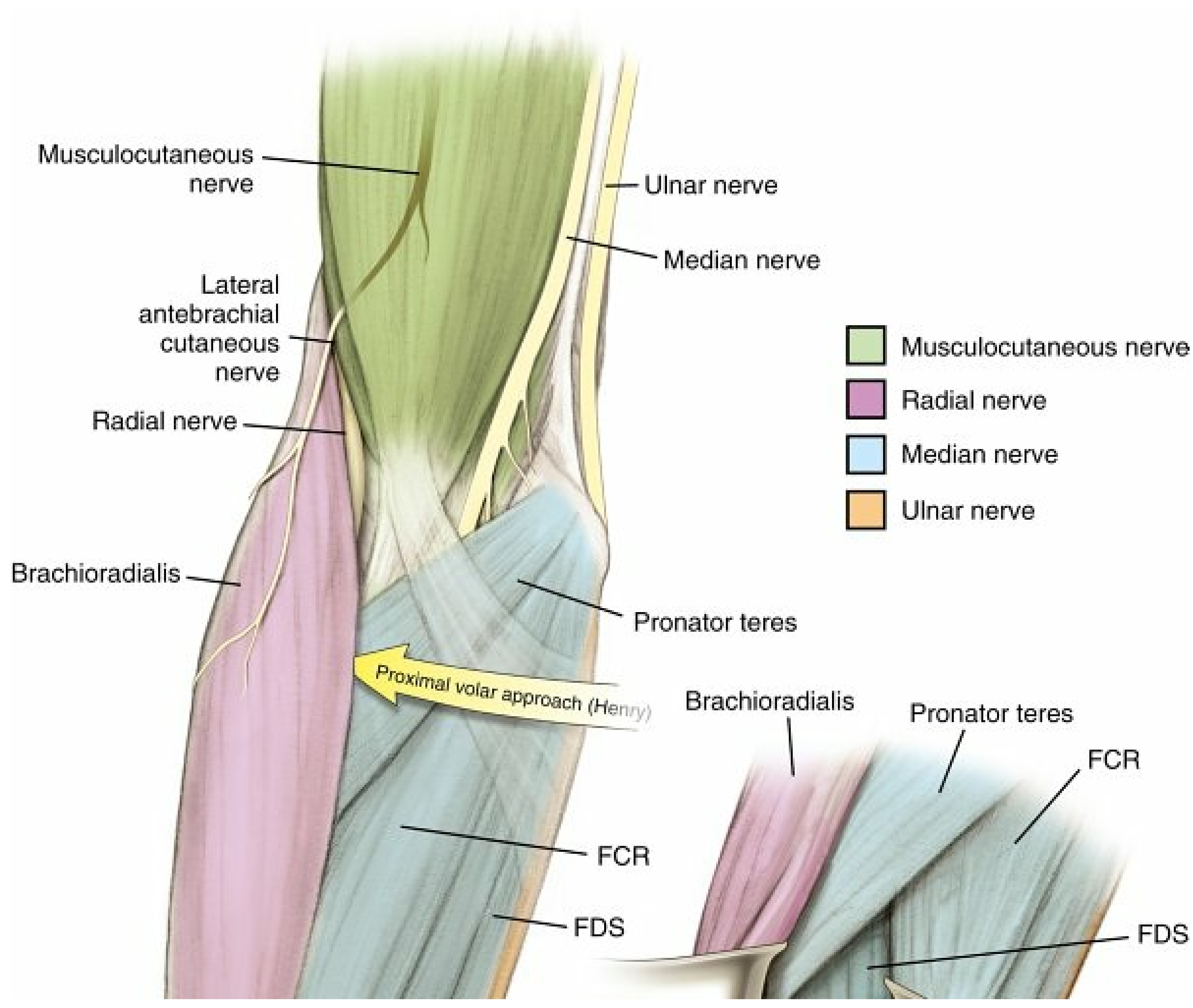


FIG. 2.32 Posterior approach to the elbow. (A) Superficial exposure. (B) Deep exposure. An olecranon osteotomy is shown.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures EF-46 and EF-47.



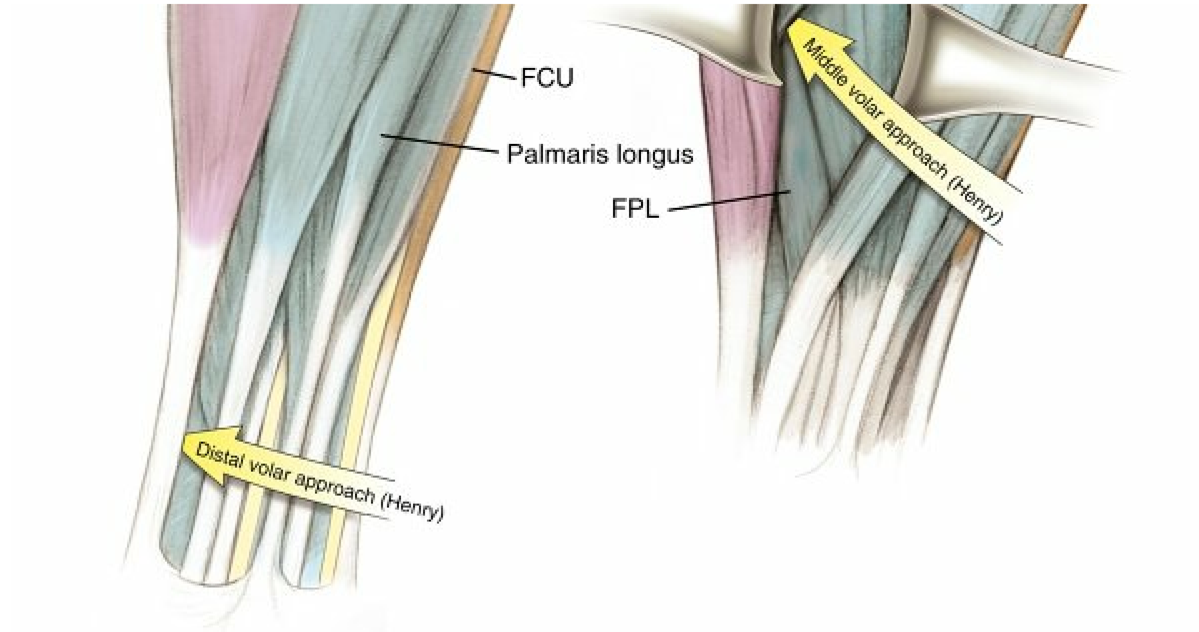


FIG. 2.33 Volar approaches to the forearm.
From Miller MD et al: *Orthopaedic surgical approaches*, ed 2, Philadelphia, 2014, Saunders, Figure 3-11.

- Surgical approaches to the forearm (Figs. 2.33 and 2.34)
  - Anterior (Henry) approach (Fig. 2.35)
    - Interval: between the brachioradialis (radial nerve) and pronator teres proximally or FCR distally (median nerve)
    - Dissection
      - Proximally: isolate and ligate the leash of Henry (radial artery branches) proximally and strip the supinator from its insertion subperiosteally. Supination of the forearm displaces the PIN ulnarly (i.e., laterally and posteriorly).
      - Middle third: pronate forearm and incise the insertion of the pronator teres subperiosteally.
      - Distally: dissect off the FPL and PQ.
    - Risks
      - Superficial branch of the radial nerve must be protected (retract laterally) with the brachioradialis.
      - Radial artery is at risk for injury proximally because it courses medial to the biceps tendon and distally with retraction of the brachioradialis.
      - PIN can be injured during deep dissection of proximal exposure (fully

supinate to move laterally).

- Posterior (Thompson) approach (Fig. 2.36)
  - Interval: between ECRB (radial nerve/PIN) and EDC or EPL distally (PIN)

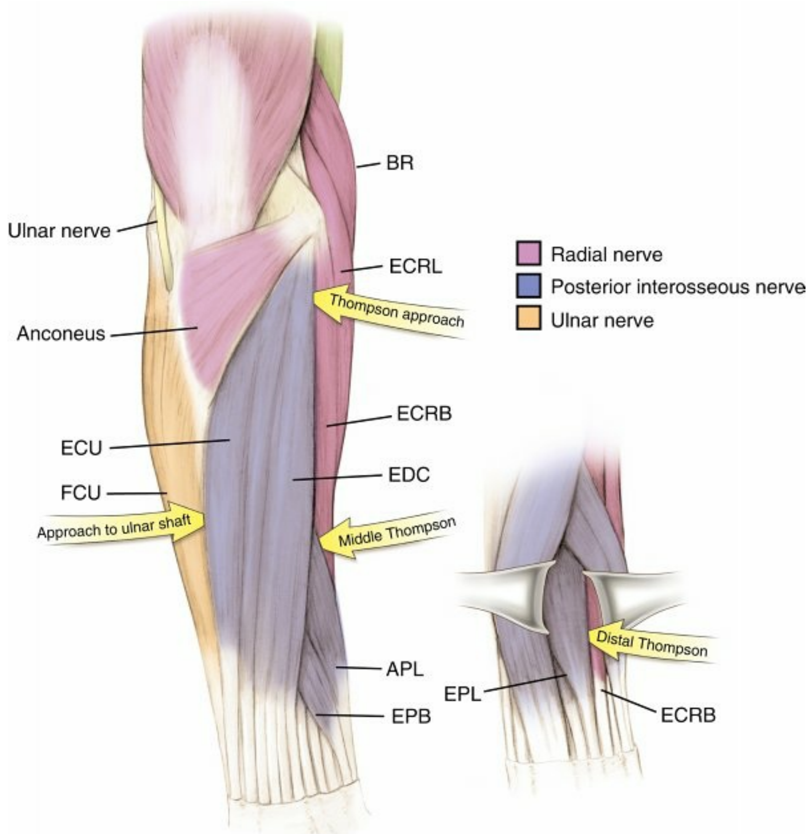


FIG. 2.34 Internervous planes for dorsal approaches to the forearm.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 3-11.

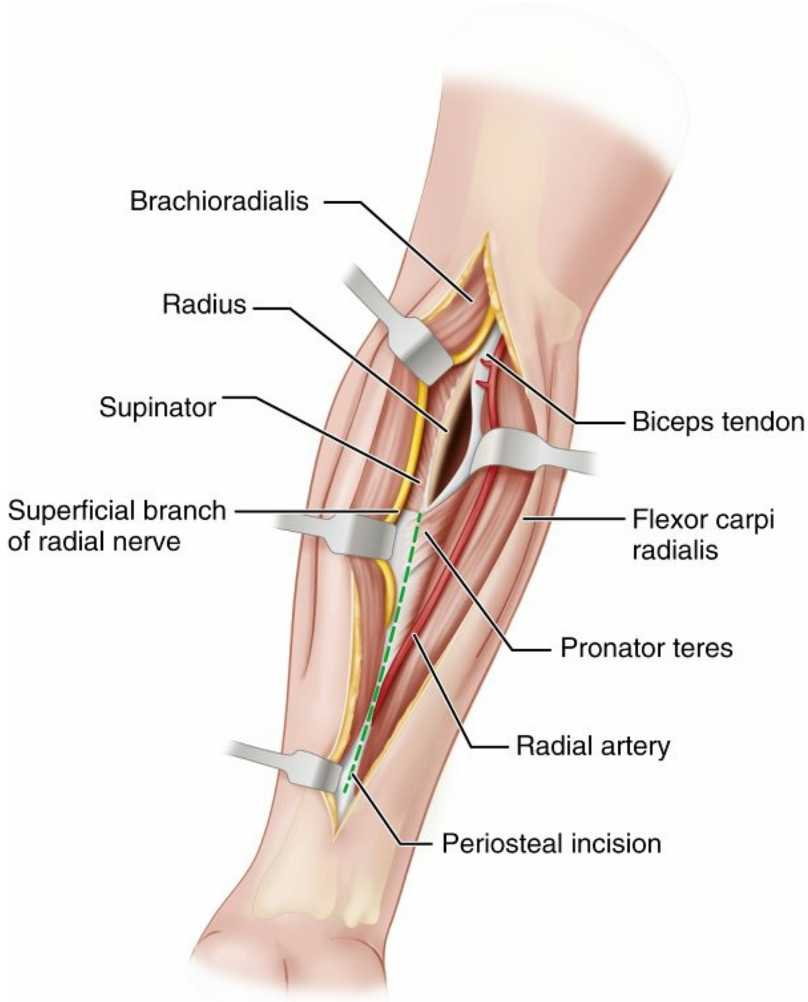


FIG. 2.35 Anterior (Henry) approach to the forearm.

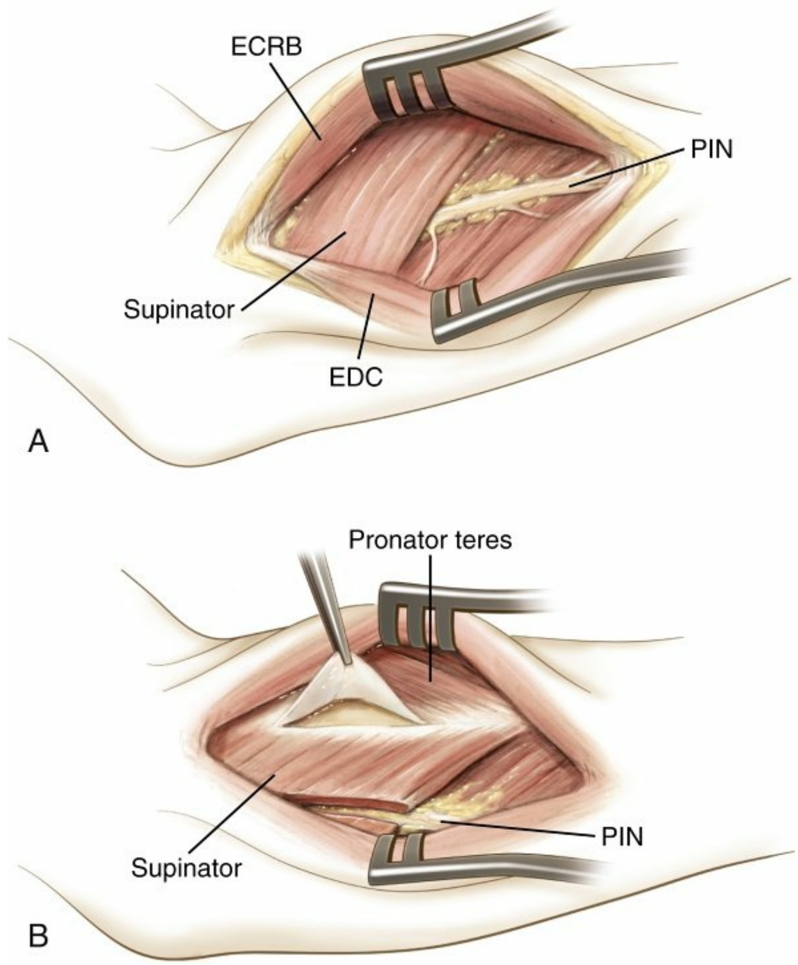


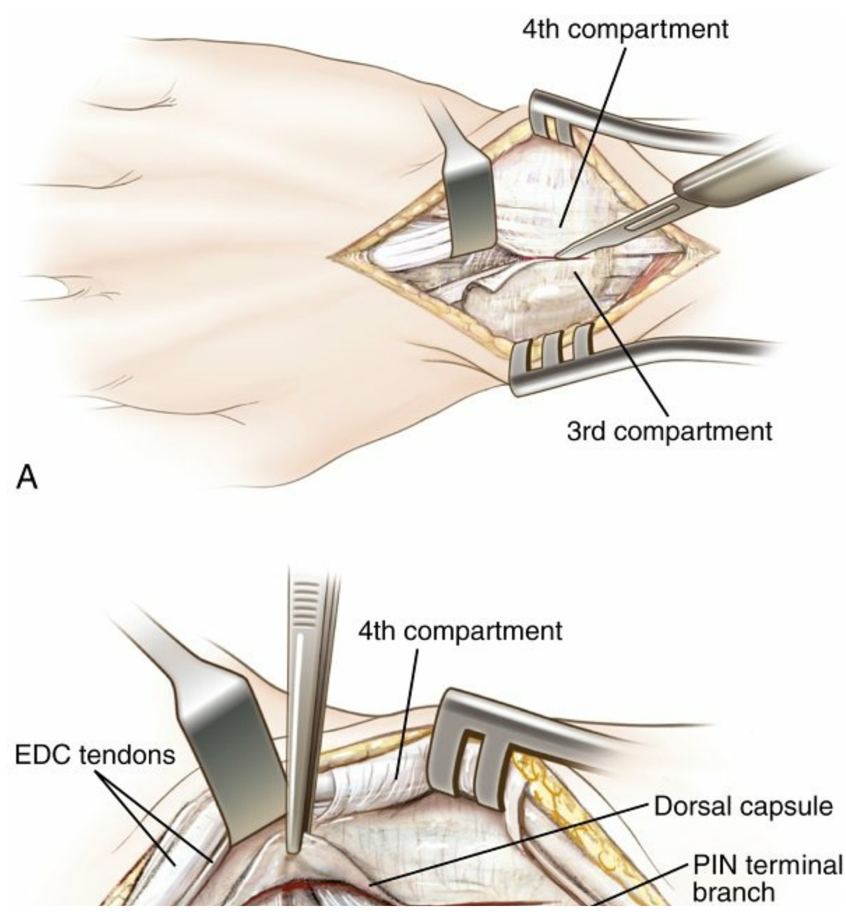
FIG. 2.36 Dorsal (posterior [Thompson]) approach to the forearm. (A) Superficial exposure. (B) Deep exposure with the forearm supinated.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures EF-65 and EF-68.

- Dissection
    - Identify PIN as it exits the supinator before the forearm is supinated and reflect the supinator off the anterior surface of the proximal radius.
    - Distally, retract the APL and EPB to gain access to the middle and distal portions of the radius.
- Risks: PIN must be identified and protected.

- Exposure of the ulna (ECU/FCU approach)
    - Interval: between the ECU (PIN) and the FCU (ulnar nerve)
    - Dissection: strip muscles from the ulna subperiosteally.
    - Risks: FCU stripped subperiosteally to protect ulnar nerve and artery

□ Surgical approaches to the wrist and hand

- Dorsal approach to the wrist (Fig. 2.37)
  - Interval: between the third and fourth extensor compartments (EPL and extensor digitorum)
  - Dissection
    - Incise the extensor retinaculum between the third and fourth compartments.
    - Protect and retract these tendons to allow access to the distal radius and the dorsal radiocarpal joint.
    - Transpose the EPL and incise the dorsal capsule.
  - Risks: do not violate the interosseous scapholunate ligament.
- Carpal tunnel release
  - Incision is usually made in line with the fourth ray to avoid the palmar cutaneous branch of the median nerve.



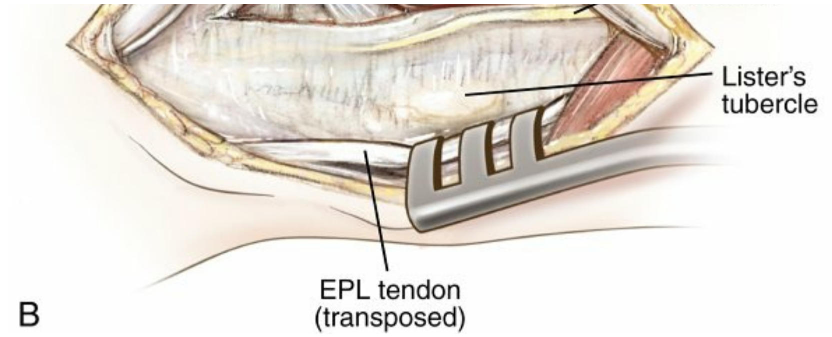


FIG. 2.37 Dorsal surgical approach to the wrist. (A) Superficial exposure. (B) Deep exposure.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures HW-13 and HW-14.

  - Dissection through the TCL must be performed carefully to avoid injury to median nerve or its motor branch.
- Volar (Russé) approach to the scaphoid
  - Interval: between FCR and radial artery
  - An approach through the radial aspect of the FCR sheath: often easier and protects the radial artery
- Dorsolateral approach to the scaphoid
  - Using an incision within the anatomic snuffbox (first and third dorsal wrist compartments) helps protect the superficial radial nerve and radial artery (deep).
- Volar approach to the flexor tendons (Bunnell)
  - Zigzag incisions across the flexor creases help to expose the flexor sheaths.
  - Digital sheaths should be avoided.
- Midlateral approach to the digits
  - Good for stabilization of fractures and neurovascular exposure
  - Requires a laterally placed incision at the dorsal extent of the interphalangeal creases
  - Exposure of the digital neurovascular bundle: volar to the incision

▪ **Cross-sectional diagrams of the upper extremity with MRI are demonstrated in** Figs. 2.38 through 2.42.

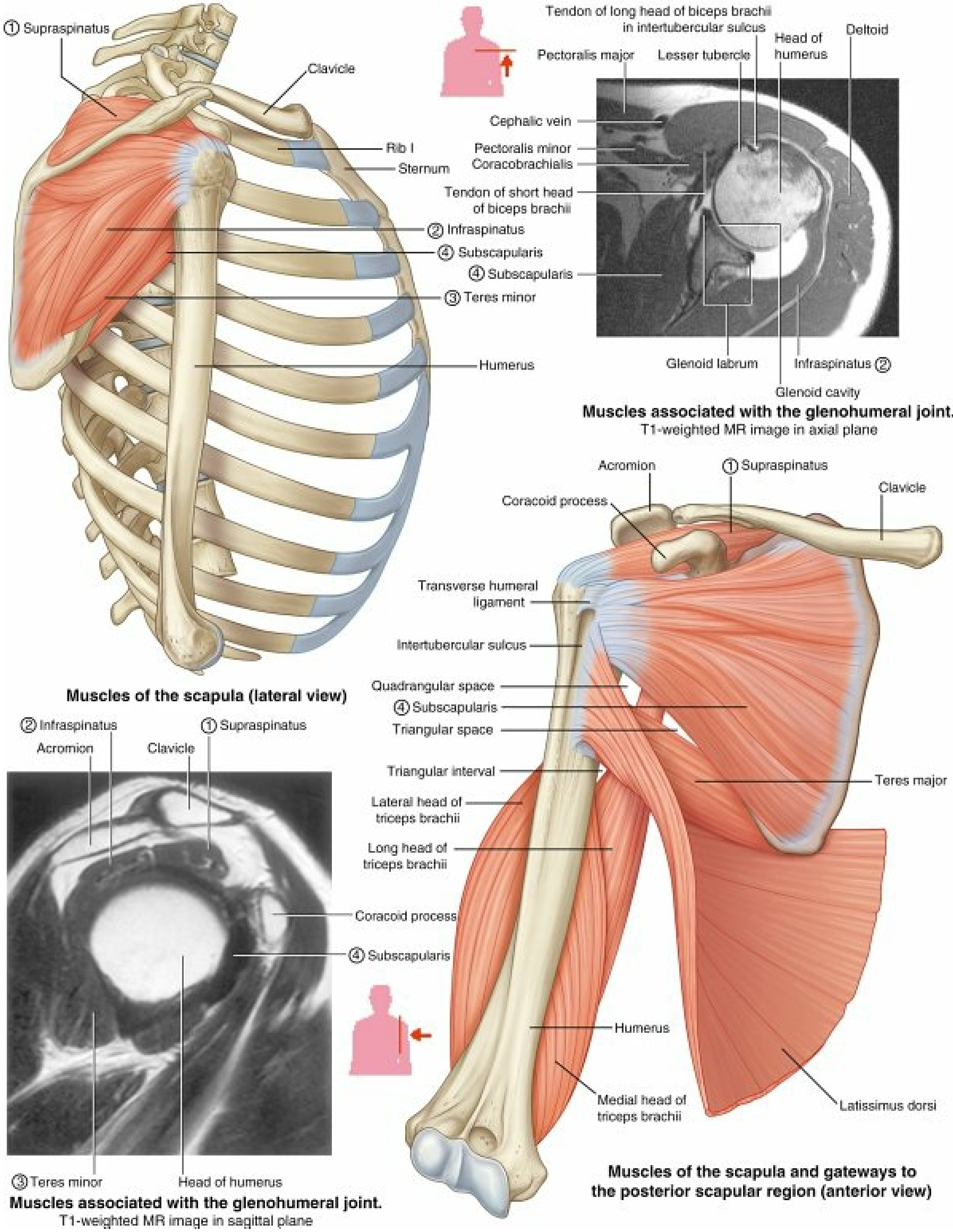


FIG. 2.38 Muscles of the scapula and glenohumeral joint.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

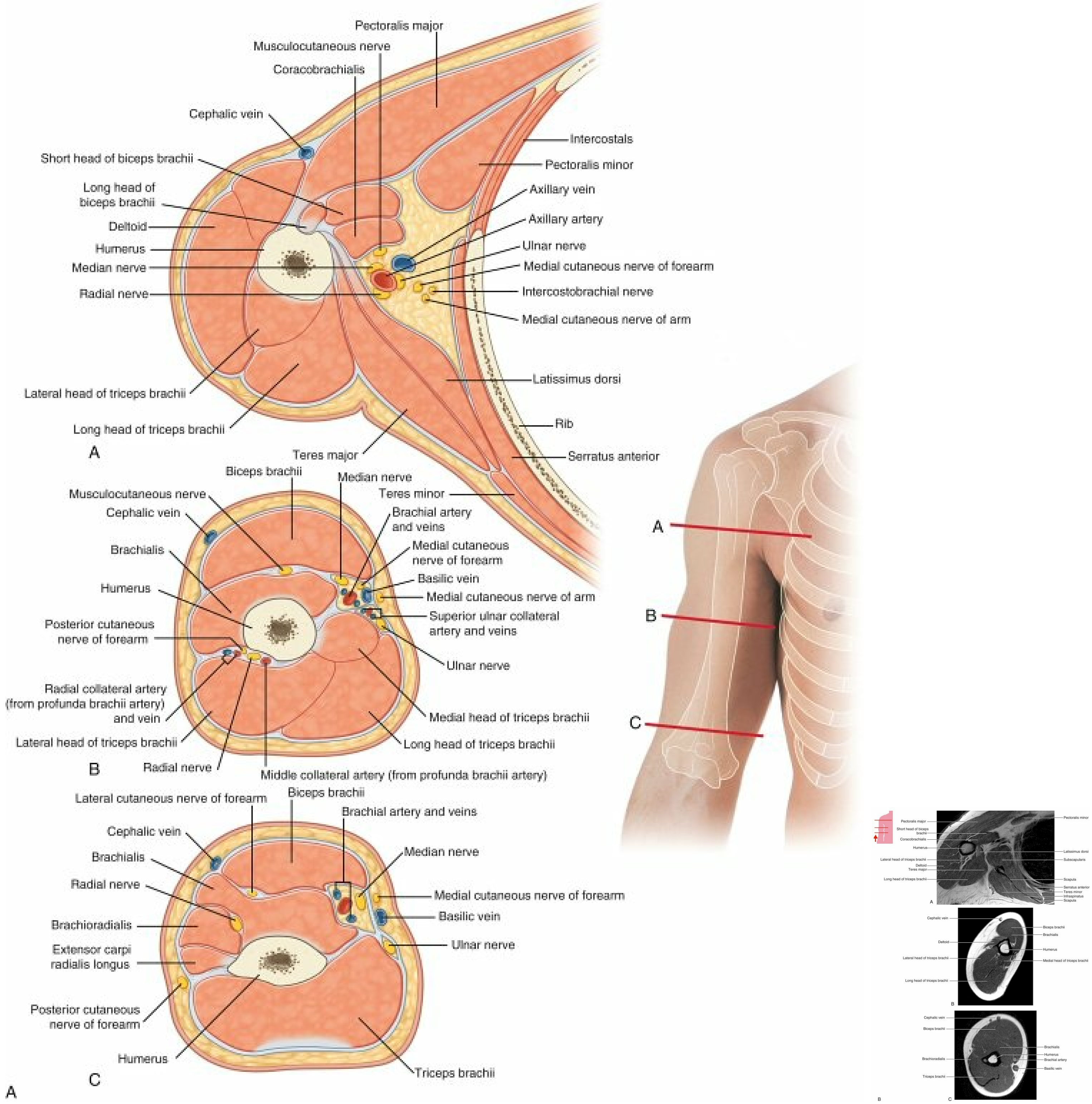


FIG. 2.39 Illustration (A) and imaging (B) of cross-sectional anatomy of the arm.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

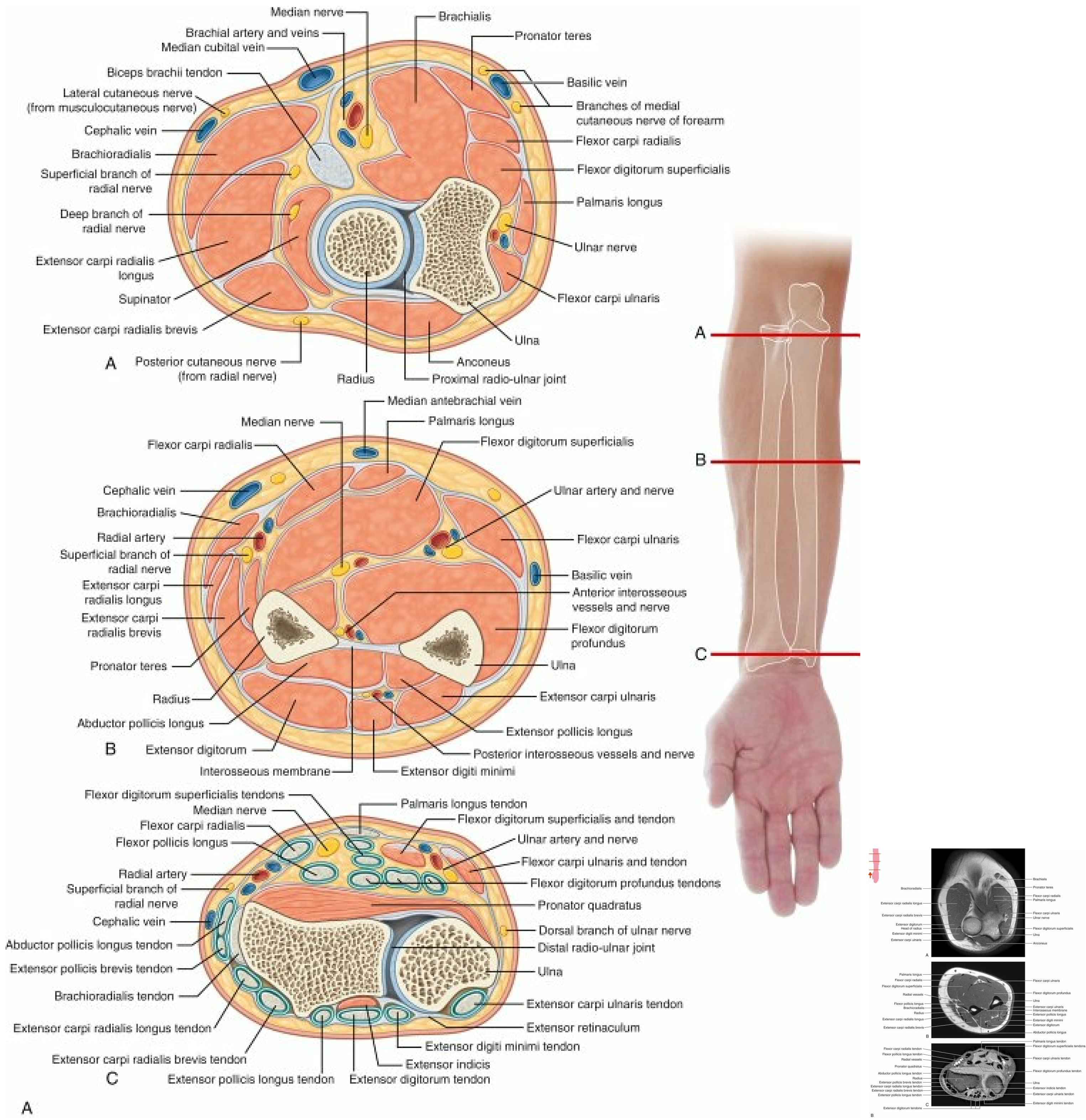


FIG. 2.40 Illustration (A) and imaging (B) of cross-sectional anatomy of the forearm. From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

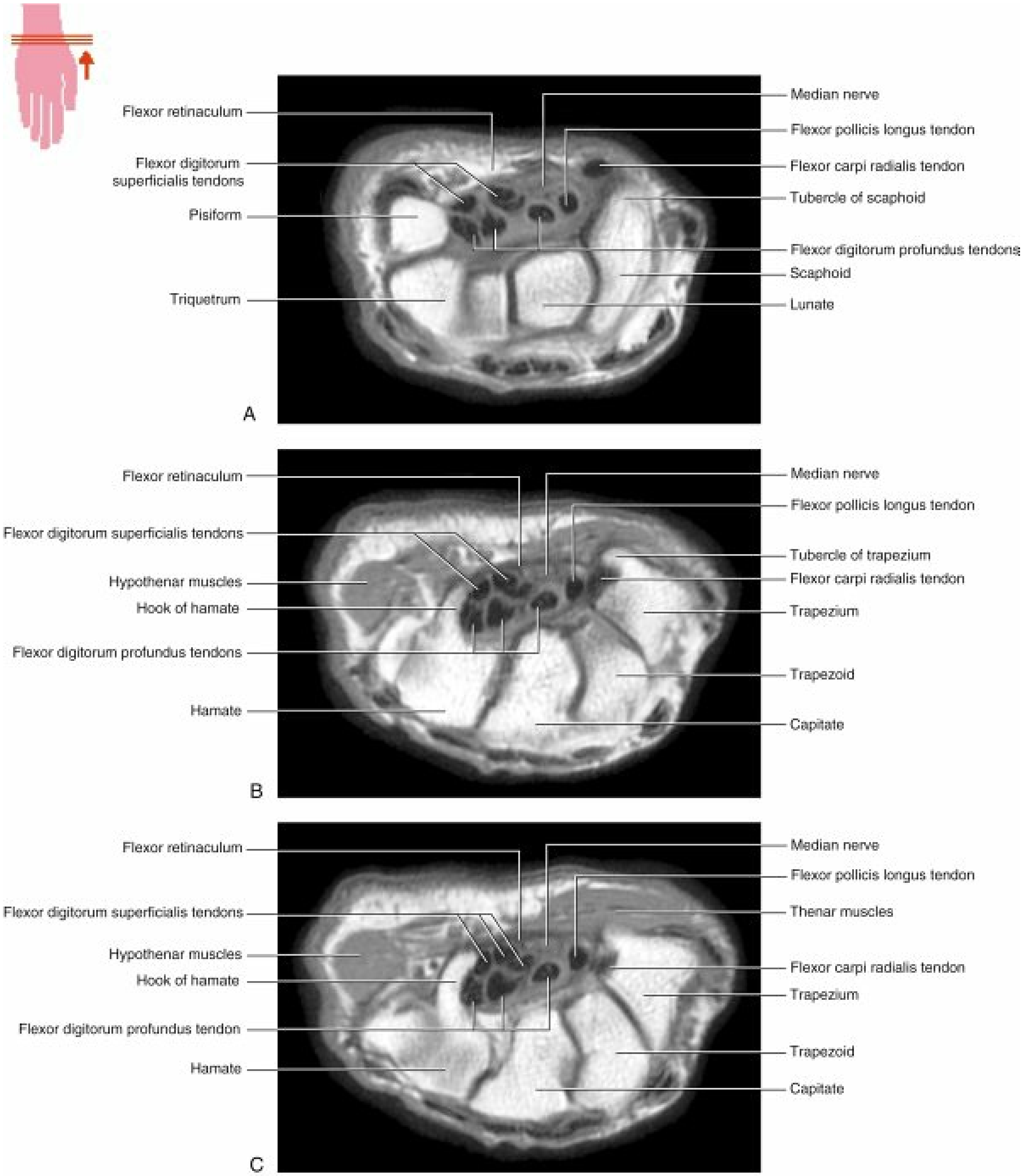


FIG. 2.41 Imaging of carpal region anatomy.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

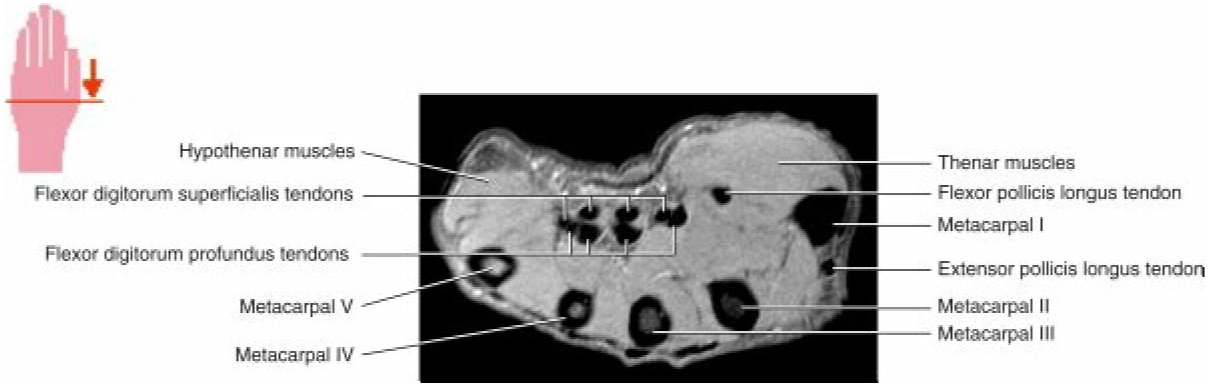


FIG. 2.42 Imaging of the anatomy of the hand.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Lower Extremity

Pelvis, Hip, and Thigh

- **Osteology**
  - ▫ Pelvic girdle is composed of two innominate (coxal) bones that articulate with the sacrum and proximal femora.
  - ▫ Each innominate bone is composed of three united bones: ilium, ischium, and pubis (Fig. 2.43).
    - Converge in the acetabular fossa at the triradiate fusion center
  - ▫ Ilium: important landmarks include iliac crest, anterior-superior iliac spine (ASIS), anterior-inferior iliac spine (AIIS), and posterior-superior iliac spine (PSIS)
    - Iliac crest: palpable rim of ilium, important site for bone graft harvest (iliac tubercle 5 cm posterior to ASIS)
    - ASIS: palpable at lateral edge of inguinal ligament; origin of sartorius muscle and transverse and internal abdominal muscles
    - AIIS: less prominent; origin of direct head of the rectus femoris and iliofemoral ligament (Y ligament of Bigelow)
    - PSIS: 4–5 cm lateral to S2 spinous process; important landmark for posterior iliac crest bone graft harvest
  - ▫ Ischium: posterior column of acetabulum
    - **Iliac spine separates greater and lesser sciatic notch; sacrospinous ligament (anterior sacrum to ischial spine) separates greater and lesser sciatic foramina**.
    - Greater sciatic notch: posterior and superior to acetabulum
    - Ischial tuberosity: origin of hamstrings; sacrotuberous ligament (posterolateral sacrum to ischial tuberosity) inferior border of lesser sciatic foramen
  - ▫ Pubis: anterior pelvic ring, bilateral pubic rami articulate at pubic symphysis
    - Iliopectineal eminence: anterior pelvic rim prominence at the union of the ilium and pubis
    - Iliopsoas muscle/tendon traverses a groove between iliopectineal eminence and AIIS.
  - ▫ Acetabulum: normally anteverted (15 degrees) and obliquely oriented in coronal plane (45 degrees caudally)
    - Posterosuperior articular surface thickened to accommodate weight bearing
    - Inferior surface contains the acetabular (cotyloid) notch,

which is bound by the transverse acetabular ligament.

- Femur
  - Femoral head blood supply changes with age (Table 2.24).
  - **Pediatric femoral nail insertion: piriformis starting point threatens the posterosuperior retinacular vessels (potential for femoral head avascular necrosis [AVN]).**
  - Adult posterior hip approach: do not completely transect the quadratus femoris muscle (to prevent damage to medial femoral circumflex artery [MFCA]).
  - Femoral neck normally anteverted approximately 14 degrees in relation to femoral condyles (range 1–40 degrees)
  - Femoral neck shaft angle averages 127 degrees (begins at 141 degrees in the fetus).
  - Proximal femoral trabecular architecture is illustrated in Fig. 2.44.
  - Ossification: femoral head is usually not present at birth but appears as one large physis that includes both trochanters at about the age of 11 months and fuses at age 18 years.
    - Slipped capital femoral epiphysis occurs through the femoral head physis (zone of hypertrophy).
    - Distal femoral epiphysis is present at birth and fuses at age 19 years.

- **Arthrology**
  - Hip (Fig. 2.45)
    - Ball-and-socket diarthrodial joint
    - Stability is based primarily on the bony architecture.
    - Fibrocartilaginous labrum deepens acetabulum, enhancing stability. Labral functions include load transmission, maintenance of vacuum seal, regulation of synovial fluid hydrodynamics, and joint lubrication.

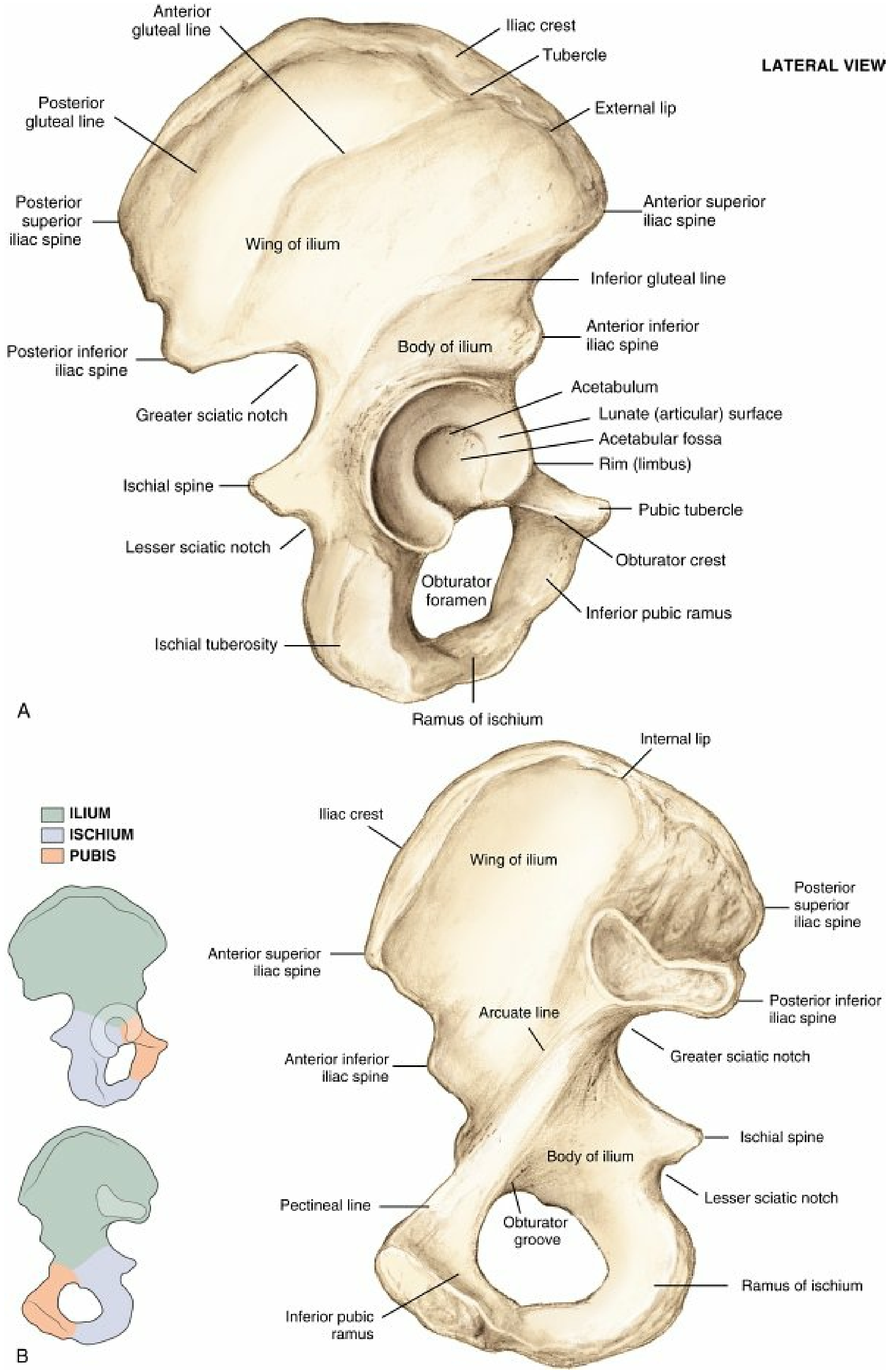


FIG. 2.43 (A) Osseous anatomy of the outer portion of the hemipelvis. (B) Osseous anatomy of the inner portion of the hemipelvis from the sacroiliac joint to the pubic symphysis.

From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figures 6-1 and 6-2.

Table 2.24

Femoral Head Blood Supply

Age	Blood Supply
Birth to 4 yr	Primary medial and lateral circumflex arteries (from deep femoral artery) Ligamentum teres with posterior division of obturator artery
4 yr to adult	Negligible amount from lateral circumflex artery Minimal amount from ligamentum teres Posterosuperior and posteroinferior retinacular from medial femoral circumflex artery
Adult	Medial femoral circumflex to lateral epiphyseal artery

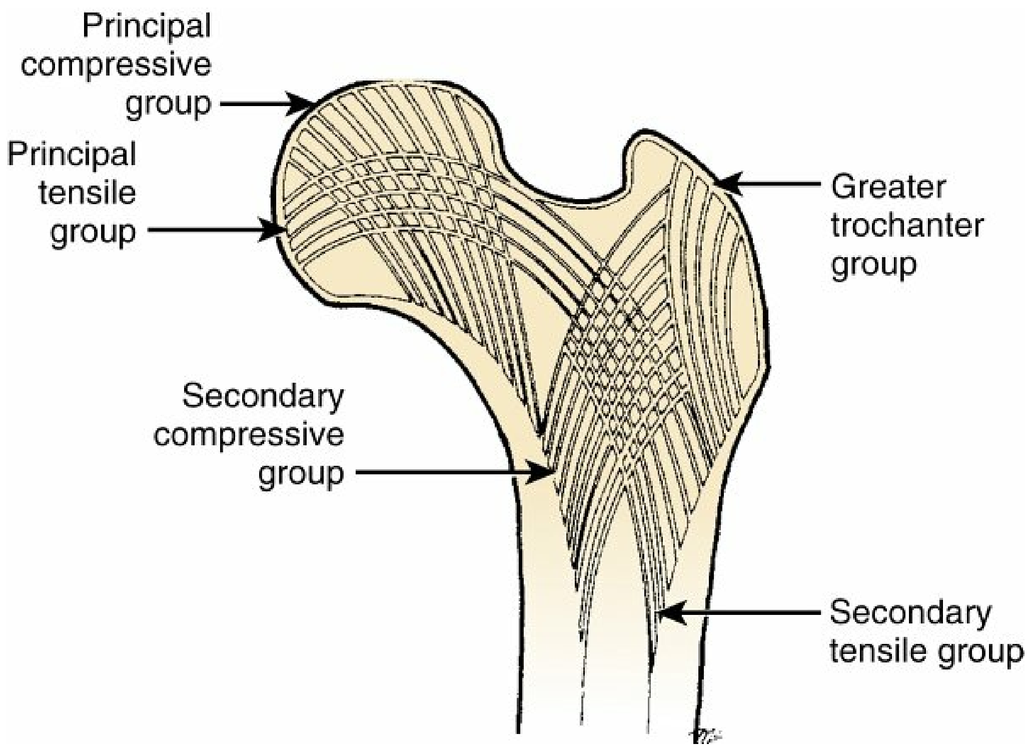


FIG. 2.44 Hip trabeculae. Trabecular patterns help determine the presence of osteopenia and displacement of femoral neck fractures. From DeLee JC: Fractures and dislocations of the hip. In Rockwood CA Jr et al, editors: *Fractures in adults,* ed 3, Philadelphia, 1991, JB Lippincott, p 1488.

- Hip joint capsule: extends anteriorly to intertrochanteric crest but posteriorly only partially across femoral neck
    - Basicervical and intertrochanteric crest regions are extracapsular.
    - Capsular ligaments
        - Iliofemoral ligament (Y ligament of Bigelow) is the strongest ligament in the body and attaches AIIS to

intertrochanteric line in an inverted Y manner.
            - Ischiofemoral and pubofemoral ligaments are weaker but provide additional stability.
            - Capsule tight in extension, relaxed in flexion
        - Ligamentum teres: arises from apex of cotyloid notch and attaches to fovea of femoral head
            - Transmits an arterial branch of the posterior division of the obturator artery to femoral head (less significant in adults)
    - Sacroiliac joint
        - Stabilized by posterior and anterior sacroiliac ligaments and interosseous ligaments
    - Symphysis pubis
        - Stabilized by superior and arcuate pubic ligaments and contains fibrocartilaginous disc
- **Muscles that act on the hip joint are shown in** Figs. 2.46 and 2.47 and listed in Table 2.25.
- **Muscles of the thigh that do not cross the hip joint are listed in** Table 2.26.
- **Muscles with dual innervation**

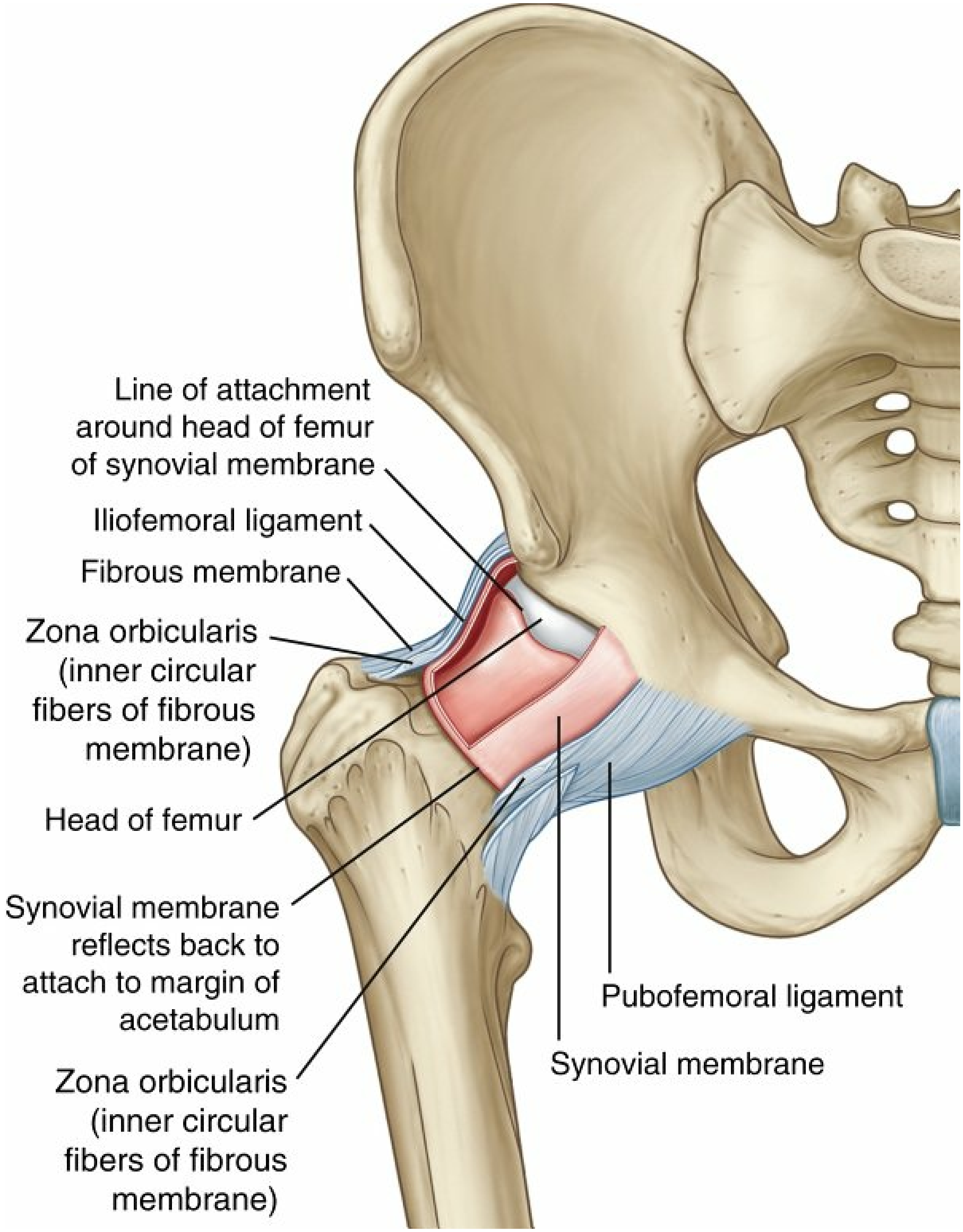


FIG. 2.45 Anatomy of the hip joint.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

□ Pectineus (obturator and femoral)
□ Adductor magnus (obturator and tibial)
□ Biceps femoris (long head, tibial nerve; short head, peroneal nerve)

- **Muscles that cross the hip and knee (more prone to strain injury)**
  - Rectus femoris (hip flexion, knee extension)
  - Sartorius (hip flexion, knee flexion)
  - Gracilis (hip adduction, knee flexion)
  - Biceps femoris, long head (hip extension, knee flexion)
  - Semimembranosus (hip extension, knee flexion)
  - Semitendinosus (hip extension, knee flexion)

Knee and Leg

- **Osteology**
  - Distal femur
    - Two femoral condyles (medial condyle is larger)
    - Sulcus terminalis on lateral femoral condyle
  - Tibia
    - Proximal medial facet (oval and concave) and lateral facet (circular and convex)
    - Gerdy tubercle on lateral side of the proximal tibia is the insertion of the iliotibial (IT) tract.
    - Tibial shaft is triangular in cross section and tapers to its thinnest point at the junction of the middle and distal thirds before widening again to form the tibial plafond.
  - Fibula
    - Fibular head attachment point for lateral collateral ligament and insertion point for biceps femoris tendon; popliteofibular ligament attaches to fibular styloid process.

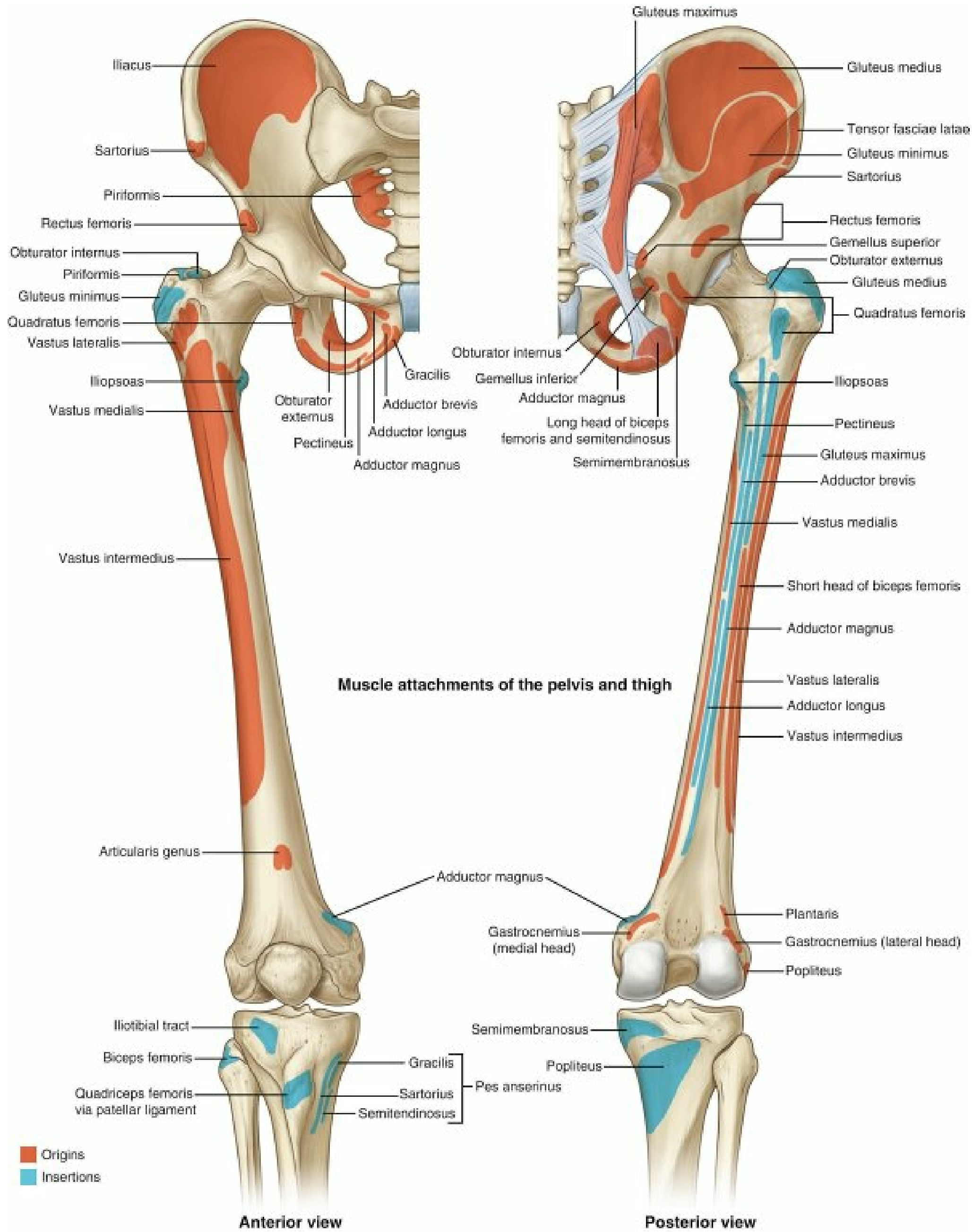
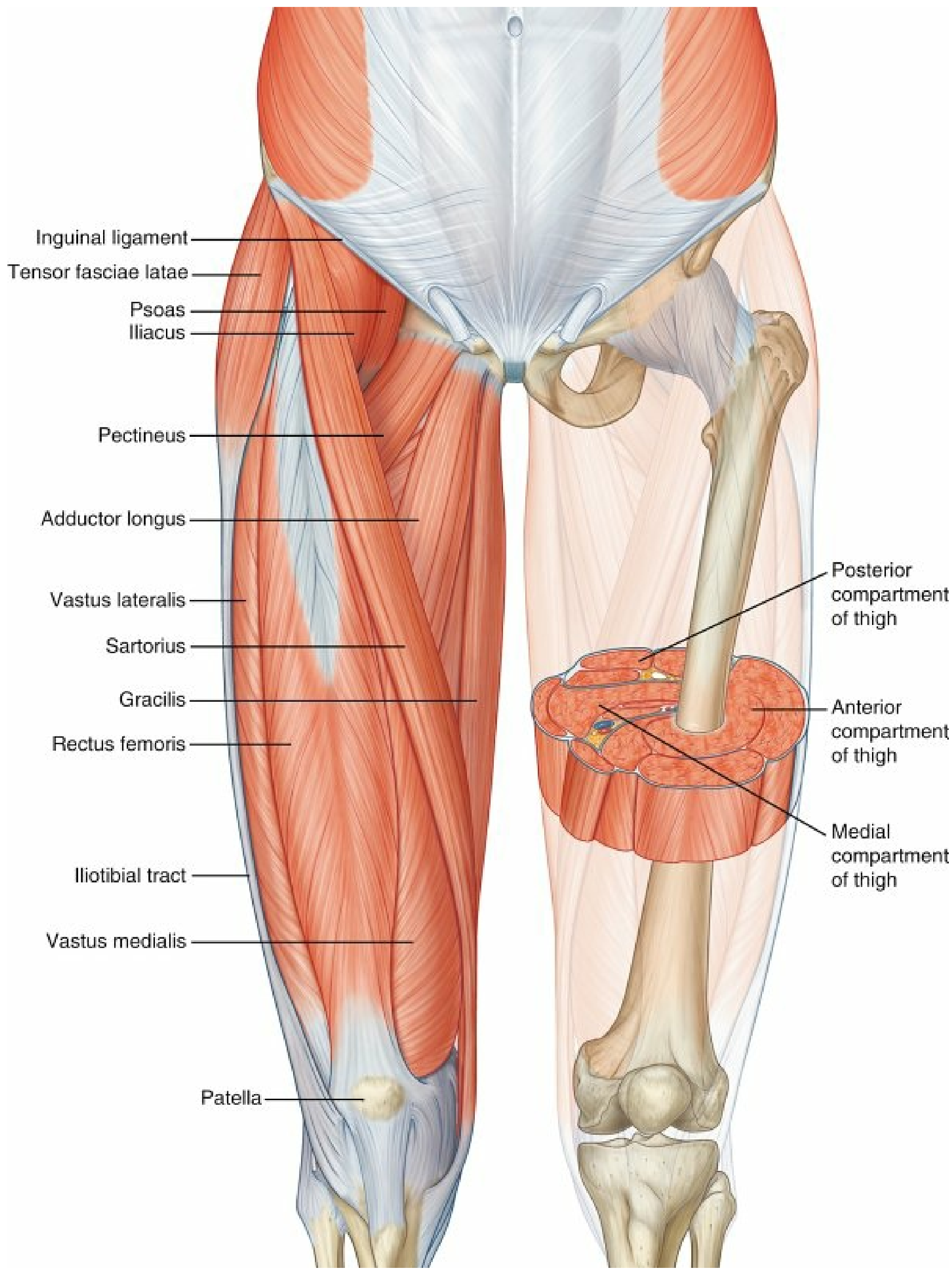


FIG. 2.46 Muscle attachments of the pelvis and thigh.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.



Inguinal ligament
Tensor fasciae latae
Psoas
Iliacus
Pectineus
Adductor longus
Vastus lateralis
Sartorius
Gracilis
Rectus femoris
Iliotibial tract
Vastus medialis
Patella
Posterior compartment of thigh
Anterior compartment of thigh
Medial compartment of thigh

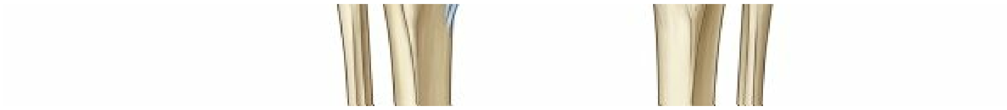


FIG. 2.47 Thigh muscles and compartments.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.25

Muscles that Cross the Hip Joint

Muscle	Origin	Insertion	Nerve	Seg
Flexors				
Iliacus	Iliac fossa	Lesser trochanter	Femoral	L2-
Psoas	Transverse processes of L1–5	Lesser trochanter	Femoral	L2-
Pectineus	Pectineal line of pubis	Pectineal line of femur	Femoral and obturator	L2-
Rectus femoris	Anterior inferior iliac spine (direct head), acetabular rim (indirect head)	Patella and tibial tubercle	Femoral	L2-
Sartorius	Anterior superior iliac spine	Proximal medial tibia	Femoral	L2-
Extensors				
Biceps femoris (long head)	Medial ischial tuberosity	Fibular head/lateral tibia	Tibial	L5-
Semitendinosus	Distal medial ischial tuberosity	Anterior tibial crest	Tibial	L5-
Semimembranosus	Proximal lateral ischial tuberosity	Oblique popliteal ligament Posterior capsule Posterior/medial tibia Popliteus Medial meniscus	Tibial	L4-
Adductors				
Adductor magnus	Inferior pubic ramus/ischial tuberosity	Linea aspera/adductor tubercle	Obturator (P) and tibial	L2-
Adductor brevis	Inferior pubic ramus	Linea aspera/pectineal line	Obturator (P)	L2-
Adductor longus	Anterior pubic	Linea aspera	Obturator (A)	L2-

	ramus			
Gracilis	Inferior symphysis/pubic arch	Proximal medial tibia	Obturator (A)	L2-
External Rotators				
Gluteus maximus	Ilium, posterior gluteal line	Iliotibial band/gluteal sling (femur)	Inferior gluteal	L5-
Piriformis	Anterior sacrum/sciatic notch	Proximal greater trochanter	Piriformis	S2
Obturator externus	Ischiopubic rami/obturator	Trochanteric fossa	Obturator	L2-
Obturator internus	Ischiopubic rami/obturator membrane	Medial greater trochanter	Obturator internus	L5-
Superior gemellus	Outer ischial spine	Medial greater trochanter	Obturator internus	L5-
Inferior gemellus	Ischial tuberosity	Medial greater trochanter	Quadratus femoris	L5-
Quadratus femoris	Ischial tuberosity	Quadrate line of femur	Quadratus femoris	L5-
Abductors				
Gluteus medius	Ilium between posterior and anterior gluteal lines	Greater trochanter	Superior gluteal	L4-
Gluteus minimus	Ilium between anterior and inferior gluteal lines	Anterior border of greater trochanter	Superior gluteal	L4-
Tensor fasciae latae (tensor fasciae femoris)	Anterior iliac crest	Iliotibial band	Superior gluteal	L4-

A, anterior; *P,* posterior.

Table 2.26

Muscles of the Thigh

Muscle	Origin	Insertion	Innervation
Anterior Thigh			
Vastus lateralis	Iliotibial line/greater trochanter/lateral linea aspera	Lateral patella	Femoral
Vastus medialis	Iliotibial line/medial linea aspera/supracondylar line	Medial patella	Femoral
Vastus intermedius	Proximal anterior femoral shaft	Patella	Femoral
Posterior Thigh			
Biceps femoris (long head)	Medial ischial tuberosity	Fibular head/lateral tibia	Tibial
Biceps (short head)	Lateral linea aspera/lateral intermuscular septum	Lateral tibial condyle	Peroneal
Semitendinosus	Distal medial ischial tuberosity	Anterior tibial crest	Tibial
Semimembranosus	Proximal lateral ischial tuberosity	Oblique popliteal ligament Posterior capsule Posterior/medial tibia Popliteus Medial meniscus	Tibial

- Fibular neck has a groove for the common peroneal nerve.

□ Patella: the largest sesamoid bone

- Serves three functions:
  - Fulcrum for quadriceps to facilitate knee extension
  - Protects knee joint
  - Enhances lubrication and nutrition of knee
- Accessory or “bipartite” patella may represent failure of fusion of the superolateral corner of the patella and is commonly confused with patellar fractures.

▪ **Arthrology**

□ Knee (Fig. 2.48)

- Capsule extends 15 mm distal to the joint (care should be taken to avoid intraarticular pin placement).

- **Shape of tibial plateau confers greater articular congruity medially than laterally (important for consequences of meniscectomy).**
- Menisci
    - Deepen concavity of facets, help protect the articular surface, and assist in rotation of the knee

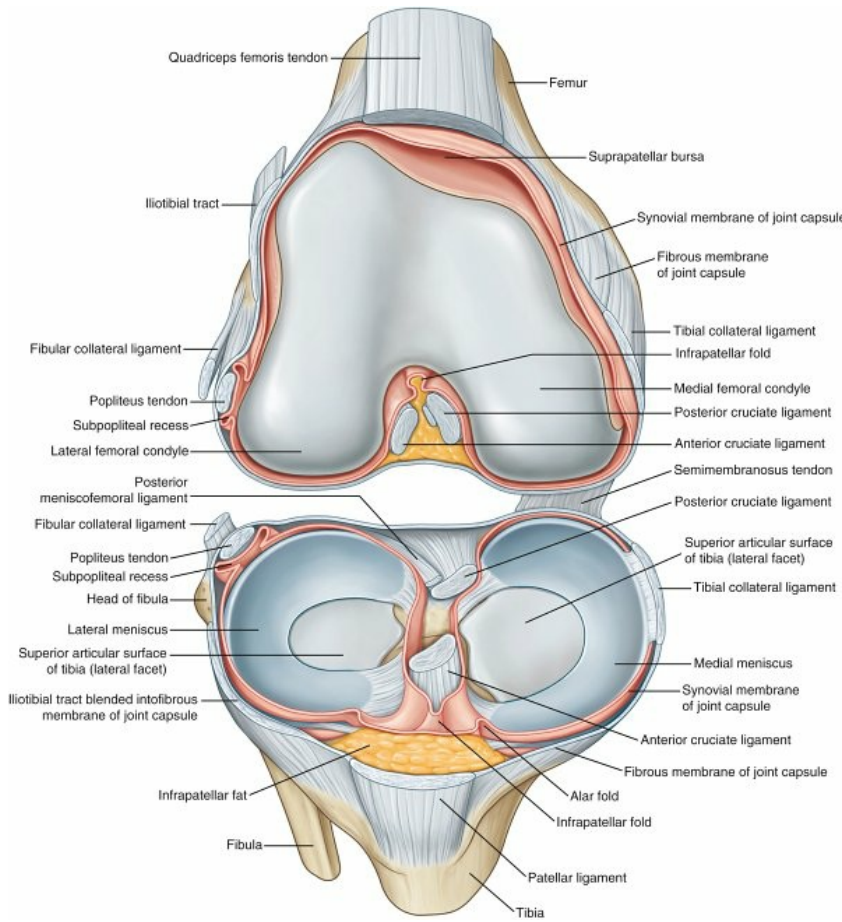


FIG. 2.48 Anatomy of the knee.
From Drake RL et al, editors: *Gray's atlas of anatomy*, ed 2, Philadelphia, 2015, Churchill Livingstone.

- Peripheral third of menisci are vascular and can be repaired (red zone); inner two-thirds are nourished by synovial fluid (white zone) and have limited healing capacity.
- **Medial meniscus tears three times more often than the more mobile lateral meniscus.**
    - Saphenous nerve must be protected during medial meniscus repair.
- Lateral meniscus is associated with meniscal cysts and discoid menisci; posterior horn is most common site of tears in acute ACL tear.

- Protect peroneal nerve during lateral meniscus repair.

- Ligaments
  - Stability of the knee is enhanced by a complex arrangement of ligaments (Table 2.27).
  - Each cruciate ligament is made up of two portions, or bundles. Anterior bundles of each cruciate tight in flexion.
  - **Anterior cruciate ligament (ACL) has anteromedial (tight in flexion) and posterolateral (tight in extension) bundles; posterior ligament (PL) bundle assessed with pivot shift test.**

Table 2.27

Ligaments of the Knee

Ligament	Proximal Attachment	Distal Attachment	Functio
Anterior Knee			
Retinacular	Vastus medialis and vastus lateralis, tibial condyles	Medial and lateral patella	Forms a caps
Medial patellofemoral	Between adductor tubercle and medial femoral epicondyle (Schottle point)	Superomedial patella	Resists l trans patel
Posterior Knee			
Posterior fibers	Femoral condyles	Tibial condyles	Forms p caps
Oblique popliteal	Semimembranosus tendon	Lateral femoral condyle/posterior capsule	Strengtl caps
Medial Knee			
Superficial MCL	Medial femoral epicondyle	Medial tibial metaphysis	Resists v force
Deep MCL	Medial femoral epicondyle/medial meniscus	Medial tibial condyle/medial meniscus	Resists v force med men
Posterior oblique	Adductor tubercle	Posteromedial tibia	Resists v force rotat
Lateral Knee			

Lateral collateral	Lateral epicondyle	Lateral fibular head	Resists v
Popliteofibular ligament	Popliteus tendon	Fibular styloid process	Resists e rotat
Arcuate ligament	Lateral femoral condyle, over popliteus	Posterior tibia/fibular head	Posterio
Cruciates/Intraarticular Ligaments			
Anterior cruciate	Posteromedial lateral femoral condyle	Anterior intercondylar tibia	Resists a trans hype
Posterior cruciate	Anteromedial femoral condyle	Posterior sulcus of tibia	Resists p trans hype
Humphrey	Medial femoral condyle (anterior to PCL)	Posterolateral meniscus	Stabilize men
Wrisberg	Medial femoral condyle (posterior to PCL)	Posterolateral meniscus	Stabilize men
Transverse meniscal	Anteromedial meniscus	Anterolateral meniscus	Stabilize

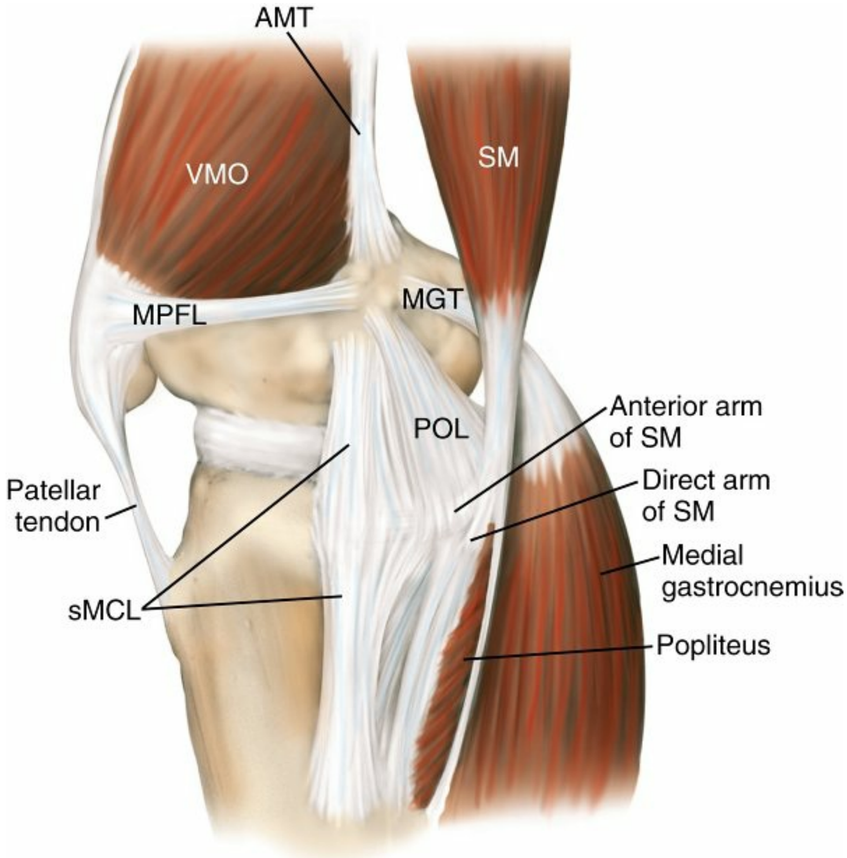


FIG. 2.49 Illustration of the main medial knee structures (right knee). *AMT,* Adductor magnus tendon; *MGT,* medial gastrocnemius tendon; *POL,* posterior oblique ligament; *SM,* semimembranosus; *sMCL,* superficial medial collateral ligament; *VMO,* vastus medialis obliquus.
From Scott WN: *Insall & Scott surgery of the knee,* ed 5, Philadelphia, 2012, Elsevier, Figure 39-3.

    - Mnemonic: "AMPLe" (*a*ntero*m*edial and *p*ostero*l*ateral bundle, *PL* tight in *e*xtension)
- **Posterior cruciate ligament (PCL) has anterolateral (tight in flexion) and posteromedial (tight in extension) bundles.**
    - Mnemonic: "PAL" (*P*CL has *a*ntero*l*ateral bundle)
- Ligament of Humphrey (anterior to PCL) and the Wrisberg ligament (posterior to PCL). Mnemonic: *H* comes before *W* in alphabet; Humphrey is anterior, Wrisberg posterior.
- Medial collateral ligament (MCL) has superficial and deep components; superficial MCL attaches 5–7 cm distal to joint (Fig. 2.49)
- Posterior oblique ligament resists internal rotation with knee in full extension.
- Posterolateral corner (PLC): fibular collateral

    ligament, popliteus tendon, and popliteofibular ligament; other PLC structures include biceps femoris tendon, lateral head of gastrocnemius, biceps femoris, arcuate ligament, and posterolateral capsule (Fig. 2.50).

- Isolated injuries to the PCL cause the greatest instability at 90 degrees of knee flexion.
- Combined injuries of the PCL and PLC result in increasing instability as the knee is flexed from 30 to 90 degrees.
- Dial test: rotational instability at 30 degrees = PLC injury, at 30 and 90 degrees combined PLC + PCL injury
- **Medial patellofemoral ligament (MPFL) runs from proximal third of medial patella to Schottle point on the femur (between adductor tubercle and medial epicondyle); just distal to vastus medialis obliquus.**

□ Proximal tibiofibular joint: stabilized by anterior and posterior ligaments of the head of the fibula

▪ **Muscles and tendons around the knee**

□ Popliteal fossa is bordered by the gastrocnemius lateral and medial heads, the semimembranosus, and the biceps; the plantaris muscle makes up the floor of the fossa.

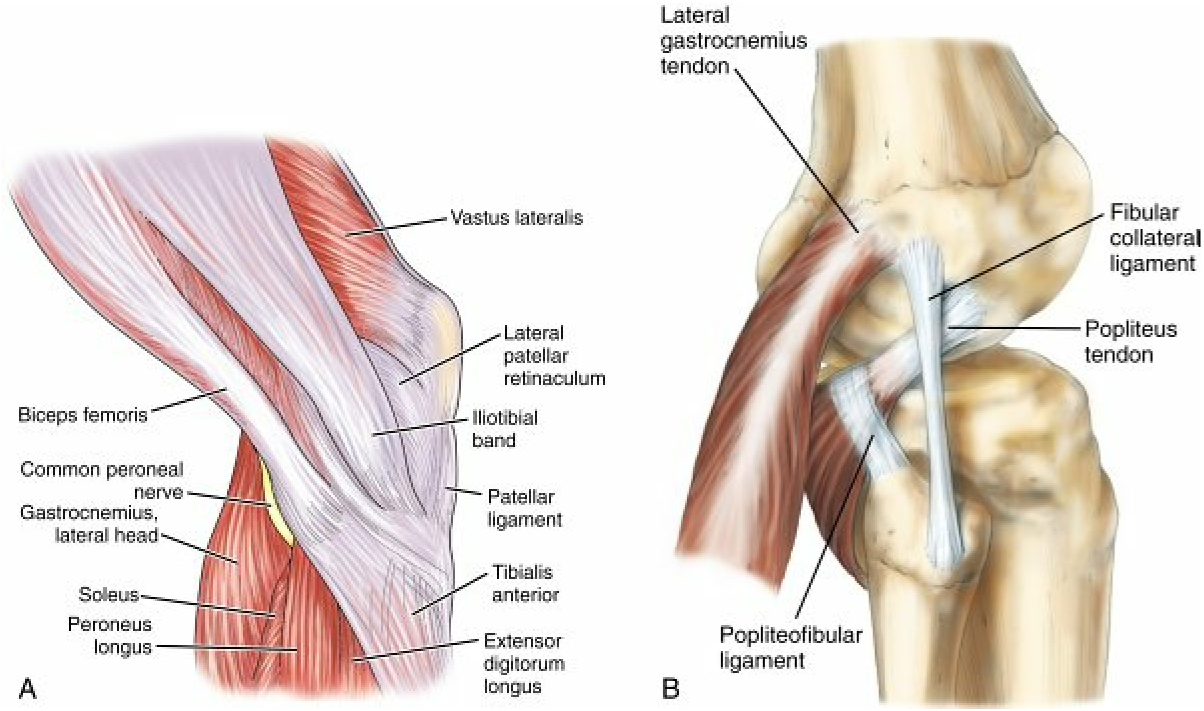


FIG. 2.50 (A) Lateral aspect of the knee, layer 1. (B) Drawing of lateral knee dissection.
From Scott WN: *Insall & Scott surgery of the knee*, ed 5, Philadelphia, 2012, Elsevier, Figures 1-70 and 40-1.

- □ Autograft hamstrings for ACL reconstruction: gracilis and semitendinosus (run deep to the sartorial fascia and superficial to the superficial MCL); saphenous nerve at risk with harvest

- **Muscles of the leg**
  - Origins and insertions are shown in Fig. 2.51.
  - Divided into compartments (anterior, lateral, superficial posterior, and deep posterior) (Fig. 2.52, Table 2.28)
  - Anterior and lateral compartments are supplied by the common peroneal nerve (anterior supplied by the deep peroneal nerve, and lateral supplied by the superficial peroneal nerve) and contain postaxial muscles.
  - Posterior compartments are supplied by the tibial nerve and contain preaxial muscles.
  - Four compartment releases of the leg are key testable material and are summarized in Table 2.29.
  - The saphenous nerve (termination of the femoral nerve) is subcutaneous.

Ankle and Foot

- **Osteology**
  - □ Ankle
    - Distal tibia flares to form an inferior quadrilateral surface for articulation with the talus and the pyramid-shaped medial

malleolus.

- Laterally, the fibular notch forms articulation with the fibula.
- Lateral malleolus: distal fibula expansion that extends beyond distal tip of medial malleolus and serves as lateral buttress of ankle joint

- ◻ Foot
    - Divided into the hindfoot (talus and calcaneus), midfoot (navicular, cuboid, and three cuneiforms), and forefoot (metatarsals and phalanges)
    - Tarsals: include talus, calcaneus, cuboid, navicular, and three cuneiforms
    - Talus (Fig. 2.53)
        - Two-thirds of the talus covered with cartilage; no muscular attachments.
        - **Groove posteriorly for the tendon of the flexor hallucis longus (FHL). Os trigonum (if present) lateral to FHL.**
        - Posterior process (for posterior talofibular ligament)
        - Talar body wider anteriorly, conferring greater stability with ankle in dorsiflexion
        - Talar neck connects with the head, which in turn articulates with the navicular distally and the calcaneus inferiorly.
        - **Primary blood supply to the talar body is from the artery of the tarsal canal (posterior tibial artery) (Fig. 2.54).**

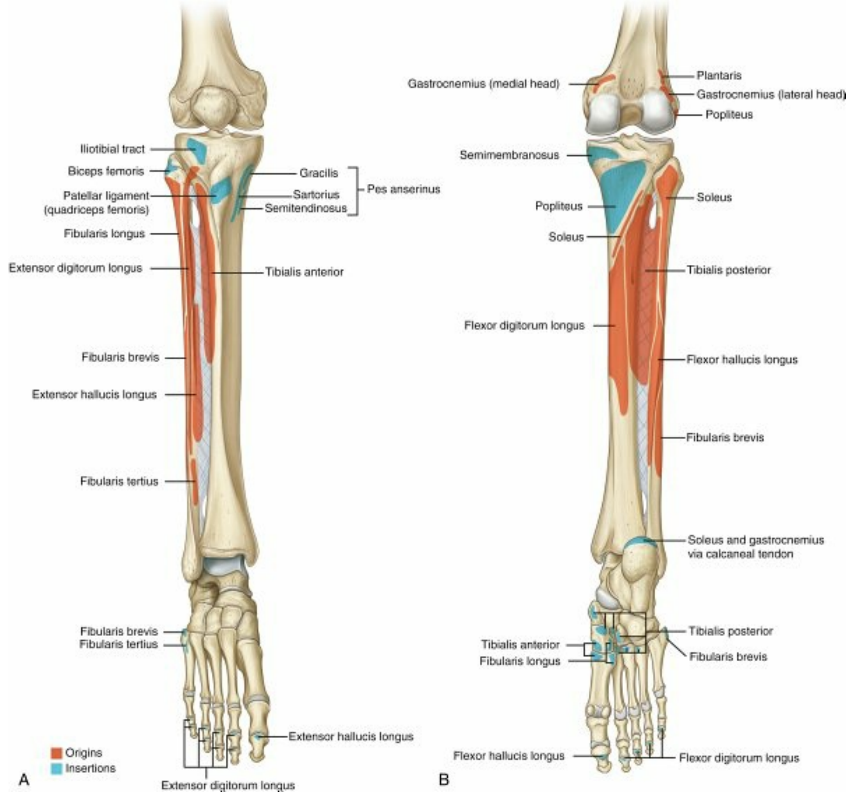


FIG. 2.51 Origins and insertions of muscles of the leg. (A) Anterior view. (B) Posterior view.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

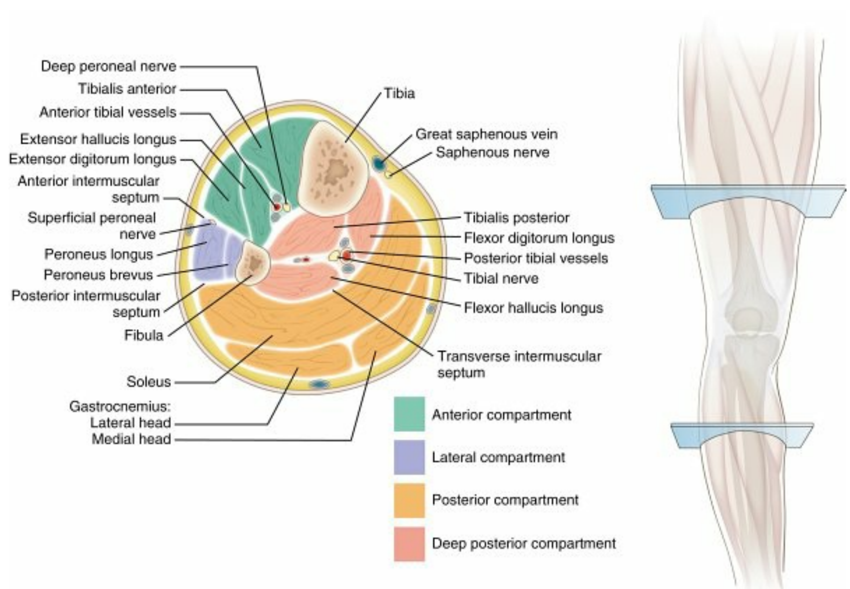


FIG. 2.52 Compartments of leg.
From DeLee JC, Drez D Jr: *Orthopaedic sports medicine: principles and practice,* Philadelphia, 1994, WB Saunders, p 1618.

Table 2.28

Leg Compartments

Muscle	Origin	Insertion	Action

Anterior Compartment			
Tibialis anterior	Lateral tibia	Medial cuneiform, first metatarsal	Dorsiflexing, inverting foot
Extensor hallucis longus	Midfibula	Great toe, distal phalanx	Dorsiflexing, extending toe
Extensor digitorum longus	Tibial condyle/fibula	Toe, middle and distal phalanges	Dorsiflexing, extending toe
Peroneus tertius	Fibula and extensor digitorum longus tendon	Fifth metatarsal	Everting, dorsiflexing, abducting foot
Lateral Compartment			
Peroneus longus	Proximal fibula	Medial cuneiform, first metatarsal	Everting, plantar flexing, abducting foot
Peroneus brevis	Distal fibula	Tuberosity of fifth metatarsal	Everting foot
Superficial Posterior Compartment			
Gastrocnemius	Posterior medial and lateral femoral condyles	Calcaneus	Plantar flexing foot
Soleus	Fibula/tibia	Calcaneus	Plantar flexing foot
Plantaris	Lateral femoral condyle	Calcaneus	Plantar flexing foot
Deep Posterior Compartment			
Popliteus	Lateral femoral condyle, fibular head	Proximal tibia	Flexing, internally rotating knee
Flexor hallucis longus	Fibula	Great toe, distal phalanx	Plantar flexing great toe
Flexor digitorum longus	Tibia	Second to fifth toes, distal phalanges	Plantar flexing toes, foot
Tibialis	Tibia, fibula,	Navicular,	Inverting/plantar

posterior	interosseous membrane	medial cuneiform	flexing foot

- Other blood supply is from the superior neck vessels (anterior tibial artery) and the artery of the tarsal sinus (dorsalis pedis).
- Calcaneus
    - Three surfaces that articulate with the talus: a large posterior facet, an anterior facet, and a middle facet
    - Sustentaculum tali is an overhanging horizontal eminence on the anteromedial surface of the calcaneus.
        - **Supports the middle articular surface above it and has an inferior groove for the FHL tendon (can be injured by long screw during calcaneous open reduction and internal fixation [ORIF])**

Table 2.29

Compartment Releases

Compartment	Muscles	Neurovascular Structures Released
Anterior	Tibialis anterior, extensor hallucis longus, extensor digitorum longus, peroneus tertius	Deep peroneal nerve and anterior tibial artery
Lateral	Peroneus longus and brevis	Superficial peroneal nerve
Superficial posterior	Gastrocnemius-soleus complex, plantaris	Sural nerve
Deep posterior	Popliteus, flexor hallucis longus, flexor digitorum longus, tibialis posterior	Posterior tibial artery and vein, tibial nerve, peroneal artery and vein

- Cuboid
    - Grooved on the plantar surface by the peroneus longus
- Navicular
    - Medial plantar projection serves as the insertion for the posterior tibial tendon.
- Cuneiforms
    - **Intermediate cuneiform does not extend as far distally as the medial cuneiform, allowing the**

second metatarsal to "key" into place (Fig. 2.55)

- Metatarsals
    - First metatarsal has a plantar crista that articulates with the fibular and tibial sesamoids contained within the flexor hallucis brevis tendon.
- Phalanges
    - Similar to those of the hand. Great toe (analogous to thumb) has two phalanges, and the remaining digits have three.
- Ossification
    - Calcaneus, talus, and usually the cuboid are present at birth.
    - Lateral cuneiform appears during the first year, the medial cuneiform during the second year, and the intermediate cuneiform and navicular during the third year.
    - Posterior center for the calcaneus usually appears during the eighth year.
    - The second through fifth metatarsals have two ossification centers:
        - Primary center in the shaft
        - Secondary center for the head, which appears at ages 5 to 8 years

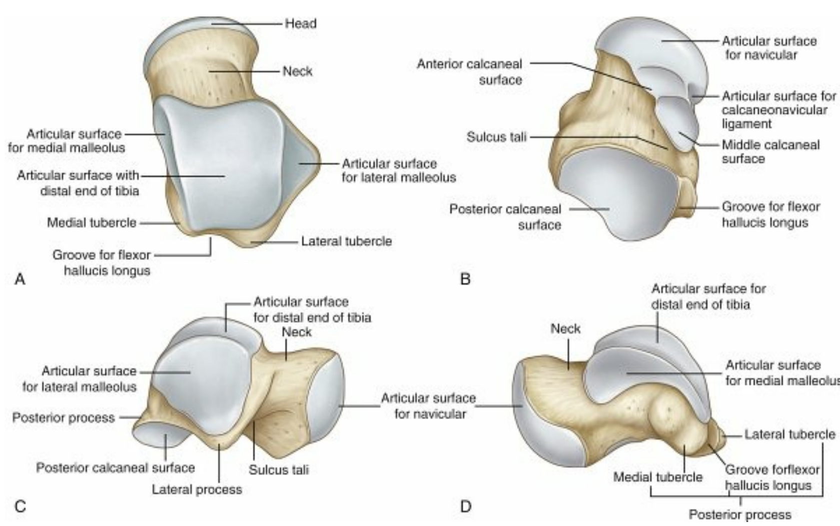


FIG. 2.53 (A to D) Talus from different angles.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

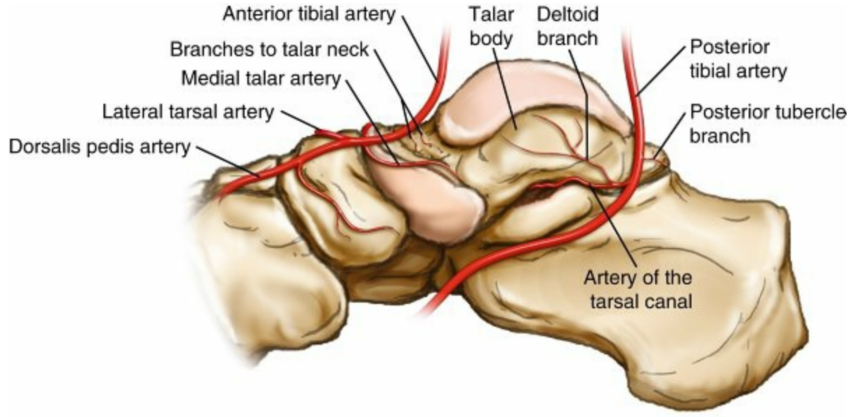


FIG. 2.54 Arterial supply to the talus.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figure FA-26.

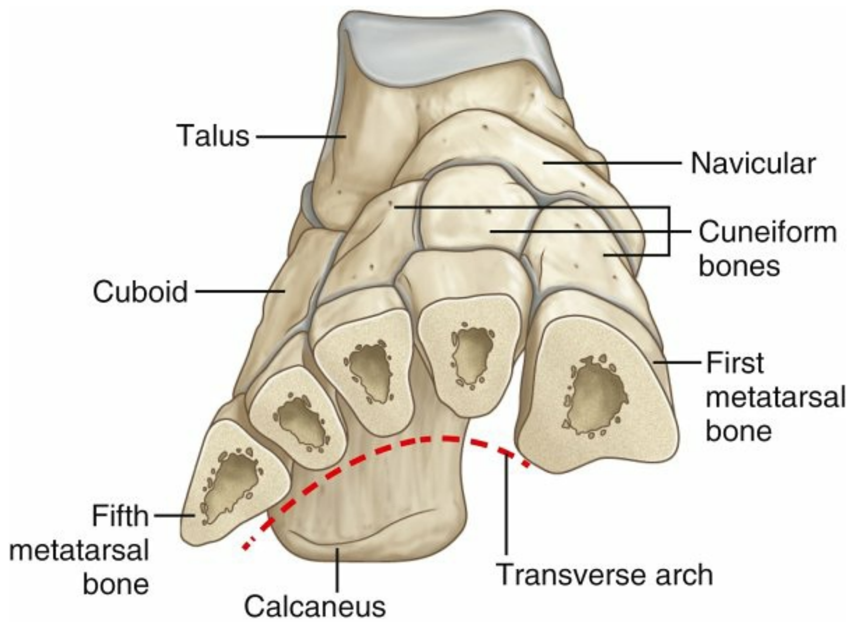


FIG. 2.55 Bones of the foot.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

- Phalanges and first metatarsal have secondary centers at their bases that appear proximally during the third or fourth year and distally during the sixth or seventh year.

- **Arthrology**
  - Distal tibiofibular joint
    - Ankle syndesmosis (connection between the tibia and fibula) supported by four ligaments: anterior and posterior inferior tibiofibular ligaments, a transverse tibiofibular ligament, and an interosseous ligament. Syndesmotic injury often referred to as "high-ankle sprain."
    - Anteroinferior tibiofibular ligament (AITFL) is an oblique band that connects the bones anteriorly. **Bony avulsion of this ligament in adolescents may result in a Tillaux fracture.**

- □ Ankle joint (Table 2.30)
  - Deltoid ligament composed of two layers (Fig. 2.56)
    - Superficial layer (tibionavicular and tibiocalcaneal) crosses ankle and subtalar joint.
    - Deep layer (anterior and posterior tibiotalar) crosses ankle joint only.
  - Lateral fibular ligaments: anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL) (Fig. 2.57)
    - ATFL is the weakest and is intracapsular (intracapsular thickening). Injured with lateral ankle sprain.
    - **CFL crosses both the ankle and the subtalar joint.**
    - Position of the ankle is critical when the lateral ligament complex is tested. Plantar flexion tightens the anterior talofibular ligament, and inversion with neutral flexion tightens the calcaneofibular ligament.
- □ Subtalar joint
  - Talar plantar facets articulate with the calcaneus (Fig. 2.58).
  - Stability is derived from four ligaments: medial ligament, lateral ligament, interosseous talocalcaneal ligament, and cervical ligament.
- □ Intertarsal joints: several ligamentous structures are important (Table 2.31).
- □ **Plantar calcaneonavicular ligament (spring ligament) supports head of talus; attenuated in pes planus deformity (Fig. 2.59).**
- □ Other joints
  - Base of first metatarsal is not ligamentously connected to second metatarsal.
  - **Lisfranc ligament connects medial (shortest) cuneiform to second (longest) metatarsal.**
    - Plantar and dorsal structure in about 20% of patients
  - Deep transverse metatarsal ligaments interconnect metatarsal heads.
    - **Digital nerve courses in a plantar direction under the transverse metatarsal ligament and is the spot where interdigital neuritis (Morton neuroma, usually the second or third interdigital space) occurs.**
    - Transverse metatarsal ligament attaches second metatarsal head to fibular sesamoid.

- Holds hallucal sesamoids in place and gives the appearance of sesamoid subluxation when the first metatarsal moves medially in hallux valgus.
- Plantar and collateral ligaments support the metatarsophalangeal joints.
  - Primary stabilizing structure of the metatarsophalangeal joint is the plantar plate.

Table 2.30

Ankle Joint

Ligament	Proximal Attachment	Distal Attachment	Function
Tibiofibular (Syndesmosis)			
Anterior inferior tibiofibular	Tibia	Fibula	Stability of ankle mortise
Interosseous	Tibia	Fibula	Stability of ankle mortise
Posterior inferior tibiofibular	Tibia	Fibula	Stability of ankle mortise
Medial Ankle (Deltoid)			
Tibionavicular	Medial malleolus	Navicular tuberosity	Limits talar external rotation
Tibiocalcaneal	Medial malleolus	Sustentaculum tali	Limits hindfoot eversion
Anterior tibiotalar	Medial malleolus	Medial surface of talus	Limits lateral displacement of talus, external rotation
Posterior tibiotalar	Medial malleolus	Inner side of talus	Limits lateral displacement
Lateral Ankle			
Anterior talofibular	Lateral malleolus	Transversely to talus anteriorly	Limits inversion in plantar flexion
Calcaneofibular	Lateral malleolus	Obliquely to calcaneus posteriorly	Limits inversion in neutral or dorsiflexion
Posterior talofibular	Lateral malleolus	Transversely to talus posteriorly	Limits posterior talar displacement and external rotation

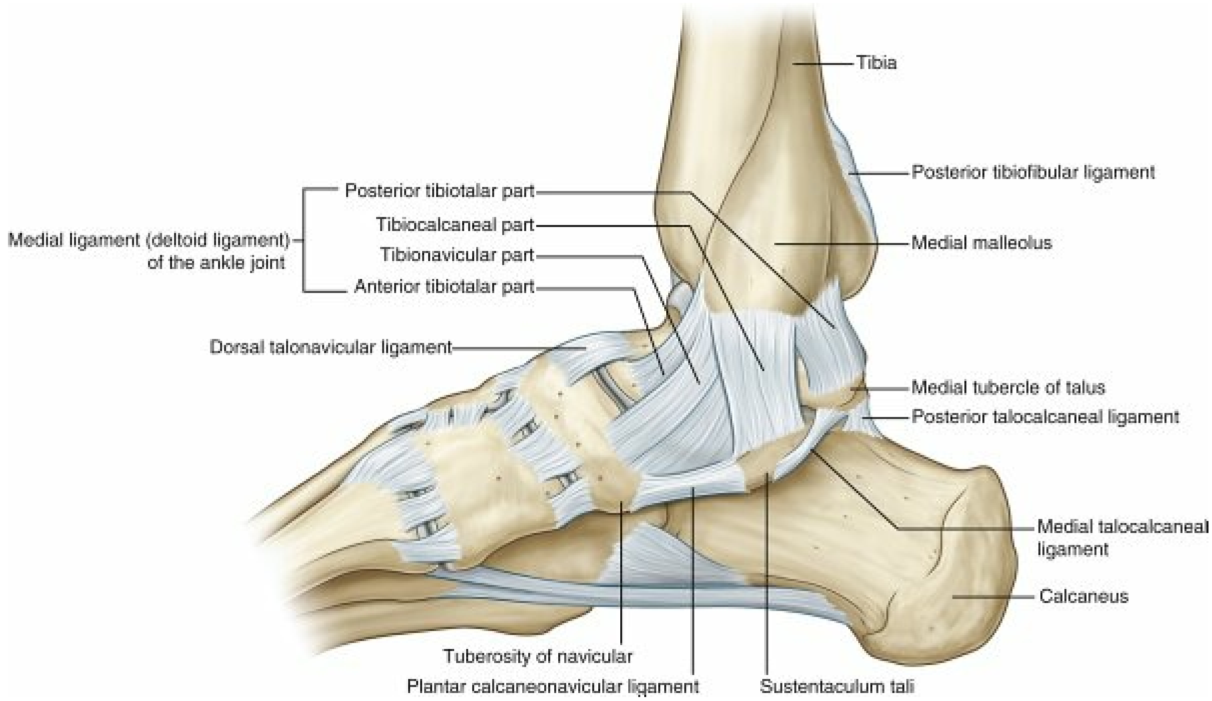


FIG. 2.56 Ligaments of the ankle (medial view).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

- **Muscles**
  - Origins and insertions of muscles are shown in Fig. 2.60.
  - Major tendons crossing the ankle joint include (Fig. 2.61)
    - Anterior (from lateral to medial): peroneus tertius, extensor digitorum longus (EDL), extensor hallucis longus (EHL), tibialis anterior
    - Medial (mnemonic: "Tom, Dick, and Harry"): *t*ibialis posterior, flexor *d*igitorum longus (FDL), and flexor *h*allucis longus
    - Lateral: peroneal tendons with longus (superficial) and brevis (deep)
    - Posterior: Achilles
      - Maximum anteroposterior dimension on MRI is 8 mm.
  - Only one dorsal intrinsic muscle of the foot: the extensor digitorum brevis (EDB) (innervated by the lateral terminal branch of the deep peroneal nerve)
  - Arrangement of muscles and tendons in the foot is best considered in layers (Fig. 2.62, Table 2.32).
    - Plantar heel spurs originate in the flexor digitorum brevis (medial plantar nerve innervation).
    - Lumbrical muscles are located plantar to the transverse metatarsal ligament, and interosseous tendons are dorsal.
    - The tendons are arranged about the toe as shown in Fig. 2.63.
  - Neuromuscular interactions of the foot are listed in Table 2.33.

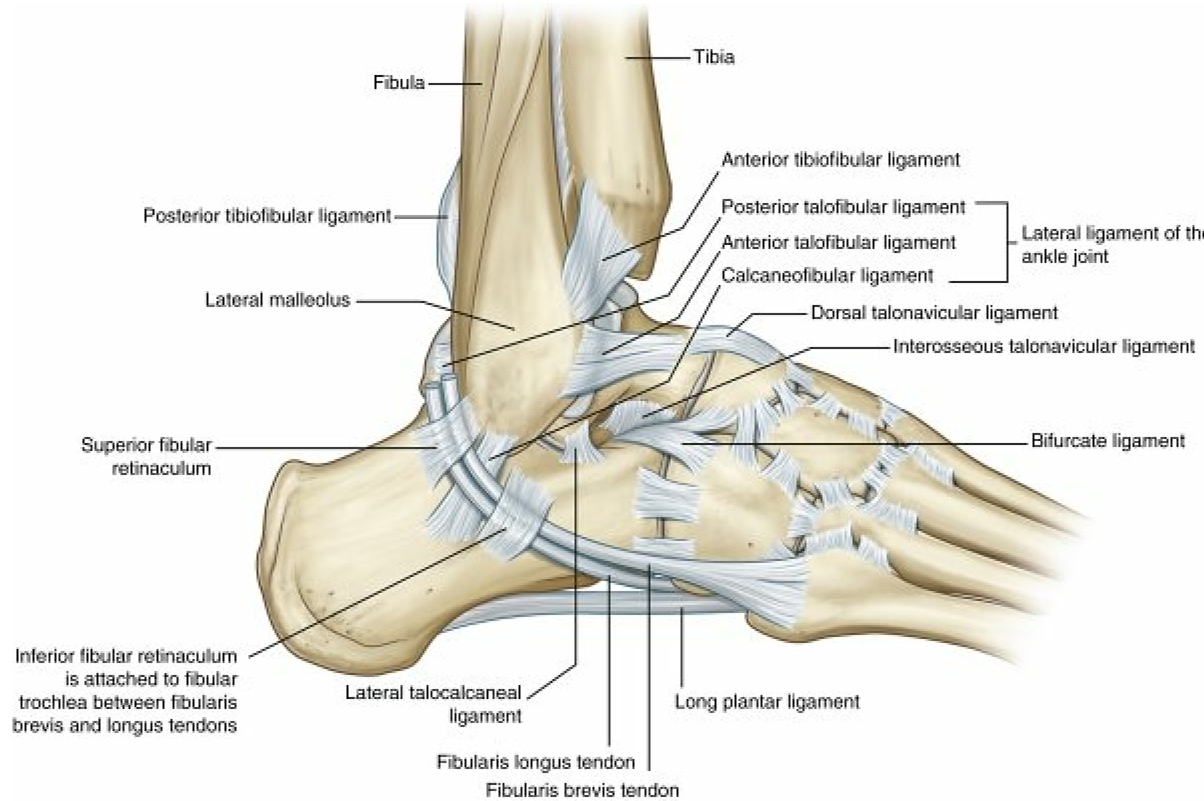


FIG. 2.57 Ligaments of the ankle (lateral view).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

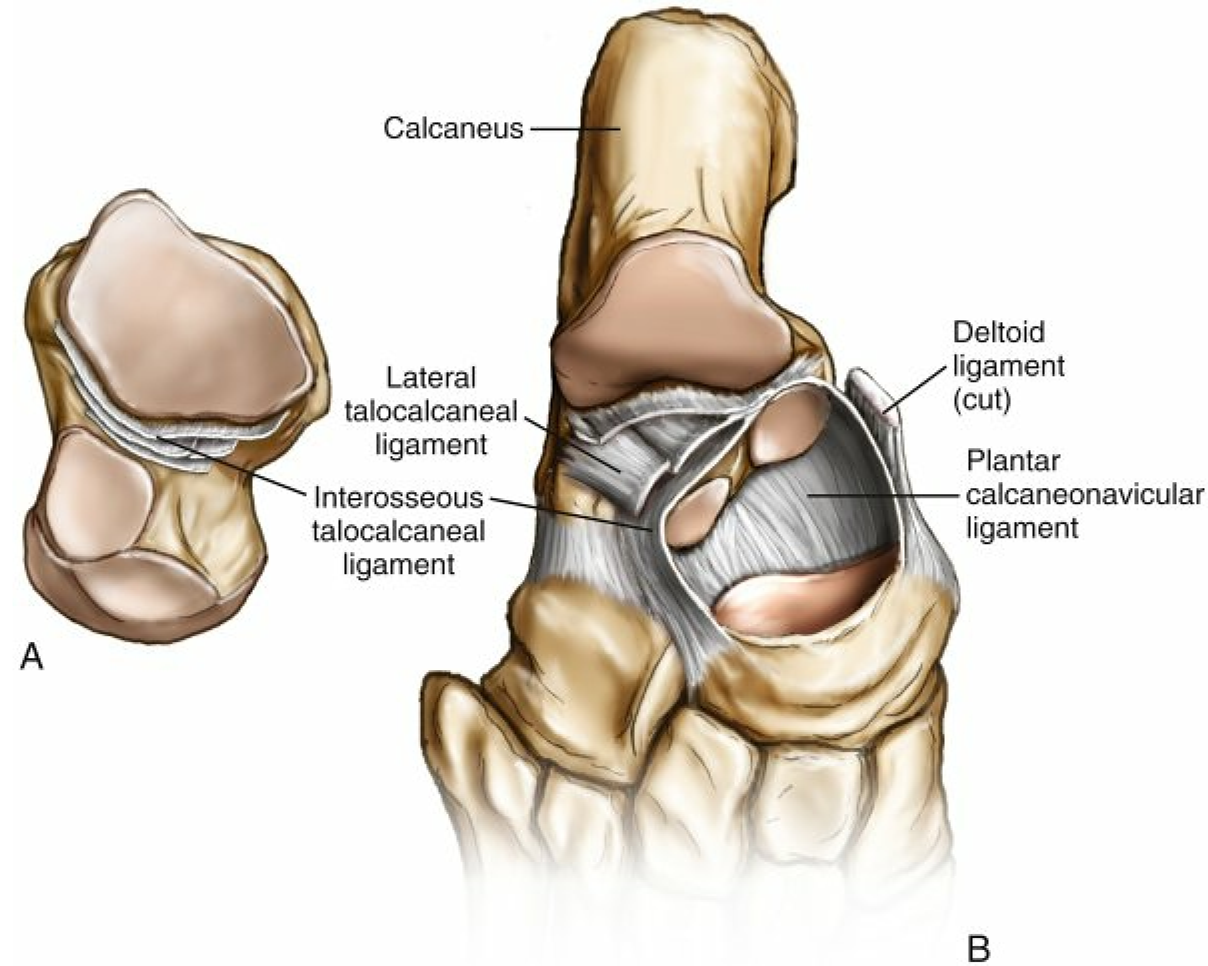


FIG. 2.58 (A) Inferior view of the talus showing the interosseous ligament. (B) Dorsal view of the hindfoot (after removal of the talus) showing the calcaneal facets with the spring ligaments.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 8-7.

Table 2.31

Ligaments of Intertarsal Joints

Ligament	Common Name	Proximal Attachment	Distal Attachment
Interosseous talocalcaneal	Cervical	Talus	Calcaneus
Calcaneocuboid/calcaneonavicular	Bifurcate	Calcaneus	Cuboid and navicular
Calcaneocuboid-metatarsal	Long plantar	Calcaneus	Cuboid and first to fifth metatarsals
Plantar calcaneocuboid	Short plantar	Calcaneus	Cuboid
Plantar calcaneonavicular	Spring	Sustentaculum tali	Navicular
Tarsometatarsal	Lisfranc	Medial cuneiform	Second metatarsal base

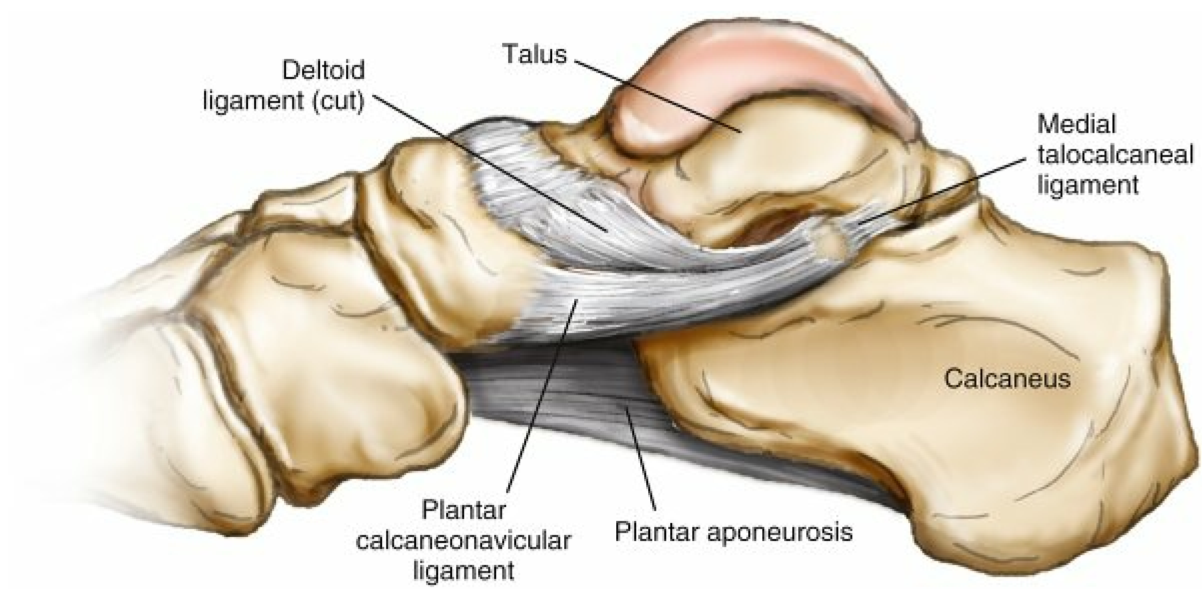


FIG. 2.59 Calcaneonavicular (spring) ligament.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 8-6.

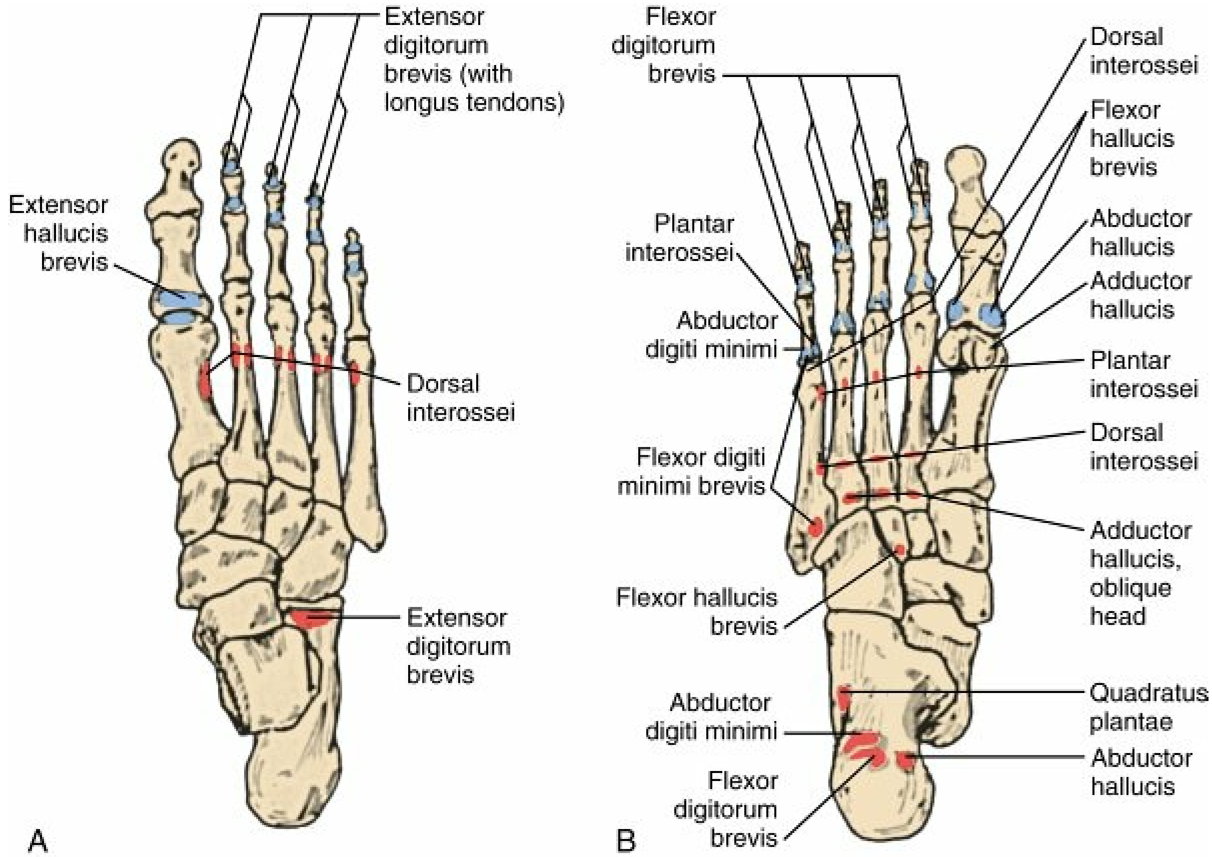


FIG. 2.60 Origins and insertions of the muscles of the foot. (A) Dorsal view. (B) Plantar view. From Jenkins DB: *Hollinshead's functional anatomy of the limbs and back,* ed 6, Philadelphia, 1991, Saunders, Figure 20-7.

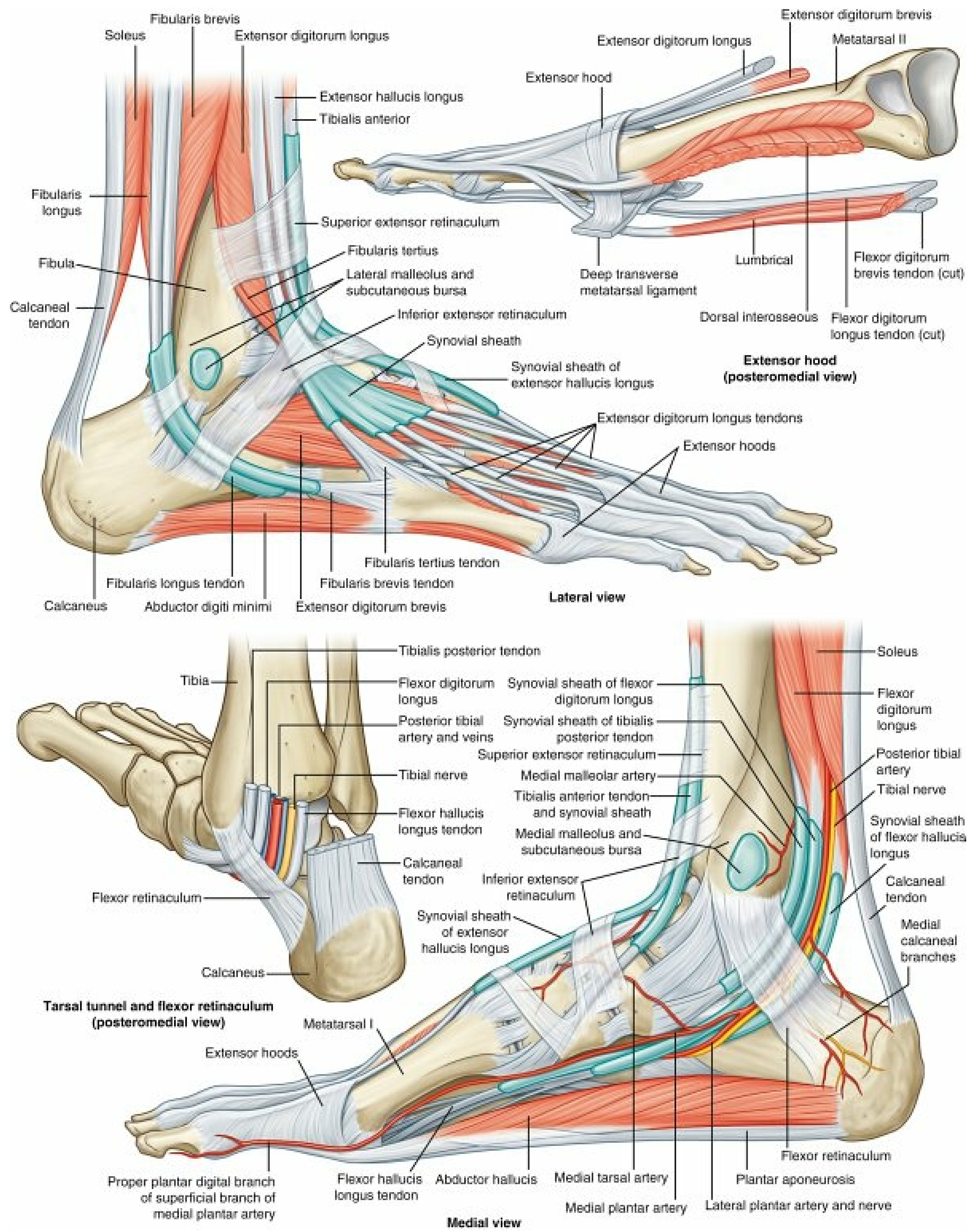
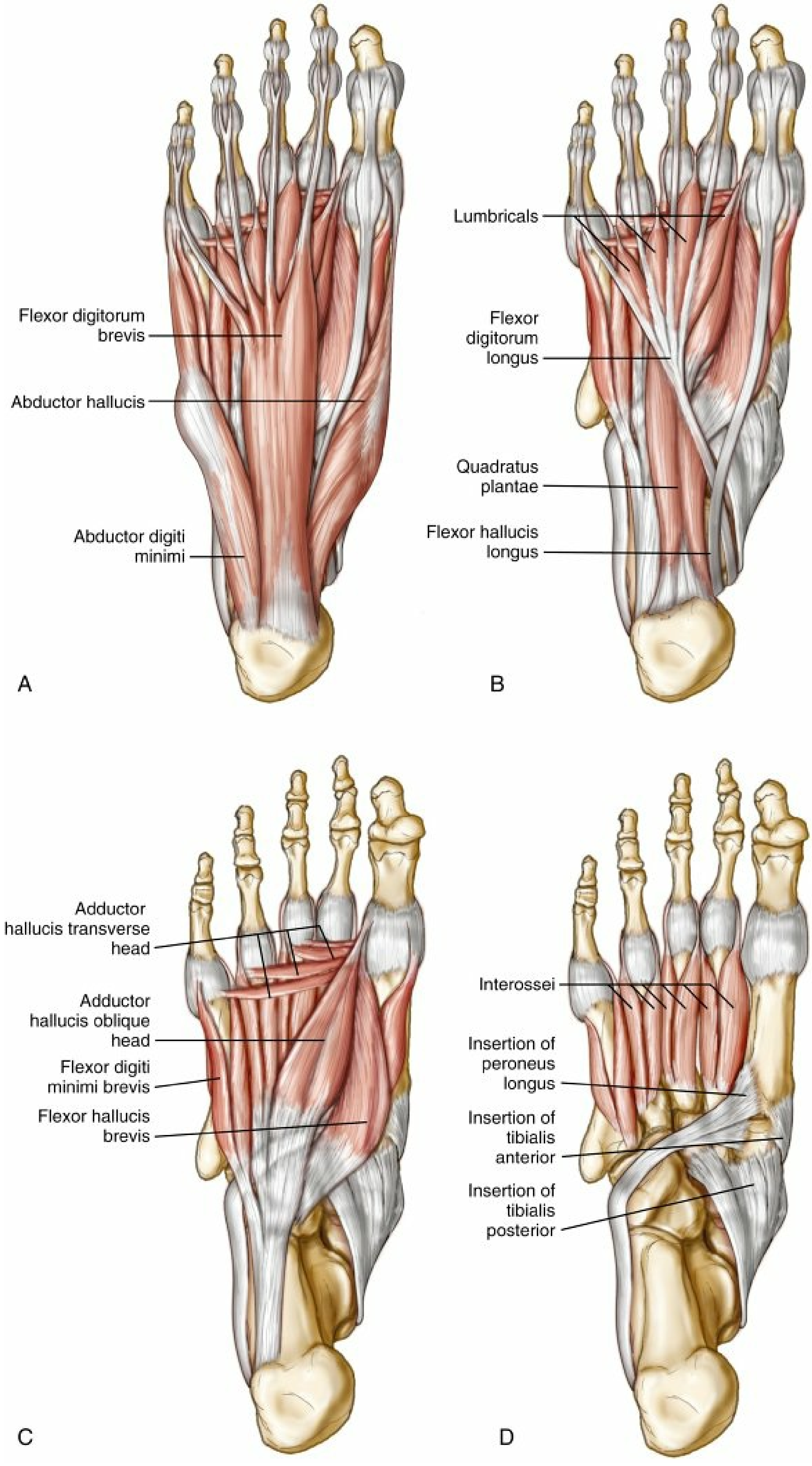


FIG. 2.61 Anatomy of the foot.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.



Flexor digitorum brevis
Abductor hallucis
Abductor digiti minimi
A
Lumbricals
Flexor digitorum longus
Quadratus plantae
Flexor hallucis longus
B
Adductor hallucis transverse head
Adductor hallucis oblique head
Flexor digiti minimi brevis
Flexor hallucis brevis
C
Interossei
Insertion of peroneus longus
Insertion of tibialis anterior
Insertion of tibialis posterior
D

FIG. 2.62 Four layers of the plantar surface of the foot. (A) First layer. (B) Second layer. (C) Third layer. (D) Fourth layer.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures FA-17 to FA-20.

Table 2.32

Muscles of Foot

Muscle	Origin	Insertion	Action	Inner
Dorsal Layer				
Extensor digitorum brevis	Superolateral calcaneus	Base of proximal phalanges	Extending	Deep ne
First Plantar Layer				
Abductor hallucis	Calcaneal tuberosity	Base of great toe, proximal phalanx	Abducting great toe	Media ne
Flexor digitorum brevis	Calcaneal tuberosity	Distal phalanges of second to fifth toes	Flexing toes	Media ne
Abductor digiti minimi	Calcaneal tuberosity	Base of small toe	Abducting small toe	Latera ne
Second Plantar Layer				
Quadratus plantae	Medial and lateral calcaneus	Flexor digitorum longus tendon	Helping flex distal phalanges	Latera ne
Lumbrical muscles	Flexor digitorum longus tendon	Extensor digitorum longus tendon	Flexing metatarsophalangeal joint, extending interphalangeal joint	Media lat ne
Flexor digitorum longus and flexor hallucis longus	Tibia/fibula	Distal phalanges of digits	Flexing toes, inverting foot	Tibial
Third Plantar Layer				
Flexor hallucis	Cuboid/lateral	Proximal phalanx of	Flexing great toe	Media

brevis	cuneiform	great toe		ne
Adductor hallucis	Oblique: second to fourth metatarsals	Proximal phalanx of great toe (lateral)	Adducting great toe	Latera ne
Flexor digiti minimi brevis	Base of fifth metatarsal head	Proximal phalanx of small toe	Flexing small toe	Latera ne
Fourth Plantar Layer				
Dorsal interosseous	Metatarsal	Dorsal extensors	Abducting	Latera ne
Plantar interosseous (peroneus longus and tibialis posterior)	Third to fifth metatarsals	Proximal phalanges medially	Adducting toes	Latera ne
	Fibula/tibia	Medial cuneiform/navicular	Everting/inverting foot	Super pe ne

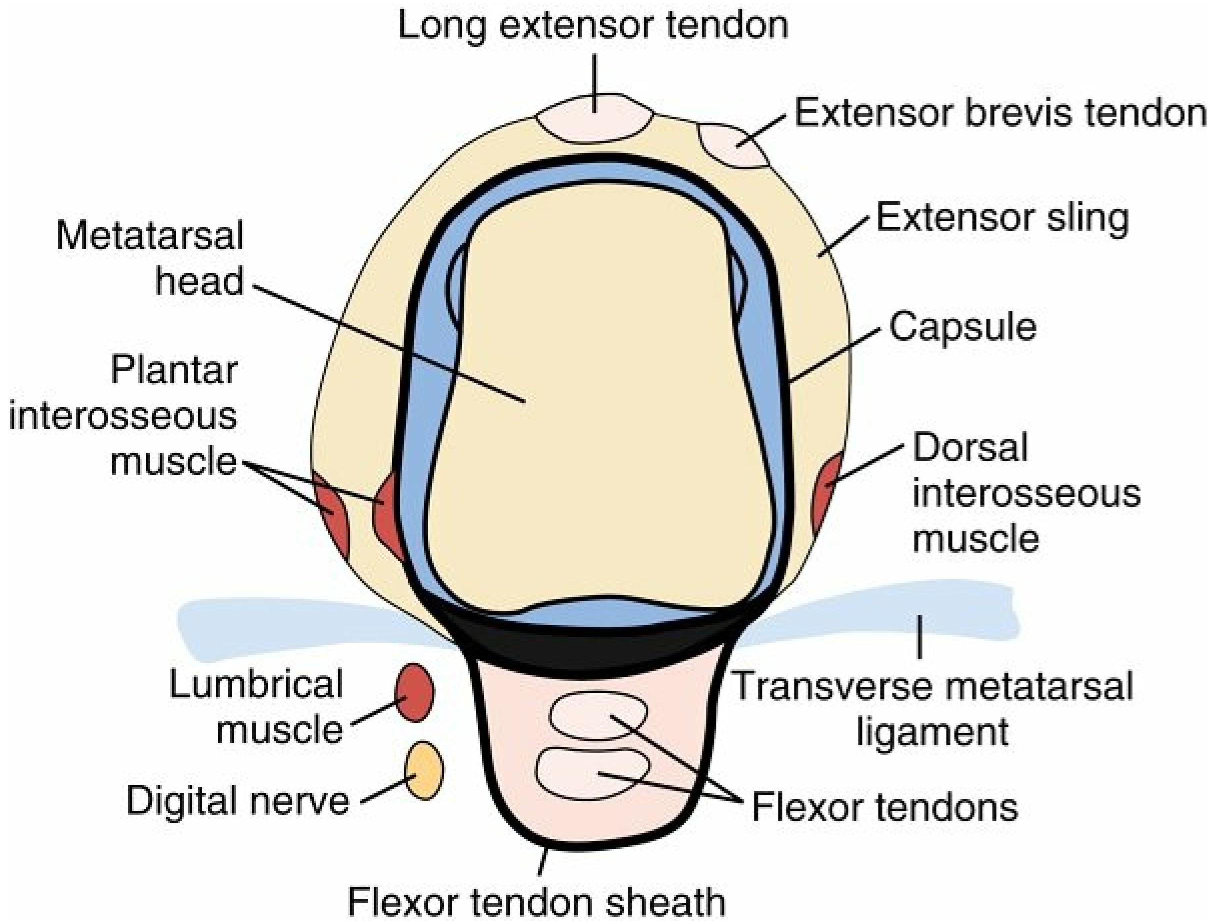


FIG. 2.63 Cross-sectional view of the toe at the metatarsal head. (From Jahss MH: *Disorders of the foot,* Philadelphia, 1982, Saunders, p 623.)

- **Nerves of the lower extremity arise from the lumbosacral plexus (** Fig. 2.64, Tables 2.34 through 2.36)
  - Lumbar plexus
    - Ventral rami of T12–L4; forms part of lumbosacral plexus
    - Anterior and posterior divisions
    - Anterior surface of quadratus lumborum under (and within) psoas major muscle
    - Genitofemoral nerve pierces the psoas and then lies on the anteromedial surface of the psoas.
  - Sacral plexus
    - Ventral rami of L4–S3; lies posterior to psoas muscle
    - Anterior and posterior divisions

Table 2.33

Foot Neuromuscular Interactions

Foot Function	Muscle	Innervation
Inversion	Tibialis anterior	Deep peroneal nerve (L4)
	Tibialis posterior	Tibial nerve (S1)
Dorsiflexion	Tibialis anterior, extensor digitorum longus, extensor hallucis longus	Deep peroneal nerve: tibialis anterior (L4), extensor digitorum longus, and extensor hallucis longus (L5)
Eversion	Peroneus longus and peroneus brevis	Superficial peroneal nerve (S1)
Plantar flexion	Gastrocnemius-soleus complex, flexor digitorum longus, flexor hallucis longus, tibialis posterior (also hindfoot inverter)	Tibial nerve (S1)

- **L5 nerve root on anterior sacrum is at risk with anteriorly placed sacroiliac screw.**

□ Sciatic foramen

- Piriformis is the "key" to the sciatic foramen—major reference point for sciatic nerve and other neurovascular structures (Fig. 2.65).
- Structures exiting the greater and lesser sciatic foramina are listed in Table 2.37.
- Superior and inferior gluteal nerve and vessels named for position relative to piriformis muscle (superior exits above muscle and inferior below)
- Pudendal nerve and vessels and nerve to obturator internus exit the greater sciatic foramen and reenter the pelvis through the lesser sciatic foramen.

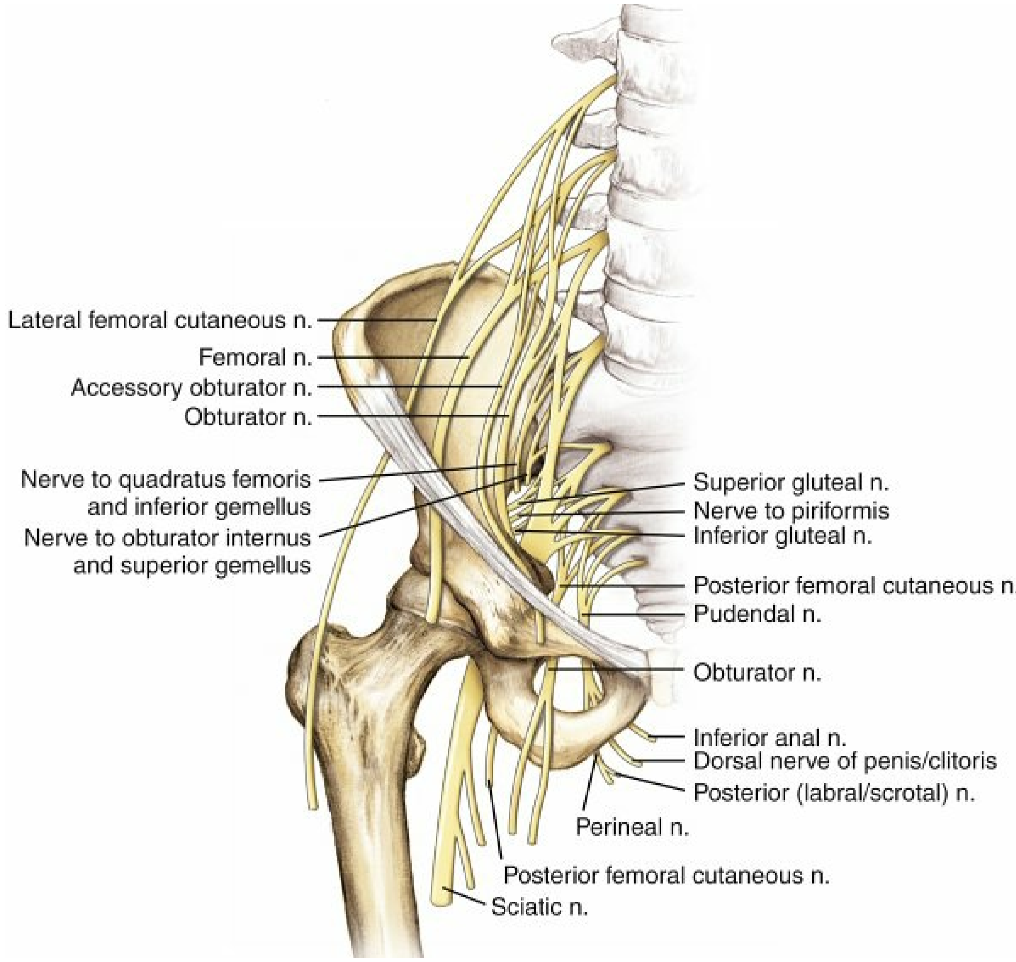


FIG. 2.64 Divisions of the lumbosacral plexus.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 6-14.

Table 2.34

Lumbosacral Plexus

Nerve	Level
Lumbar Plexus, Anterior Division	
Iliohypogastric	T12, L1
Ilioinguinal	L1
Genitofemoral	L1, 2
Obturator	L2-–4
Lumbar Plexus, Posterior Division	
Lateral femoral cutaneous nerve	L2, 3
Femoral	L2–4
Sacral Plexus, Anterior Division	
Tibial	L4–S3
Quadratus femoris	L4–S1
Obturator internus	L5–S2
Pudendal	S2–4
Coccygeus	S4
Levator ani	S3–4
Sacral Plexus, Posterior Division	
Peroneal	L4–S2
Superior gluteal	L4–S1
Inferior gluteal	L5–S2
Piriformis	S2
Posterior femoral cutaneous	S1–3

Table 2.35

Innervation of Lower Extremity

Nerve	Muscles Innervated
Femoral	Iliacus, psoas, pectineus (along with obturator nerve), sartorius, quadriceps femoris (rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis)
Obturator	Pectineus (along with femoral nerve), adductor brevis, adductor longus, adductor magnus (along with tibial nerve), gracilis
Superior gluteal	Gluteus medius, gluteus minimus, tensor fasciae latae
Inferior gluteal	Gluteus maximus
Sciatic	Semitendinosus, semimembranosus, biceps femoris (long head [tibial division] and short head [peroneal division]), adductor magnus (with obturator nerve)
Tibial	Gastrocnemius, soleus, tibialis posterior, flexor digitorum longus, flexor hallucis longus, foot intrinsic musculature (except extensor digitorum brevis) via medial and lateral plantar nerves
Deep peroneal	Tibialis anterior, extensor digitorum longus, extensor hallucis longus, peroneus tertius, extensor digitorum brevis
Superficial peroneal	Peroneus longus, peroneus brevis

Table 2.36

Important Neurology of the Lower Extremity

Joint	Function	Neurologic Level
Hip	Flexion	T12–L3
	Extension	S1
	Adduction	L2–4
	Abduction	L5
Knee	Flexion	L5, S1
	Extension	L2–4
Ankle	Dorsiflexion	L4, 5
	Plantar flexion	S1, 2
	Inversion	L4
	Eversion	S1

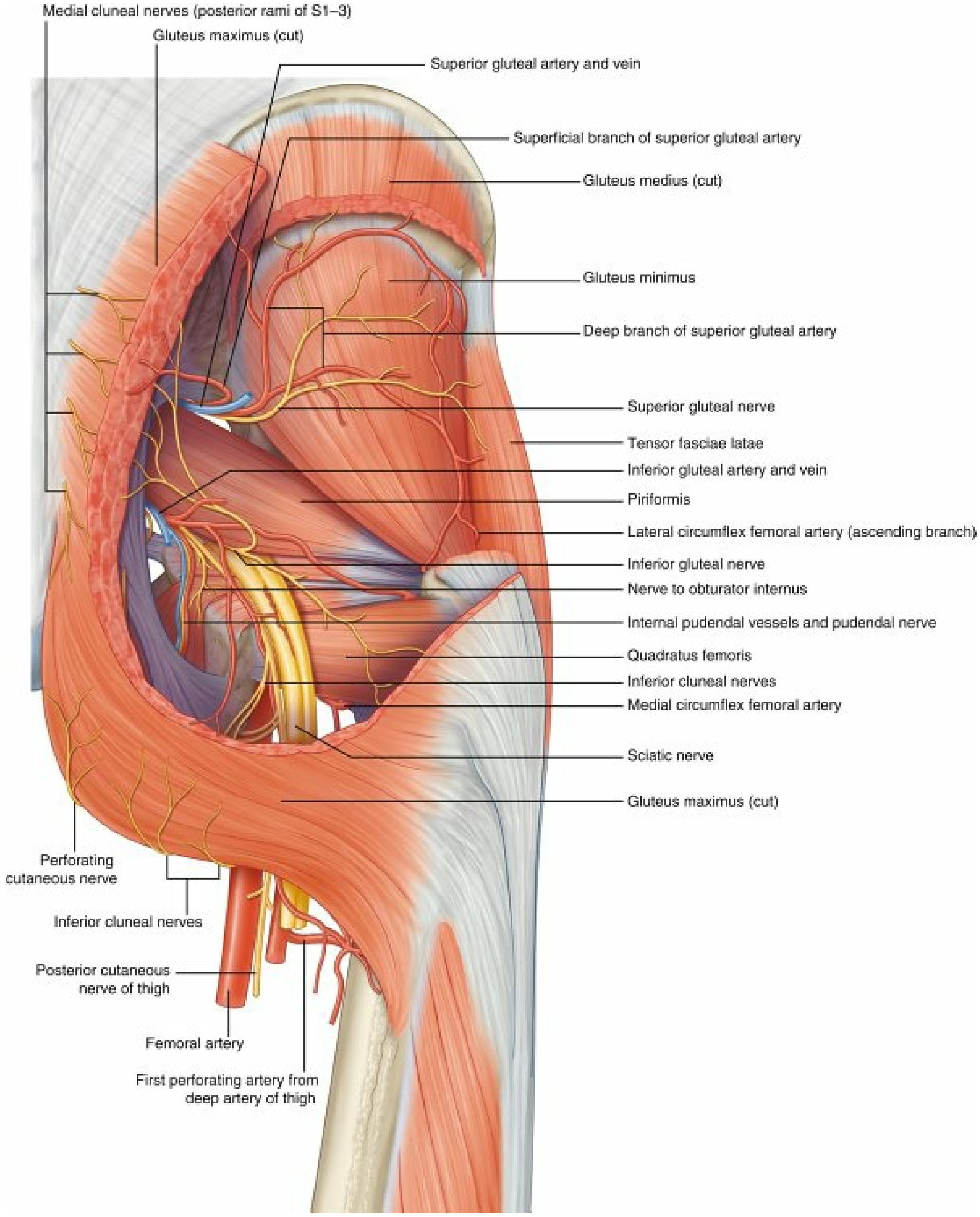


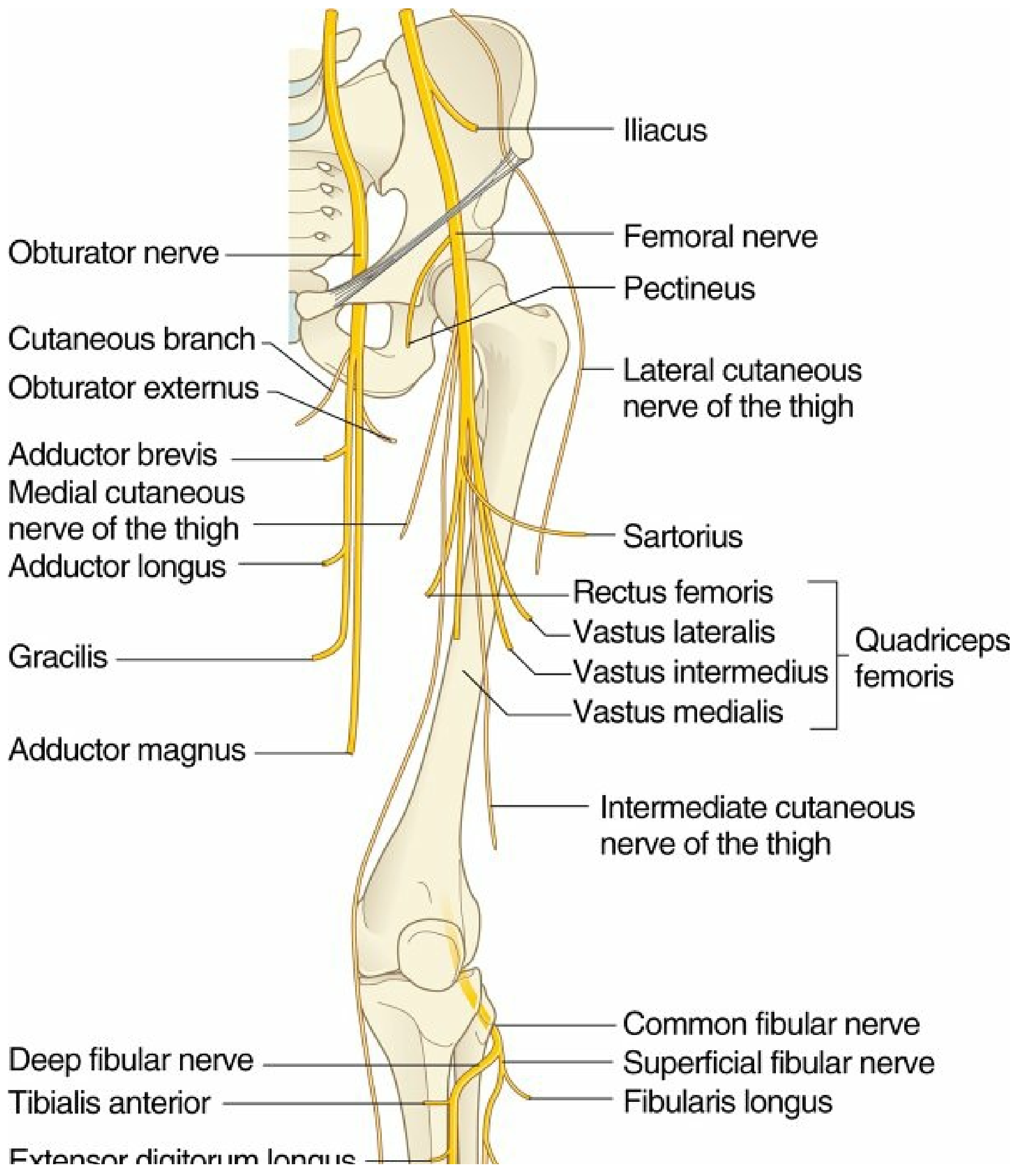
FIG. 2.65 Arteries and nerves of the gluteal region.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.37

Structures That Exit the Greater and Lesser Sciatic Foramina

Foramen	Structures Exiting
Greater sciatic	Piriformis
	Superior and inferior gluteal nerve
	Superior and inferior gluteal vessels
	Sciatic nerve
	Pudendal nerve [a]
	Internal pudendal vessels [a]
	Posterior femoral cutaneous nerve
	Nerve to obturator internus [a]
	Nerve to quadratus femoris
Lesser sciatic	Obturator internus
	Pudendal nerve [a]
	Nerve to obturator internus [a]
	Internal pudendal vessels [a]

[a] Pudendal nerve, internal pudendal artery and vein, and nerve to obturator internus exit the greater sciatic foramen and reenter the lesser foramen.



Iliacus
Femoral nerve
Pectineus
Lateral cutaneous nerve of the thigh
Sartorius
Rectus femoris
Vastus lateralis
Vastus intermedius
Vastus medialis
Quadriceps femoris
Intermediate cutaneous nerve of the thigh
Common fibular nerve
Superficial fibular nerve
Fibularis longus
Obturator nerve
Cutaneous branch
Obturator externus
Adductor brevis
Medial cutaneous nerve of the thigh
Adductor longus
Gracilis
Adductor magnus
Deep fibular nerve
Tibialis anterior

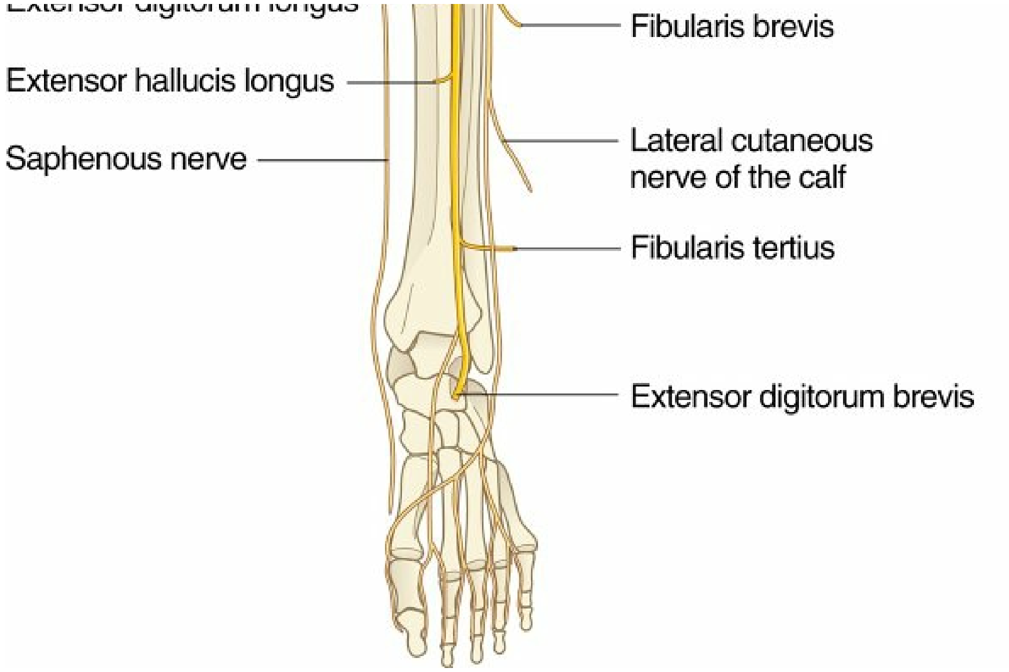


FIG. 2.66 Nerves of the hip, leg, and foot (anterior view).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

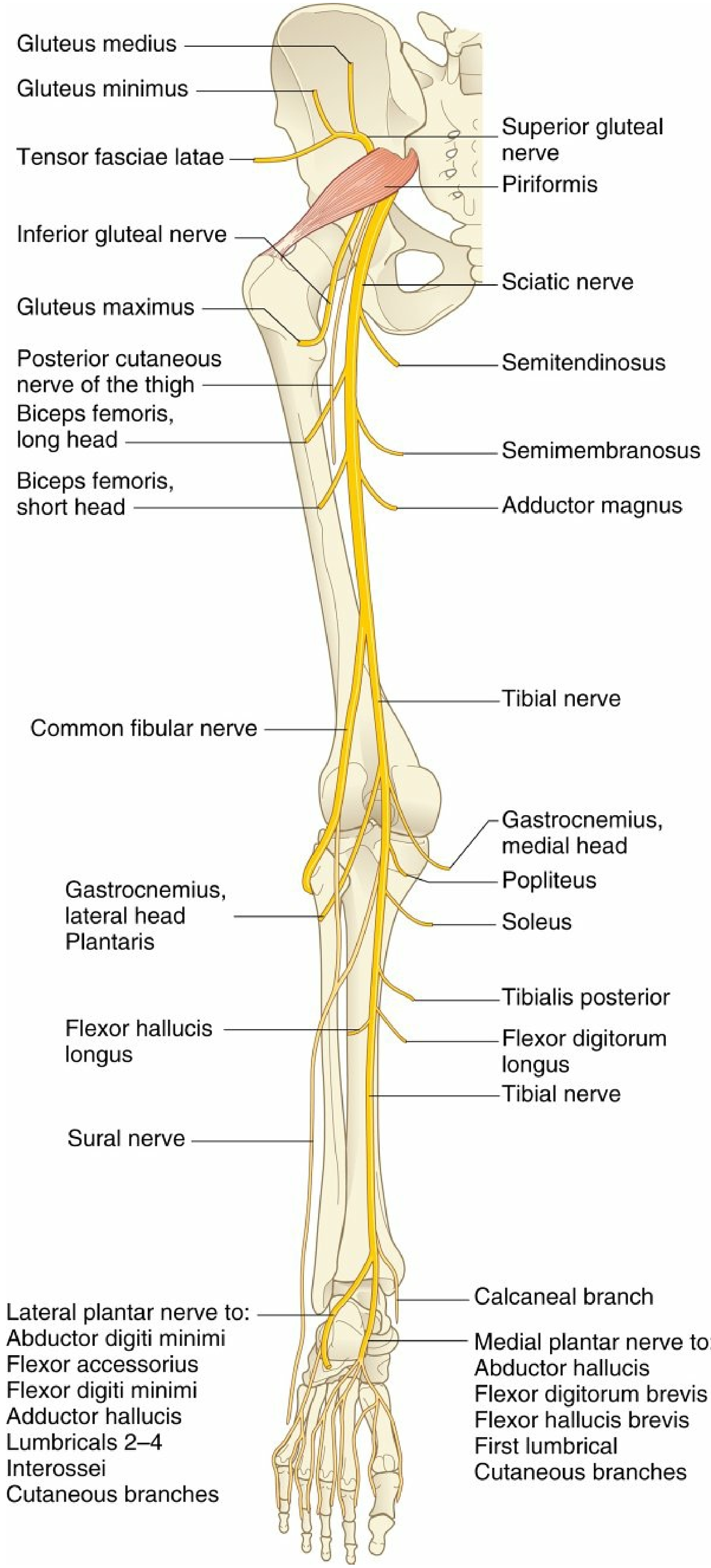

Gluteus medius
Gluteus minimus
Tensor fasciae latae
Superior gluteal nerve
Piriformis
Inferior gluteal nerve
Sciatic nerve
Gluteus maximus
Semitendinosus
Posterior cutaneous nerve of the thigh
Biceps femoris, long head
Semimembranosus
Biceps femoris, short head
Adductor magnus
Tibial nerve
Common fibular nerve
Gastrocnemius, medial head
Popliteus
Gastrocnemius, lateral head
Plantaris
Soleus
Tibialis posterior
Flexor hallucis longus
Flexor digitorum longus
Tibial nerve
Sural nerve
Calcaneal branch
Lateral plantar nerve to:
Abductor digiti minimi
Flexor accessorius
Flexor digiti minimi
Adductor hallucis
Lumbricals 2–4
Interossei
Cutaneous branches
Medial plantar nerve to:
Abductor hallucis
Flexor digitorum brevis
Flexor hallucis brevis
First lumbrical
Cutaneous branches

FIG. 2.67 Nerves of the hip, leg, and foot (posterior view).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

- **Mnemonic for nerves exiting below piriformis: "POP'S IQ" (*p*udendal, nerve to *o*bturator internus, *p*osterior femoral cutaneous, *s*ciatic, *i*nferior gluteal, nerve to *q*uadratus femoris)**

▪ **Peripheral nerve anatomy (**Figs. 2.66 and 2.67)

□ Lateral femoral cutaneous nerve (L2, 3)

- Travels on the surface of the iliacus muscle and exits the pelvis 1– 2 cm medial to ASIS under the lateral attachment of the inguinal ligament
- Supplies the skin and fascia on the surface of the anterolateral thigh from the greater trochanter to the knee

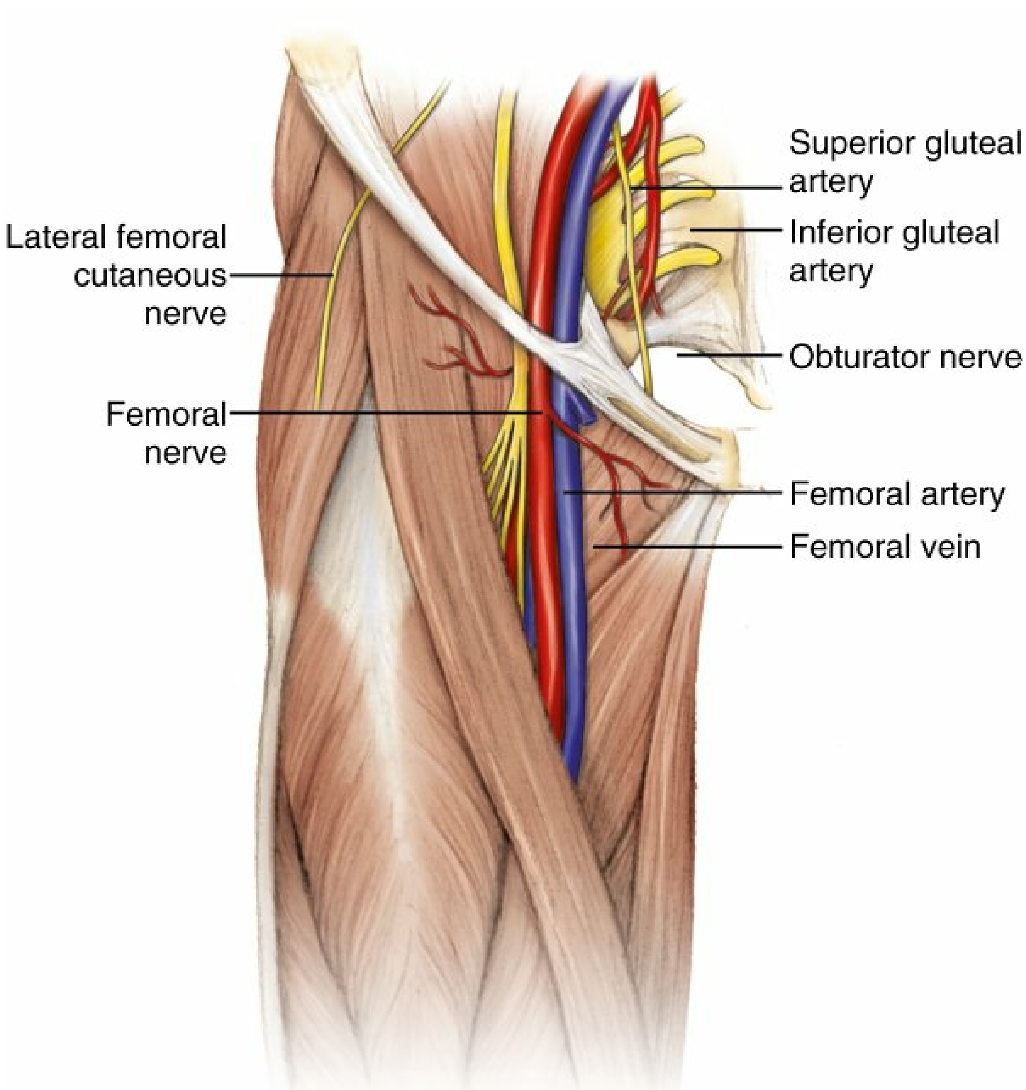


FIG. 2.68 Femoral triangle. The order of structures of the femoral canal from lateral to medial: iliopsoas/iliacus, femoral nerve, femoral artery, femoral vein, and pectineus.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figure HP-24.

        - Meralgia paresthetica: lateral femoral cutaneous nerve (LFCN) compression
- ▫ Femoral nerve (L2–4)
    - Largest branch of the lumbar plexus and supplies thigh muscles
    - **Femoral nerve lies between the iliacus and psoas muscles. Iliacus hematoma may irritate the femoral nerve because of its proximity.**
    - Anteriorly, the great nerves and vessels enter the thigh (and the femoral triangle) under the inguinal ligament (Fig. 2.68).
    - Femoral triangle
        - Borders: sartorius (lateral), pectineus (medial), inguinal ligament (superior)
        - Floor (lateral to medial): iliacus, psoas, pectineus, adductor longus
        - Structures (lateral to medial): femoral *n*erve, *a*rtery, *v*ein *a*nd the *l*ymphatic vessels (mnemonic: "NAVaL").
- ▫ Saphenous nerve (L3, 4)
    - Branches off femoral nerve at apex of femoral triangle and travels under the sartorius muscle
    - Becomes subcutaneous on medial aspect of knee between the sartorius and gracilis; travels with greater saphenous vein
    - At risk with medial meniscus repair, hamstring harvest
    - Supplies sensation to the medial aspect of the leg and foot
    - Infrapatellar branch supplies skin of the medial side of the front of the knee and patellar ligament and can be damaged during total knee replacement surgery or patella tendon harvest.
    - Terminal branch supplies sensation to medial ankle and foot.
- ▫ Obturator nerve (L2–4)
    - Exits the pelvis via the obturator canal
    - Divides into anterior and posterior divisions within the canal
    - Anterior division proceeds anteriorly to the obturator externus and posteriorly to the pectineus, supplying the adductor longus, adductor brevis, and gracilis; it then delivers cutaneous branches to the medial thigh.
    - Posterior division supplies the obturator externus, adductor brevis, and upper part of the adductor magnus, and it delivers other branches to the knee joint.
    - **Pain from the hip can be referred to the knee as a result of the continuation of the obturator nerve anteriorly, which can provide sensation to the medial side of the knee.**

- Retractors placed behind transverse acetabular ligament or screw placed in anteroinferior quadrant of acetabulum can injure the obturator nerve and artery.

□ Sciatic nerve (L4–S3)

- **Passes anterior to piriformis and posterior to obturator internus and short external rotators**
- Passes through the piriformis in 2% of people
- Descends below gluteus maximus and proceeds posterior to adductor magnus and between the long head of the biceps femoris and semimembranosus
- Functionally separate tibial and peroneal divisions throughout length
- Peroneal division more lateral than tibial division, making it more vulnerable to iatrogenic injury (most common nerve injury during total hip arthroplasty)
- Tibial division supplies all posterior thigh musculature except short head of biceps femoris (peroneal division).
- Divides into the common peroneal nerve and the tibial nerve at the popliteal fossa
- All sensation in foot is supplied by terminal branches of sciatic nerve, except for medial foot (saphenous nerve branch of femoral nerve).

□ Tibial nerve (L4–S3)

- Emerges into popliteal fossa laterally, proceeds posteriorly to the vessel, then descends between the heads of the gastrocnemius
- Crosses over the popliteus muscle and splits the two heads of the gastrocnemius, passing deep to the soleus on its course to the posterior aspect of the medial malleolus (tarsal tunnel) (Fig. 2.69)
- Muscular branches supply the posterior leg along its course (superficial and deep posterior compartments).
- **Supplies all intrinsic foot muscles except the EDB (deep peroneal nerve) and plantar sensation**
- Splits into two branches (the medial and lateral plantar nerves) under the flexor retinaculum
    - Both of these nerves run in the second layer of the foot.
    - Medial plantar nerve runs deep to the abductor hallucis, and the lateral plantar nerve runs obliquely under the cover of the quadratus plantae.
    - **Most proximal branch of the lateral plantar nerve**

is the nerve to the abductor digiti quinti (Baxter nerve).

- Distribution of the sensory and motor branches of the plantar nerves is similar to their distribution in the hand.

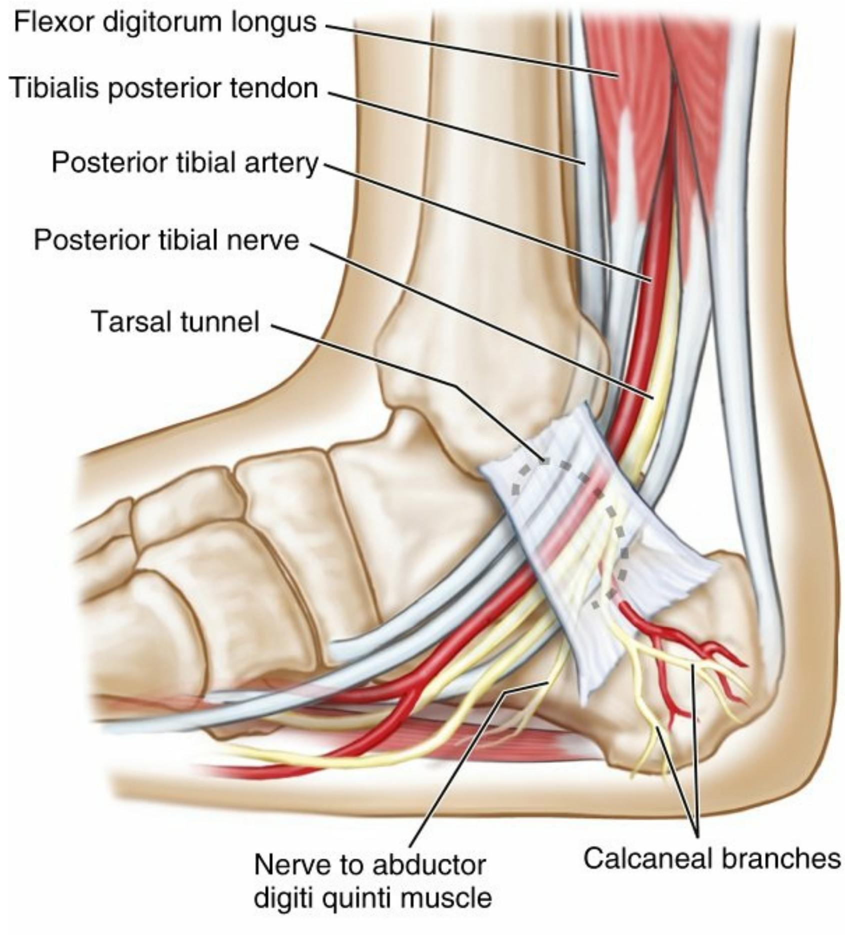
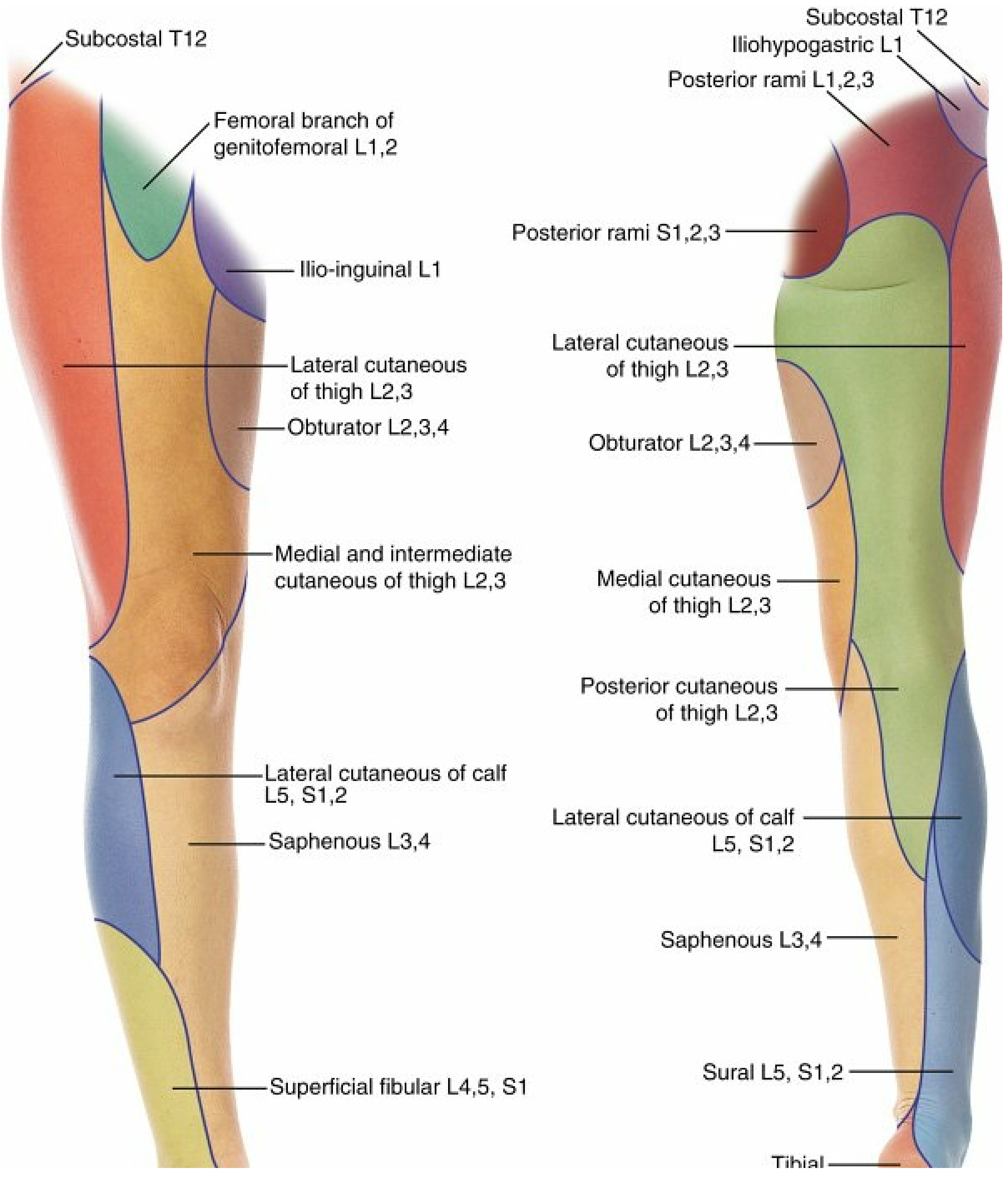


FIG. 2.69 Tibial nerve anatomy at the tarsal tunnel. From Miller MD, Thompson SR, editors: *DeLee and Drez's orthopaedic sports medicine: principles and practice,* ed 4, Philadelphia, 2014, Saunders.

- Medial plantar nerve (like the median nerve of the hand) supplies plantar sensation to the medial 3½ digits and motor sensation to only a few plantar muscles (flexor hallucis brevis, abductor hallucis, flexor digitorum brevis, and the first lumbrical muscle).
- Lateral plantar nerve (like the ulnar nerve in the hand) supplies plantar sensation to the lateral 1½ digits and the remaining intrinsic muscles of the foot.

            - Digital nerve of the third web space consists of branches from both the medial and lateral plantar nerves.
        - All ankle, foot, and toe plantar flexors are supplied by tibial nerve.
- □ Common peroneal nerve (L4–S2)
    - Diverges laterally and traverses the lateral popliteal fossa deep to the biceps femoris tendon
    - Winds around fibular neck
    - Runs deep to the peroneus longus, where it divides into the superficial and deep branches
    - Potentially injured with traction and by lateral meniscal repair
- □ Superficial peroneal nerve
    - Runs along the border between the lateral and anterior compartments in the leg, supplying muscular branches to the peroneus longus and brevis (lateral compartment)
    - Terminates in two cutaneous branches (medial dorsal and intermediate dorsal cutaneous nerves) supplying the dorsal foot
    - Dorsal intermediate branch is at risk for injury during placement of the anterolateral ankle arthroscopy portal.
    - Dorsal medial cutaneous nerve (a branch of the superficial peroneal nerve) crosses the EHL in a lateral-to-medial direction and supplies sensation to the dorsomedial aspect of the great toe.
- □ Deep peroneal nerve
    - Runs along the anterior surface of the interosseous membrane, supplying the musculature of the anterior compartment: tibialis anterior, EHL, EDL, and peroneus tertius
    - Lateral terminal branch of the deep peroneal nerve ends in the proximal dorsal foot by supplying the EDB muscle.
    - Medial terminal branch supplies sensation to the first web space.
- □ Superior gluteal nerve (L4–S1) exits pelvis superior to piriformis
    - Supplies gluteus medius, minimus, and tensor fascia lata
    - Runs in gluteus medius fascia approximately 5 cm proximal to greater trochanter
    - **Injury leads to Trendelenburg gait from gluteal dysfunction.**
- □ Inferior gluteal nerve (L5–S2) exits inferior to piriformis and supplies gluteus maximus.
- □ Sural nerve (S1–2) is formed by cutaneous branches of both the tibial

(medial sural cutaneous) and common peroneal (lateral sural cutaneous) nerves.
        - Often used for nerve grafting
        - Inadvertent cutting of this nerve can cause painful neuroma.
    - Cutaneous innervation of the thigh and leg is shown in Fig. 2.70.
    - Nerves around the foot and ankle are demonstrated in Fig. 2.71.
- **Vessels (** Fig. 2.72)
    - Aorta branches into the common iliac arteries anterior to the L4 vertebral body.
    - Common iliac vessels in turn divide into the internal (or hypogastric [medial] and external [lateral]) iliac vessels at the S1 level (Fig. 2.73).
    - Important internal iliac artery branches
        - Obturator (posterior branch supplies the transverse acetabular ligament)
        - **Obturator artery and vein jeopardized by anteroinferior screws and acetabular retractors**
        - Posterior branch supplies the ligamentum teres acetabular artery. This artery is an important source of blood to the femoral head from birth to age 4.
        - Superior gluteal (can be injured in sciatic notch)
        - Inferior gluteal (supplies gluteus maximus and short external rotators)
        - Internal pudendal (reenters pelvis through lesser sciatic notch)
        - **Corona mortis is an anastomotic connection between the inferior epigastric branch of the external iliac vessels and the obturator vessels in the obturator canal.**
        - Can lead to life-threatening bleeding if injured
    - External iliac artery continues under the inguinal ligament to become the femoral artery.
        - Can be injured by placement of acetabular screws in the anterosuperior quadrant during total hip arthroplasty
    - Cruciate anastomosis: confluence of ascending branch of the first perforating artery, descending branch of the inferior gluteal artery, and transverse branches of the MFCA and lateral FCA (LFCA)



Subcostal T12
Femoral branch of genitofemoral L1,2
Ilio-inguinal L1
Lateral cutaneous of thigh L2,3
Obturator L2,3,4
Medial and intermediate cutaneous of thigh L2,3
Lateral cutaneous of calf L5, S1,2
Saphenous L3,4
Superficial fibular L4,5, S1
Subcostal T12
Iliohypogastric L1
Posterior rami L1,2,3
Posterior rami S1,2,3
Lateral cutaneous of thigh L2,3
Obturator L2,3,4
Medial cutaneous of thigh L2,3
Posterior cutaneous of thigh L2,3
Lateral cutaneous of calf L5, S1,2
Saphenous L3,4
Sural L5, S1,2
Tibial

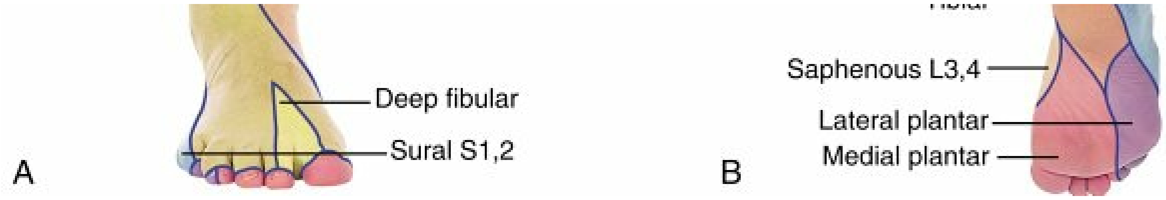
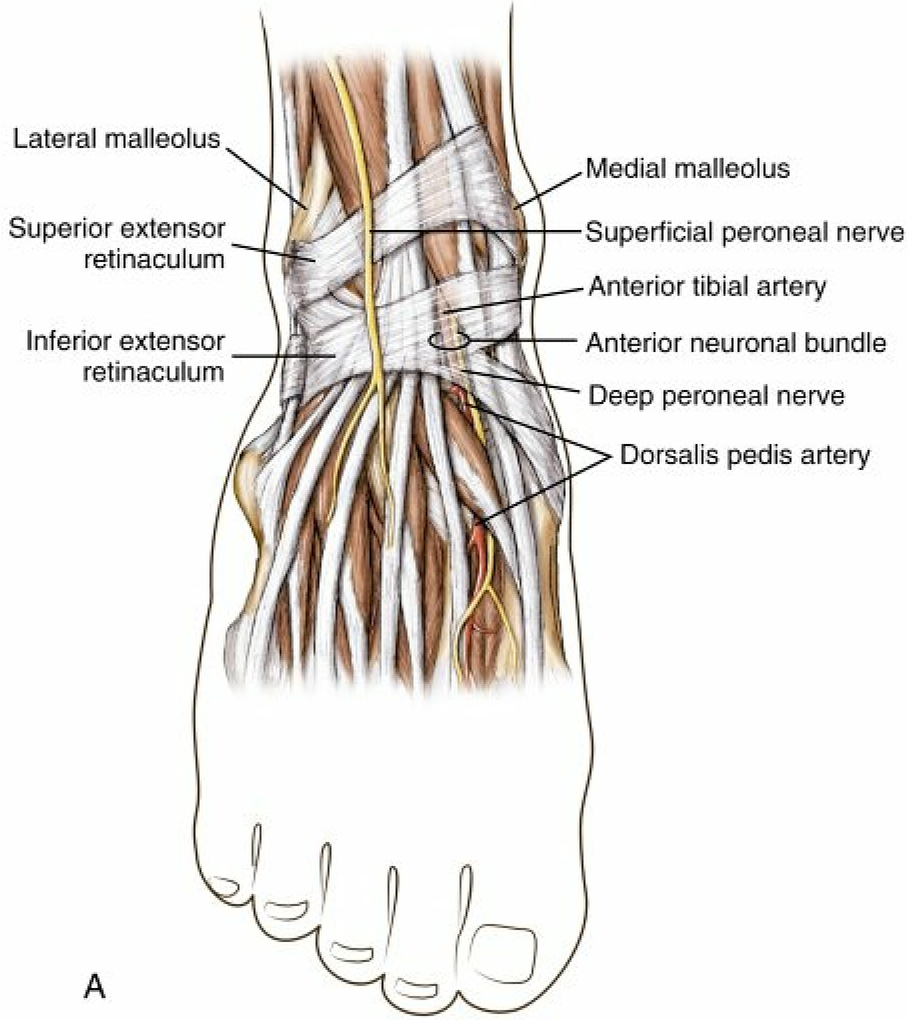


FIG. 2.70 Cutaneous innervation of the lower extremity. (A) Anterior view. (B) Posterior view.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

- ☐ Femoral artery enters the femoral triangle.
  - Two branches: superficial femoral artery and profunda femoris (deep femoral artery).
    - Superficial femoral artery supplies the leg and foot.
      - Continues on medial side of thigh (between vastus medialis and adductor longus) toward the adductor (Hunter) canal
      - Becomes popliteal artery when it passes posteriorly into the popliteal fossa
    - Profunda femoris supplies the musculature of the thigh.
  - Key branches (named for location relative to iliopsoas tendon)
    - Lateral femoral circumflex, which travels obliquely and deep to the sartorius and rectus femoris
      - **Ascending branch (at risk for injury during anterolateral approaches) proceeds to greater trochanteric region between TFL and rectus femoris**
      - Descending branch travels laterally under the rectus femoris.
    - Medial femoral circumflex supplies most of the blood to the femoral head.
      - Runs between the pectineus and iliopsoas and proceeds distally anterior to the quadratus femoris on its cranial edge just distal to the obturator externus
      - Particularly at risk for injury during psoas tenotomy through an

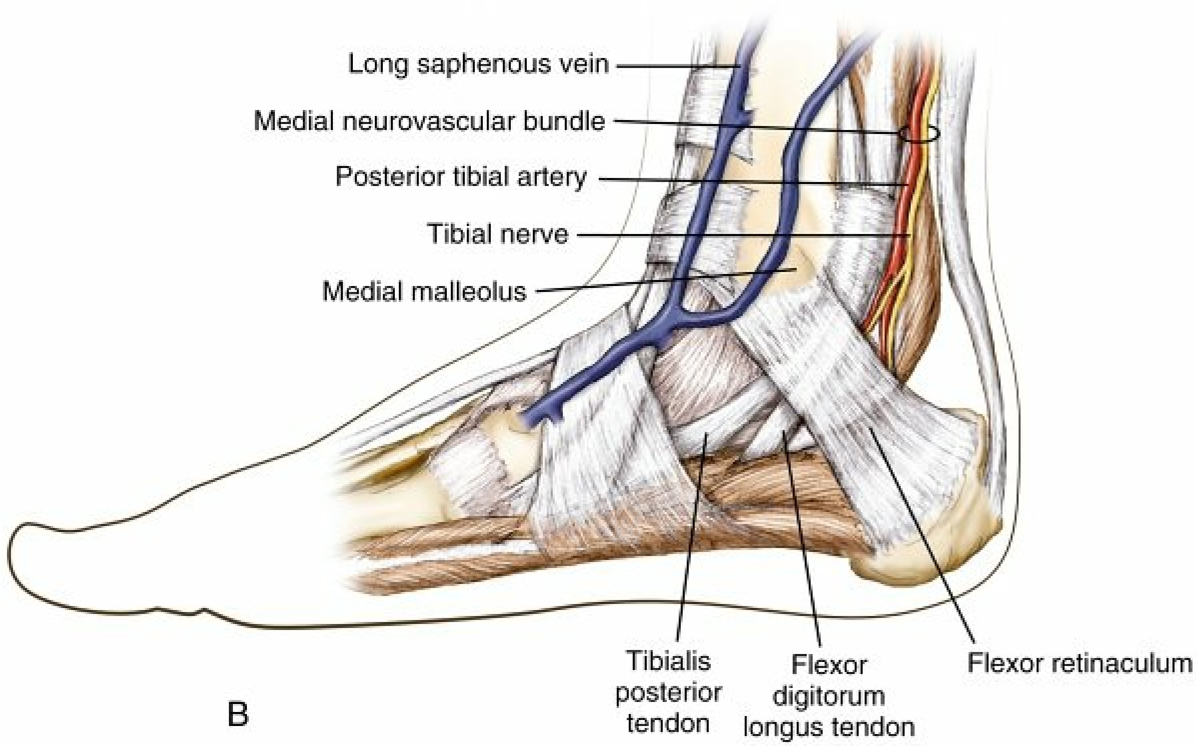
anteromedial approach for developmental dysplasia of the hip

- Also gives off the femoral artery perforators; these perforators pierce the lateral intermuscular septum to supply the vastus lateralis muscle.



Lateral malleolus
Superior extensor retinaculum
Inferior extensor retinaculum
Medial malleolus
Superficial peroneal nerve
Anterior tibial artery
Anterior neuronal bundle
Deep peroneal nerve
Dorsalis pedis artery

A



Long saphenous vein
Medial neurovascular bundle
Posterior tibial artery
Tibial nerve
Medial malleolus
Tibialis posterior tendon
Flexor digitorum longus tendon
Flexor retinaculum

B

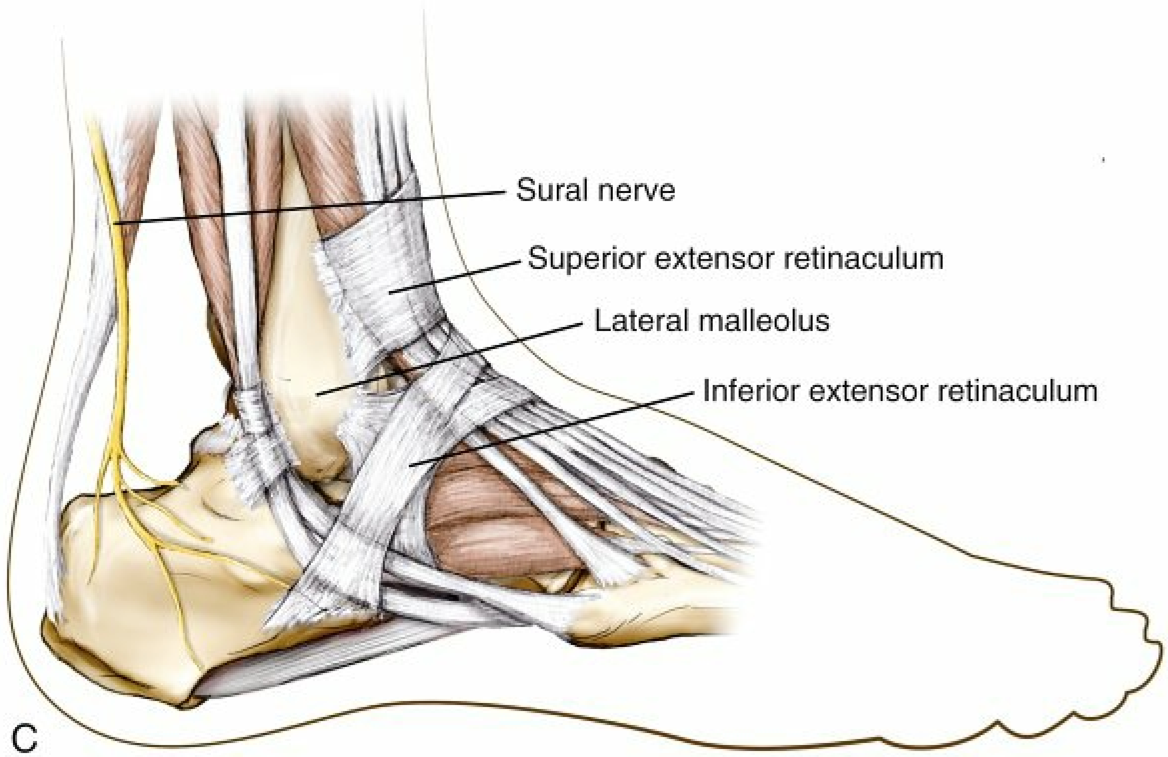


FIG. 2.71 Nerves of the ankle and foot: (A) Anterior view. (B) Medial view. (C) Lateral view.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figures 8-31, 8-32, and 8-33.

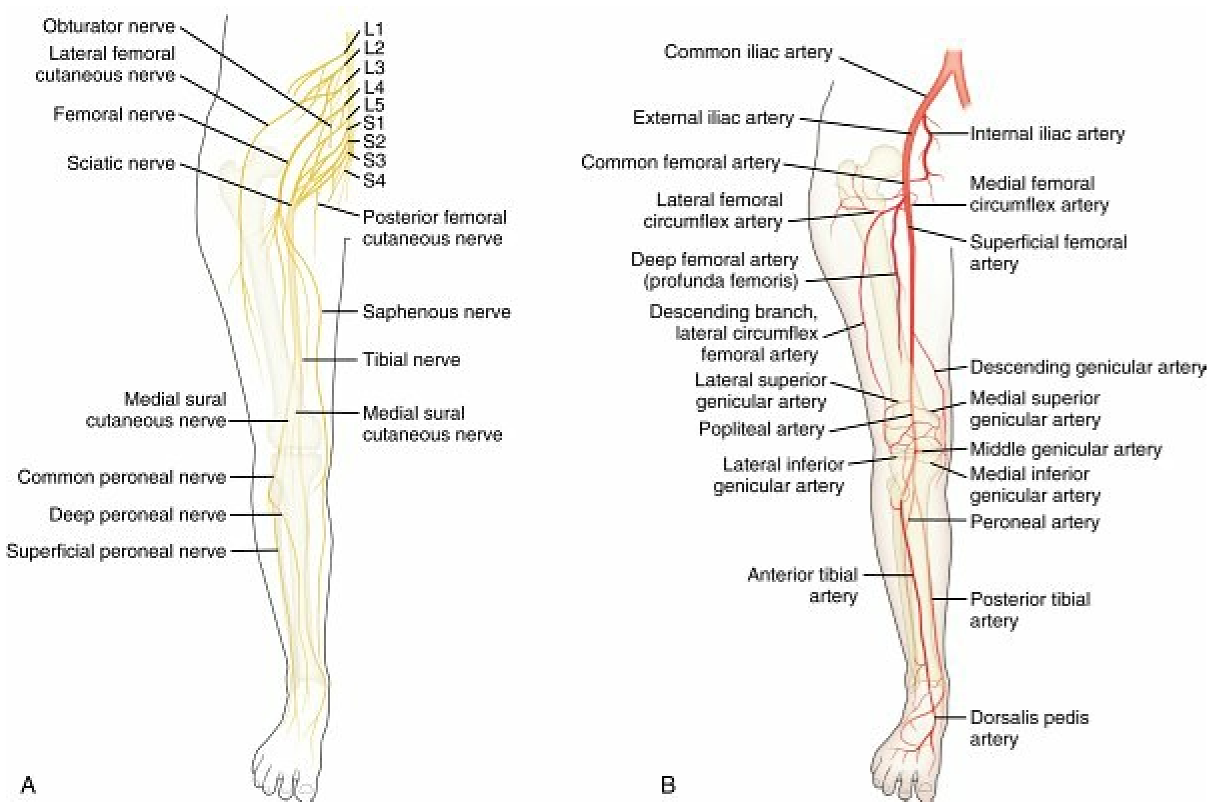


FIG. 2.72 Nerves (A) and vessels (B) of the lower extremity.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures KL-8 and KL-9.

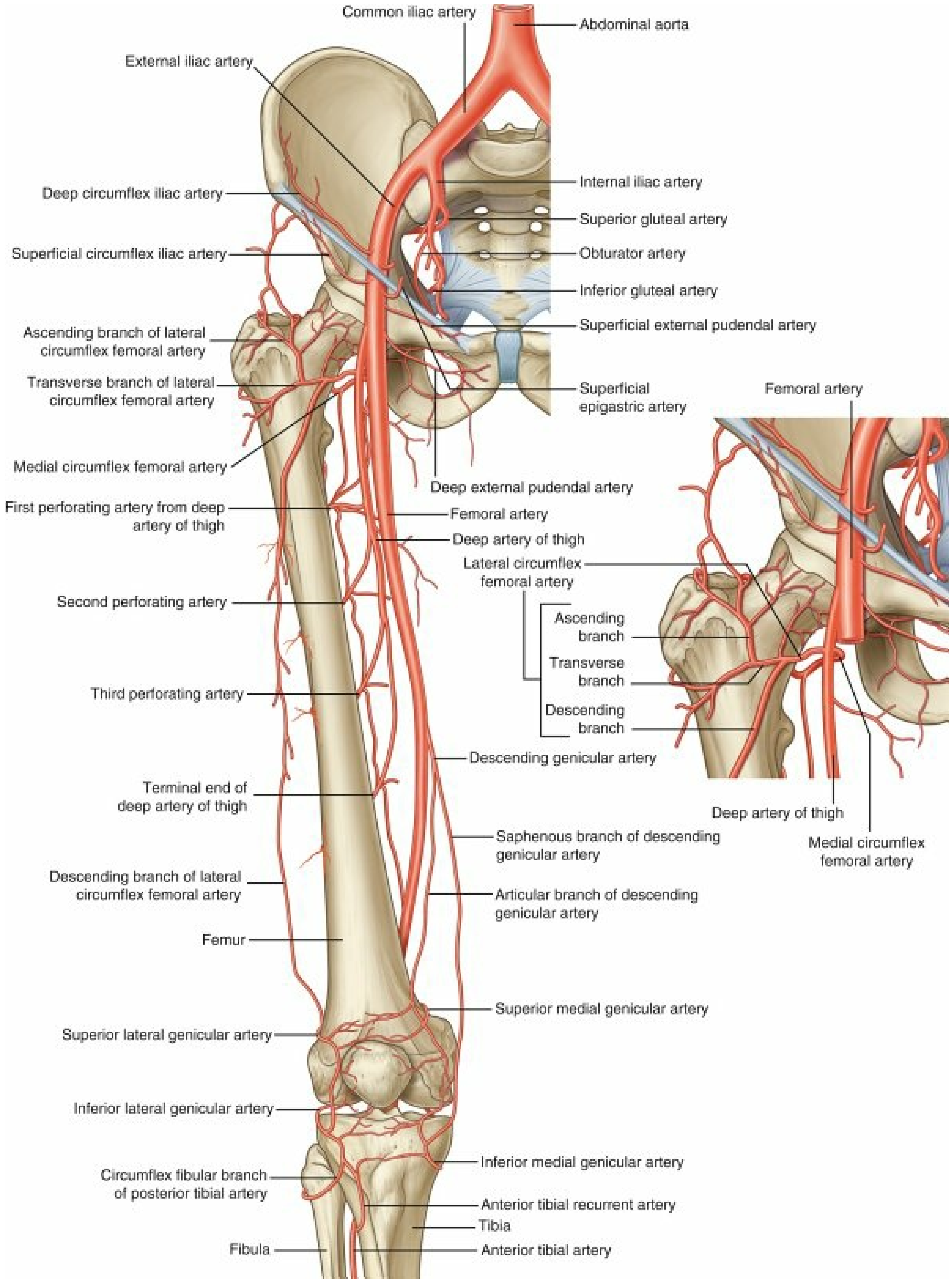


FIG. 2.73 Arteries of the hip and thigh.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

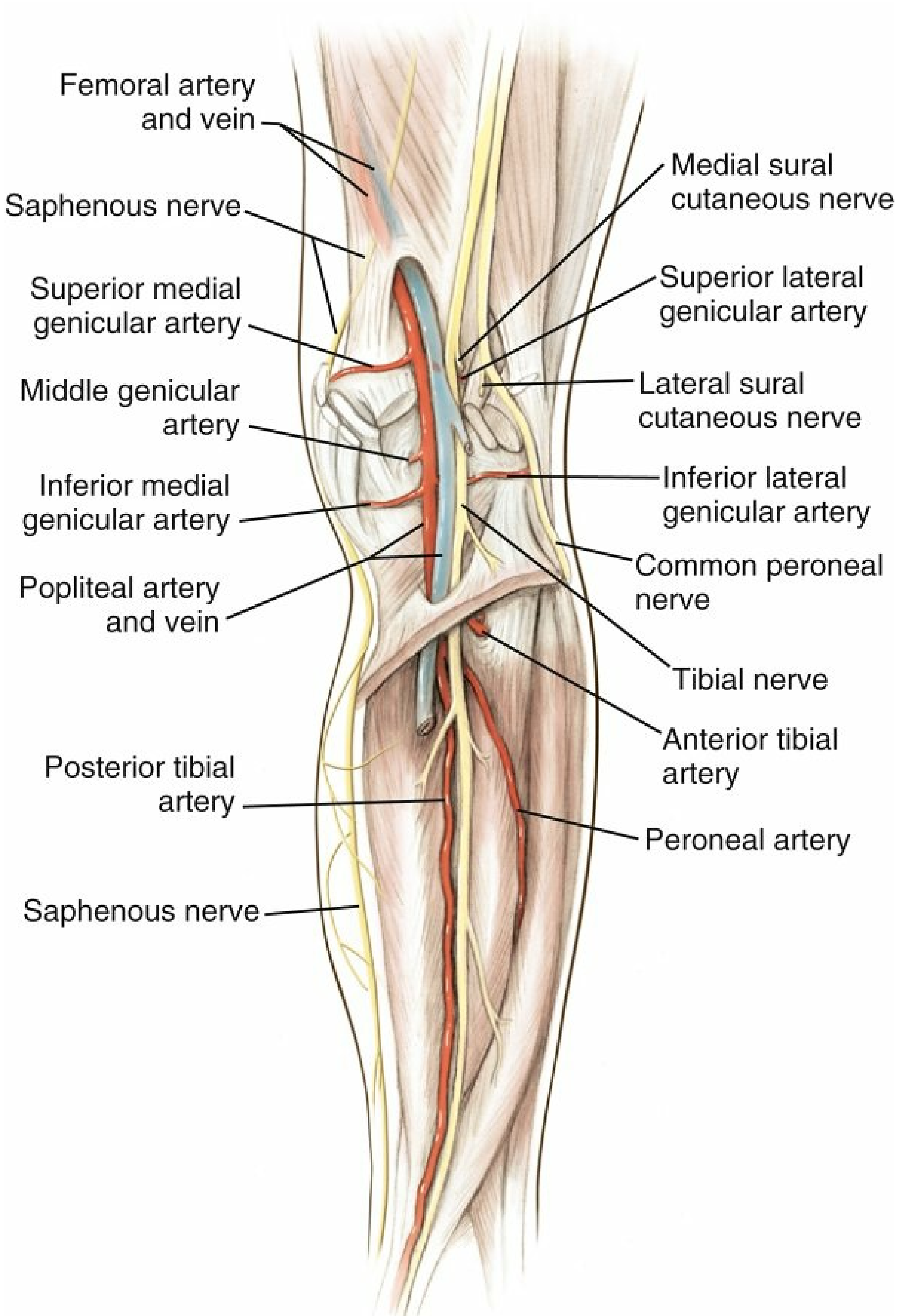


FIG. 2.74 Neurovascular structures of the posterior leg and thigh.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 7-16.

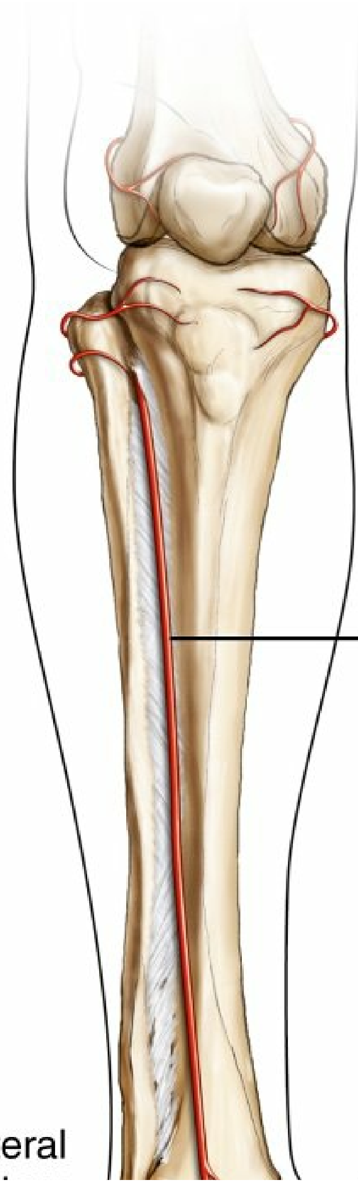
- Popliteal artery travels posterior to the knee and is the primary blood supply to the leg (Fig. 2.74).
    - Enters the popliteal fossa between the biceps and

semimembranosus and descends underneath the tibial nerve, terminating between the medial and lateral heads of the gastrocnemius and dividing into the anterior and posterior tibial arteries

- Vein usually posterior to artery
- At risk with knee dislocation and trauma about the knee
- Several genicular branches are given off in the popliteal fossa, including the medial and lateral geniculate arteries (which supply the menisci) and the middle geniculate artery (which supplies the cruciate ligaments).
- Superior lateral geniculate artery can be injured during lateral-release procedures.
- Descending geniculate artery (branch of femoral artery proximal to Hunter canal) supplies the vastus medialis at the anterior border of the intermuscular septum.
- Inferior geniculate artery passes between the popliteal tendon and the fibular collateral ligament in the posterolateral corner of the knee.

□ Anterior tibial artery (Fig. 2.75)

- First branch of the popliteal artery
- Passes between the two heads of the tibialis posterior and the interosseous membrane to lie on the anterior surface of that membrane between the tibialis anterior and EHL



Anterior tibial
artery
Anterior lateral

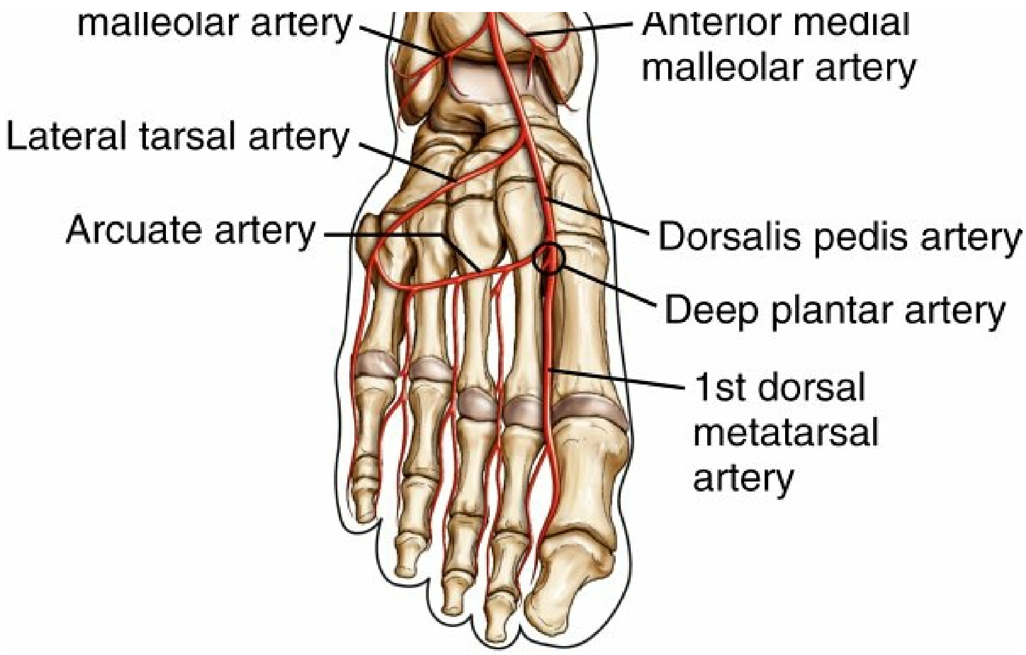


FIG. 2.75 The arterial system of the anterior leg and dorsum of the foot.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 8-23.

- Terminates as the dorsalis pedis artery
  - Dorsalis pedis artery provides the blood supply to the dorsum of the foot via its lateral tarsal, medial tarsal, arcuate, and first dorsal metatarsal branches.
  - Its largest branch, the deep plantar artery, runs between the first and second metatarsals and contributes to the plantar arch.

□ Posterior tibial artery (Fig. 2.76)

- Continues in the deep posterior compartment of the leg, coursing obliquely to pass behind the medial malleolus
- Terminates by dividing into the medial and lateral plantar arteries
- Main branch: peroneal artery
  - Given off 2.5 cm distal to the popliteal fossa and continues in the deep posterior compartment lateral to its parent artery between the tibialis posterior and FHL
  - Terminates in the calcaneal branches
- Terminal branches: medial and lateral plantar branches
  - Divide under the abductor hallucis muscle
  - Larger lateral branch receives the deep plantar artery and forms the plantar arch in the fourth layer of the plantar foot.

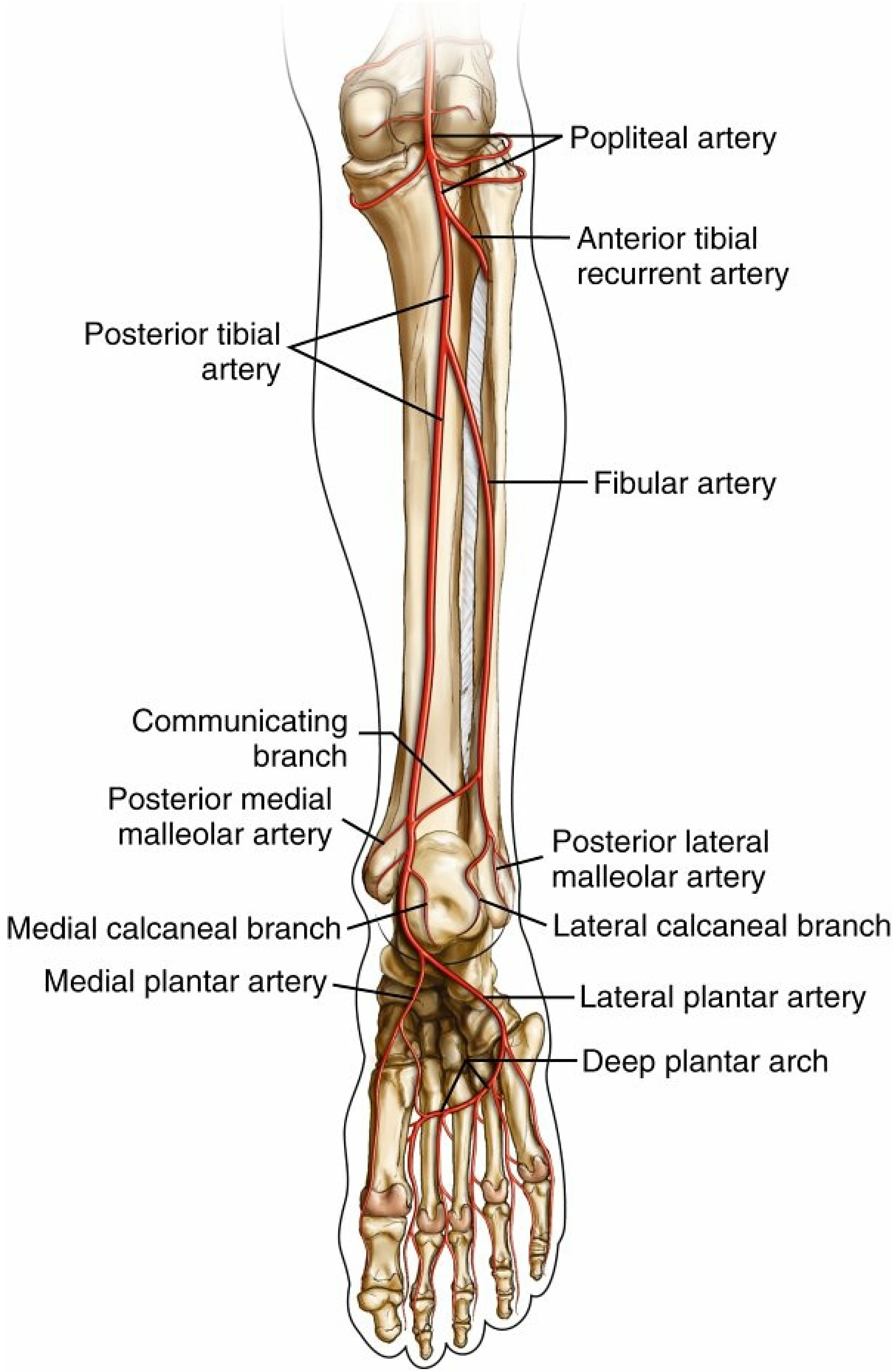


FIG. 2.76 The arterial system of the posterior leg and sole of the foot.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 8-24.

- **Lower extremity approaches (** Table 2.38)

- Pelvis
  - Iliac crest
    - Iliac crest bone graft (ICBG) may be harvested from anterior or posterior iliac crest
    - Anterior ICBG—LFCN at risk as it runs medial to ASIS
    - Posterior ICBG—superior cluneal nerves 8 cm lateral to PSIS, sciatic nerve exits pelvis through greater sciatic notch (at risk during osteotomy) (Fig. 2.77)
  - Ilioinguinal (anterior) approach to the acetabulum
    - Access to iliac fossa from pubic symphysis to sacroiliac joint, anterior column of acetabulum
    - Relies on mobilization of the rectus abdominis and iliacus
    - Three windows are available with this approach (Fig. 2.78)
      - First (lateral) window (lateral to iliopsoas/iliopectineal fascia) provides access to the internal iliac fossa, anterior sacroiliac joint, and upper portion of the anterior column.
      - Second (middle) window (between the iliopectineal fascia and the external iliac vessels) provides access to the pelvic brim from the anterior sacroiliac joint to the lateral portion of the superior pubic ramus.
      - Third (medial) window (below the vessels and spermatic cord) gives access to the symphysis pubis.
    - Stoppa modification uses a more extensive medial window and provides access to pelvic brim and quadrilateral plate.
    - Risks
      - LFCN: exits pelvis medial to ASIS; injury causes numbness of anterolateral thigh.
      - Spermatic cord: protect it as it exits superficial inguinal ring.
      - Femoral nerve: lateral to femoral vessels; injury causes weakness in knee extension, numbness in anterior

thigh.

- Inferior epigastric vessels cross just medial to inguinal ring and should be ligated.
- Corona mortis: injury can result in intrapelvic hemorrhage.

- Kocher-Langenbeck (posterior) approach to the acetabulum (Fig. 2.79)
  - Provides access to the posterior column and wall of the acetabulum
  - Not a true internervous plane—splits the gluteus maximus
  - Risks
    - Sciatic nerve: anterior to piriformis and posterior to obturator internus
      - Hip extension and knee flexion take tension off sciatic nerve.
    - Superior and inferior gluteal artery: if injured, may retract into pelvis and cause heavy bleeding
    - Superior and inferior gluteal nerve: excessive retraction may damage
    - Lateral ascending branch of medial femoral circumflex artery: divide short external rotators 1 to 2 cm off bone to protect blood supply to femoral head.
    - Damage to gluteus minimus may result in heterotopic ossification.

□ Hip (Figs. 2.80 and 2.81)

- Anterior (Smith-Peterson) approach to the hip (Fig. 2.82)
  - Gained increased utilization with minimally invasive anterior total hip replacement
  - Interval: between sartorius and TFL
  - Dissection
    - Retract LFCN anteriorly and ligate the ascending branch of the LFCA (which lies superficial to the rectus).
    - For deeper dissection, approach the interval between the rectus femoris and gluteus medius.
    - Approach anterior hip capsule

between rectus femoris and gluteus medius; may detach both heads of rectus femoris for access.

- Risks
  - LFCN: several branches anterior or medial to the sartorius muscle, about 6–8 cm below ASIS
  - Lateral femoral circumflex artery: ascending branch ligated during approach; descending branch may be injured with excessive distal reflection of the rectus tendon.
  - Superficial iliac circumflex artery: penetrates TFL just anterior to LFCN
  - Femoral nerve and artery: avoid aggressive medial retraction of the sartorius.

Table 2.38

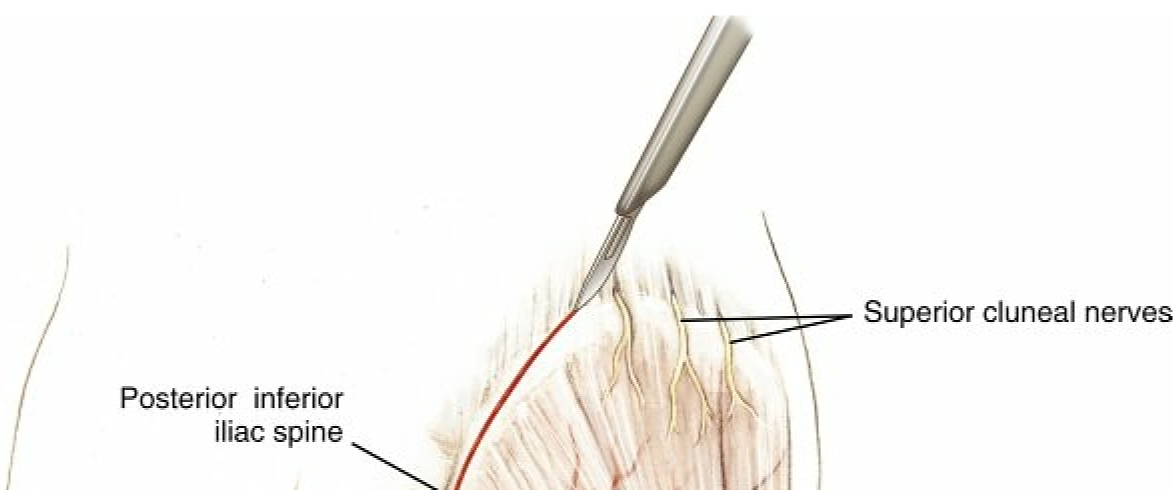
Lower Extremity Approaches

Approach	Superficial Interval (Nerve)	Deep Interval (Nerve)	Structure At Risk
Iliac Crest			
Anterior	TFL/gluteal muscles (superior/inferior gluteal) *and* external oblique (segmental)		LFCN
Posterior	Gluteus maximus (inferior gluteal) *and* latissimus dorsi (thoracodorsal), spinal erector muscles		Superior cluneal nerves Sciatic nerve Superior gluteal artery
Pelvis/Acetabulum			
Anterior (ilioinguinal)	External oblique (segmental) *and* inguinal ligament	Divide internal oblique (segmental)	LFCN Spermatic cord Inferior epigastric artery Femoral artery and nerve Corona mortis
Posterior (Kocher-	Divide gluteus maximus (inferior gluteal), IT band	Piriformis (nerve to piriformis) *and* gluteus	Sciatic nerve Superior and

Langenbeck)		medius (superior gluteal)	inferior gluteal nerve and artery MFCA
HIP			
Anterior (Smith-Peterson)	Sartorius (femoral) *and* TFL (superior gluteal)	Rectus femoris (femoral) *and* gluteus medius (superior gluteal)	LFCN Femoral nerve and artery Superficial iliac circumflex artery LFCA (ascending branch)
Anterolateral (Watson-Jones)	TFL (superior gluteal) *and* gluteus medius (superior gluteal)	Split gluteus medius (superior gluteal)	Femoral nerve and artery Superior gluteal nerve LFCA (descending branch)
Lateral (Hardinge)	Split IT band	Divide gluteus medius (superior gluteal); divide vastus lateralis (femoral)	Superior gluteal nerve LFCA (transverse branch)
Posterior (Moore, Southern)	Divide gluteus maximus (inferior gluteal), IT band	Piriformis, short external rotators, *and* femur	Sciatic nerve Inferior gluteal artery MFCA
Medial (Ludloff)	Adductor longus (obturator) *and* gracilis (obturator)	Adductor brevis (anterior division of obturator) *and* adductor magnus (obturator and tibial)	Obturator nerve MFCA Deep external pudendal artery
Thigh			
Lateral	Divide IT band	Divide or lift vastus lateralis (femoral)	Perforating branches of profunda femoris artery
Posterolateral	Vastus lateralis (femoral) *and* biceps femoris (sciatic)		Perforating branches of profunda femoris artery

Anteromedial	Rectus femoris (femoral) *and* vastus medialis (femoral)		Medial superior geniculate artery Infrapatellar branch of saphenous nerve
Knee			
Anterior (medial parapatellar)	Rectus femoris (femoral) *and* vastus medialis (femoral), patella *and* medial patellar retinaculum		Infrapatellar branch of saphenous nerve
Medial	Medial patellar retinaculum *and* sartorius (femoral)		Saphenous nerve MCL
Lateral	Iliotibial band *and* biceps femoris (sciatic)		Peroneal nerve Superior and inferior lateral geniculate artery Popliteus tendon LCL
Posterior	Semimembranosus (tibial), biceps femoris (sciatic), *and* lateral head gastrocnemius (tibial)		Popliteal artery Tibial nerve Peroneal nerve Medial sural cutaneous nerve
LEG			
Lateral	Gastrocnemius, soleus, FHL (tibial) *and* peroneal longus and brevis (superficial peroneal)		Lesser saphenous vein Superficial peroneal nerve Posterior tibial artery
Medial	Gastrocnemius, soleus (tibial) *and* tibia		Saphenous nerve and vein
Ankle			
Anterior	EHL (deep peroneal) *and* tibialis anterior (deep peroneal) *or* EDL (deep peroneal)		Superficial and deep peroneal nerve

			Anterior tibial artery
Posteromedial	Tibialis posterior, FDL, FHL (tibial) *and* Achilles tendon		Saphenous nerve and vein
Posterolateral	Peroneus brevis (superficial peroneal) *and* Achilles tendon	Peroneus brevis (superficial peroneal) *and* FHL (tibial)	Sural nerve Small saphenous vein



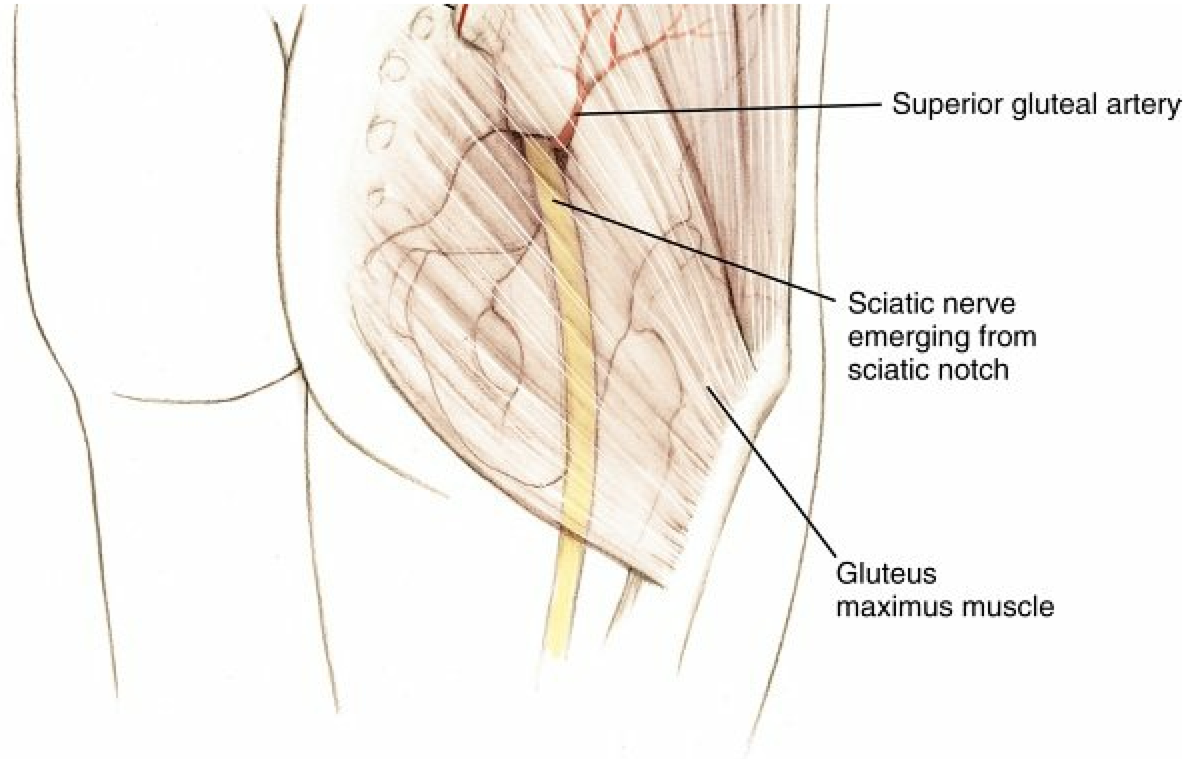


FIG. 2.77 Incision for exposure of the posterior iliac crest.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 5-120.

- Anterolateral (Watson-Jones) approach to the hip (Fig. 2.83)
  - No true interneural plane, but the intermuscular plane between the TFL and gluteus medius is used.
  - Dissection
    - Split the fasciae latae to expose the vastus lateralis.
    - Detach the anterior third of the gluteus medius from the greater trochanter and the entire gluteus minimus.
    - Dissect the reflected head of the rectus femoris (and capsular attachment of the iliopsoas if necessary), and retract it medially to gain access

to the capsule.

- Risks
    - Femoral nerve and artery: injured with excessive medial retraction
    - Superior gluteal nerve: passes about 5 cm above acetabular rim; injury may result in denervation of the TFL.
    - Lateral femoral circumflex artery: injury to the descending branch with anterior and inferior dissection

□ Lateral (Hardinge) approach to the hip (Fig. 2.84)

- Involves splitting of the gluteus medius and vastus lateralis in tandem
- Dissection
    - Incise the skin and the fasciae latae to expose the gluteus medius and the vastus lateralis.

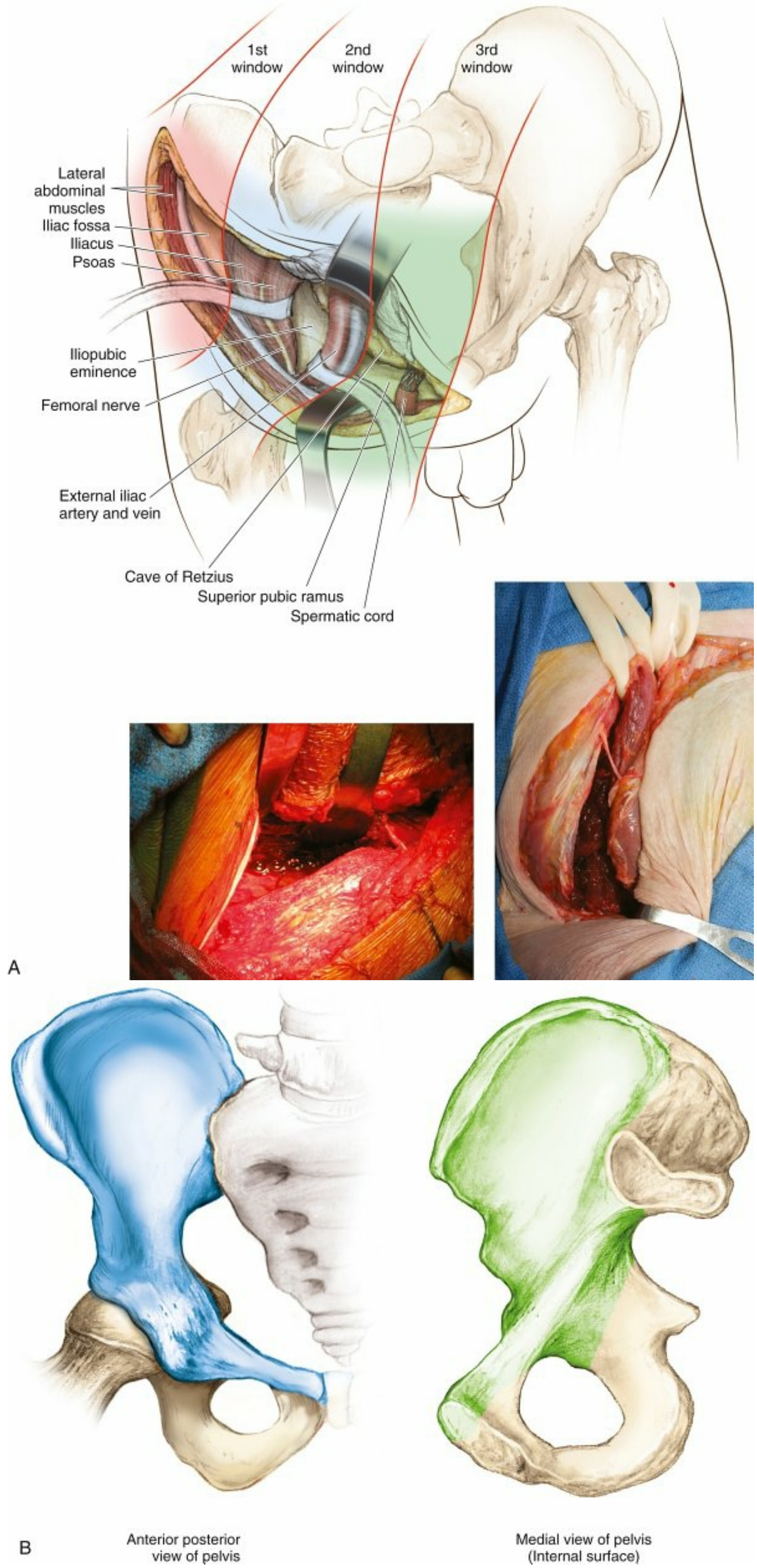


FIG. 2.78 Ilioinguinal approach: (A) Three working windows. (B) Regions of pelvis and acetabulum accessible.

From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 6-39.

- Incise the gluteus medius from the greater trochanter, leaving a cuff of tissue and the

posterior half to two-thirds attached.
        - Extend this incision to split the gluteus medius proximally.
        - Split the vastus lateralis distally along its anterior fourth down to the femoral shaft.
        - Detach the gluteus minimus from its insertion to expose the hip capsule.
    - Risks
        - Superior gluteal nerve: may be damaged if the gluteus medius split is too proximal (>5 cm proximal to greater trochanter).
        - Lateral femoral circumflex artery (transverse branch)
- □ Posterior (Moore or Southern) approach to the hip (Fig. 2.85)
    - Distal extension of posterior acetabular approach (Kocher-Langenbeck)
    - Dissection
        - IT band incised over greater trochanter, and fibers of gluteus maximus split bluntly
        - Short external rotators dissected from insertions and reflected laterally to protect sciatic nerve and expose posterior hip capsule
        - Portion of the quadratus femoris may be taken down with the short external rotators, but be aware of the significant bleeding that can come from the inferior portion of this muscle (ascending branches of medial femoral circumflex artery)

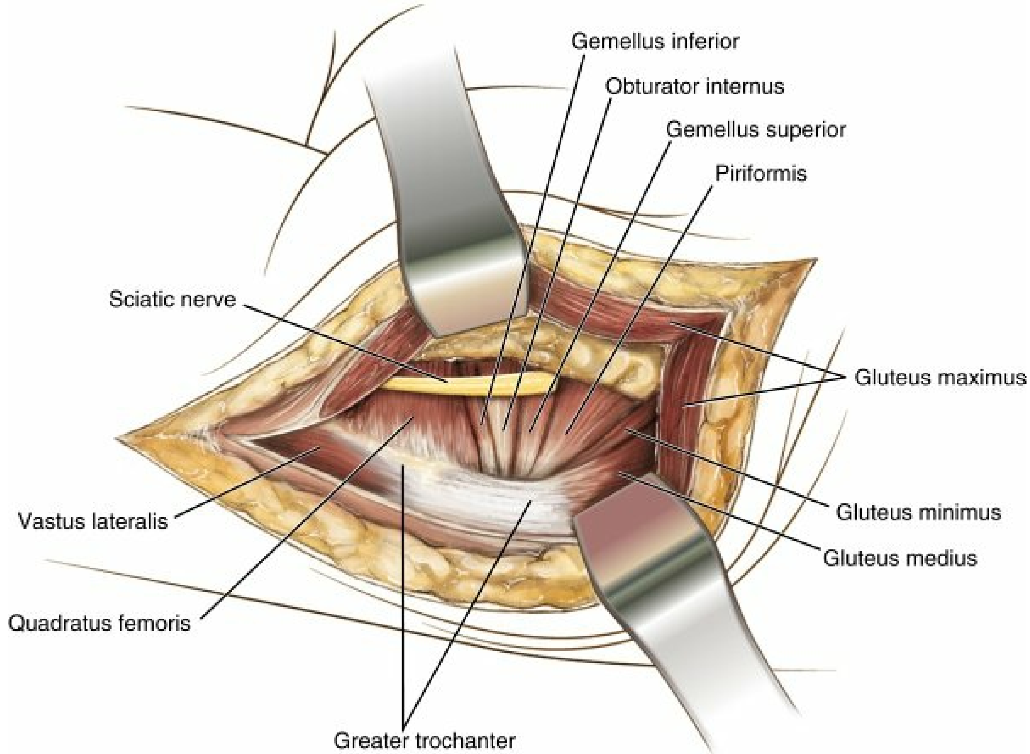


FIG. 2.79 Posterior approach to the pelvis.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 6-46.

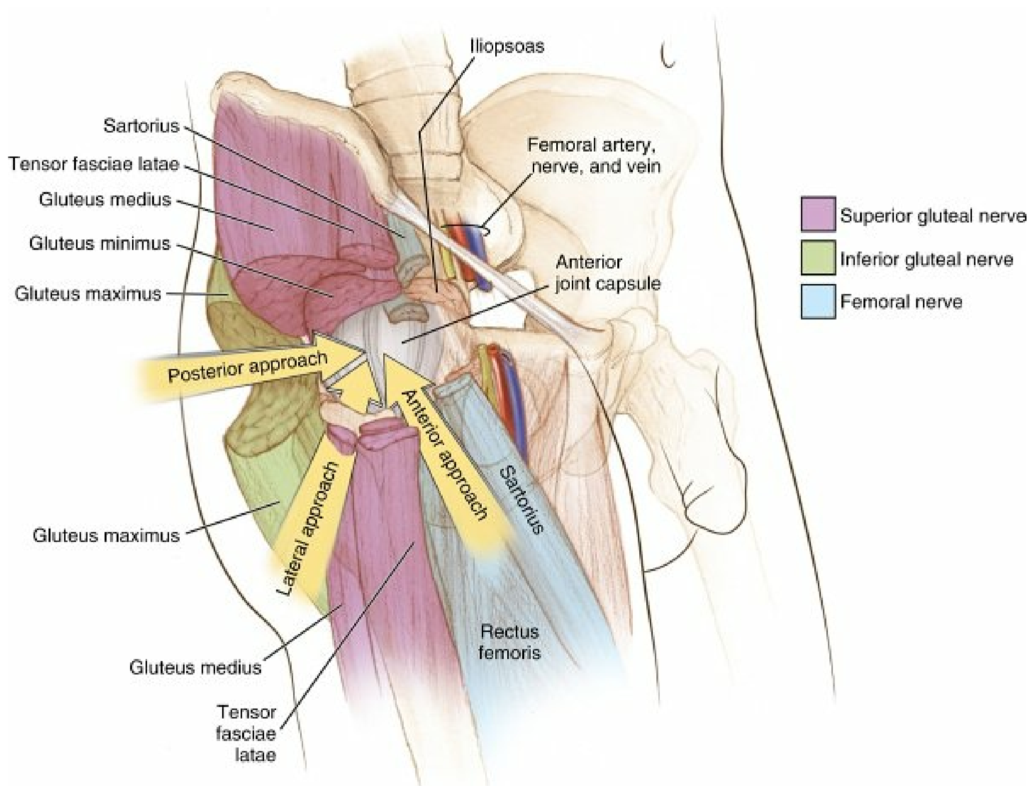


FIG. 2.80 Synopsis of the anterior, lateral, and posterior approaches to the hip joint and the anatomic planes that are exploited for each approach as depicted by the arrows.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 6-48.

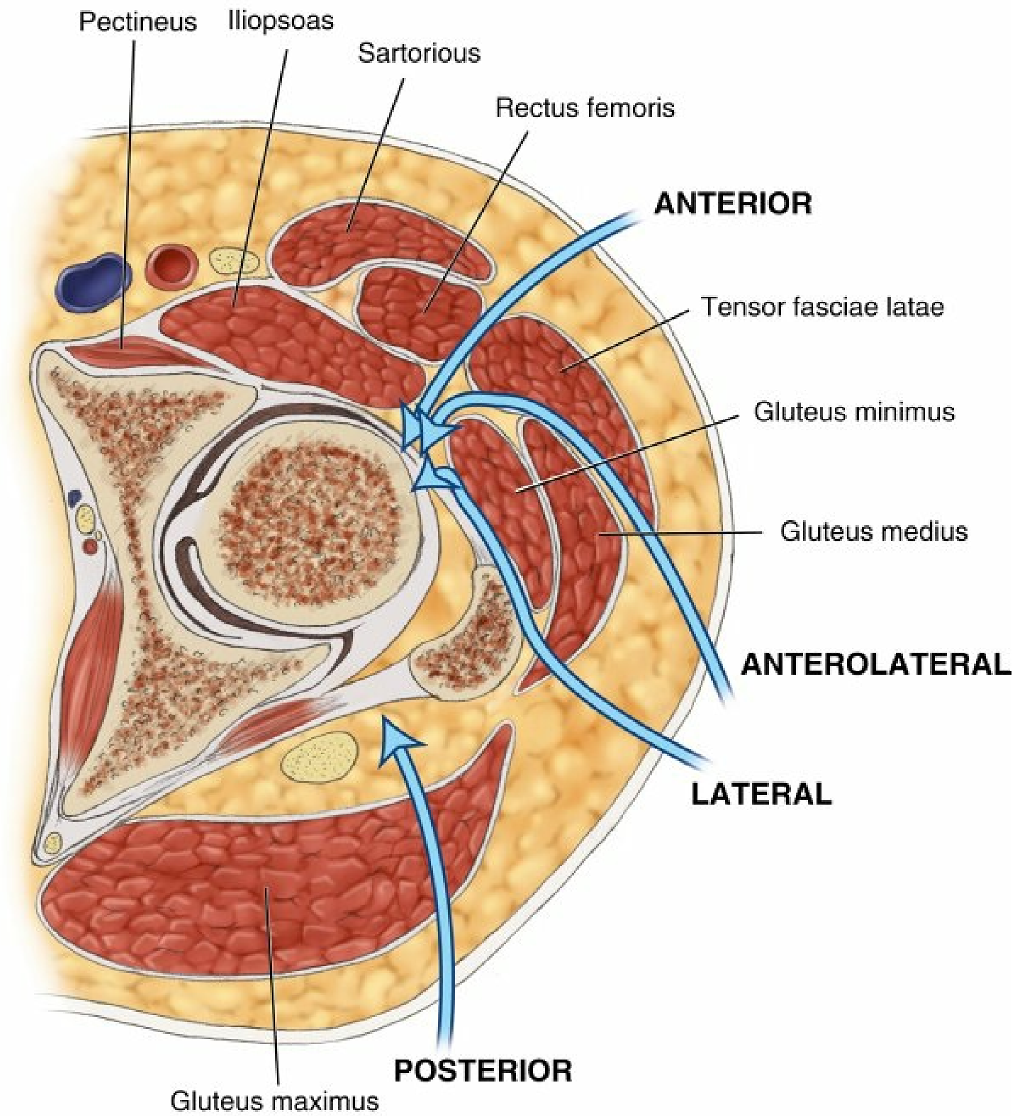


FIG. 2.81 Cross-sectional anatomy depicting various surgical approaches to the hip.

From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 6-49.

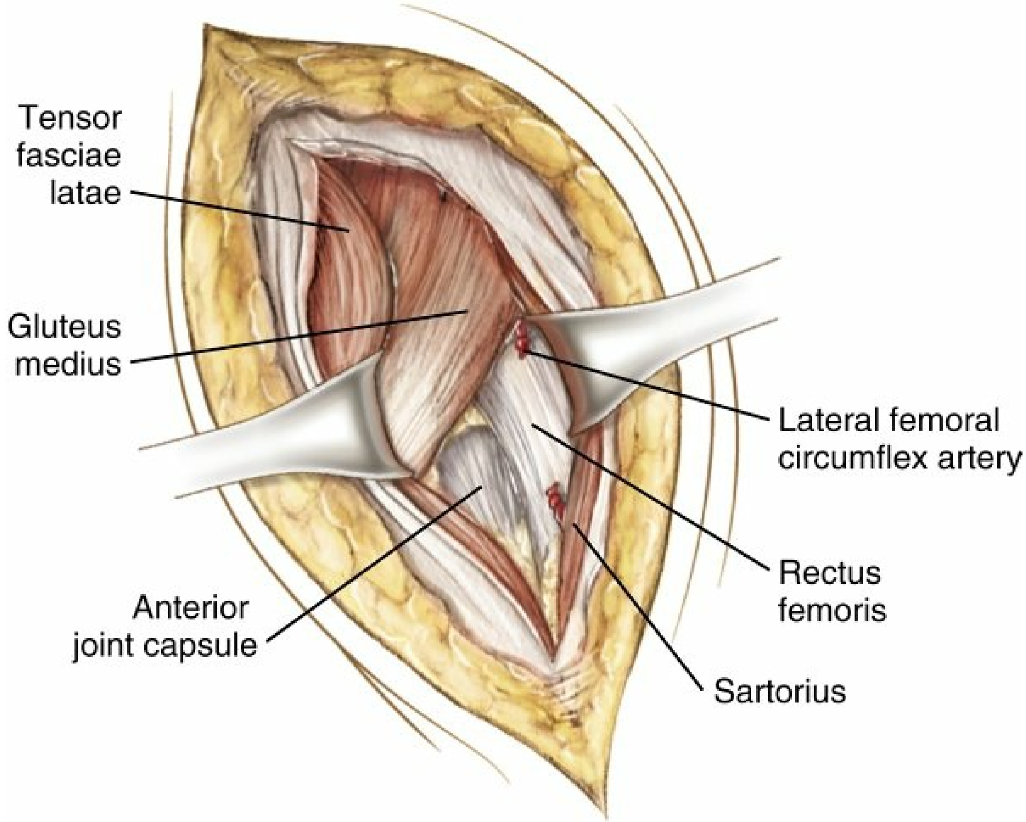


FIG. 2.82 Anterior (Smith-Peterson) surgical approach to the hip.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figure HP-49.

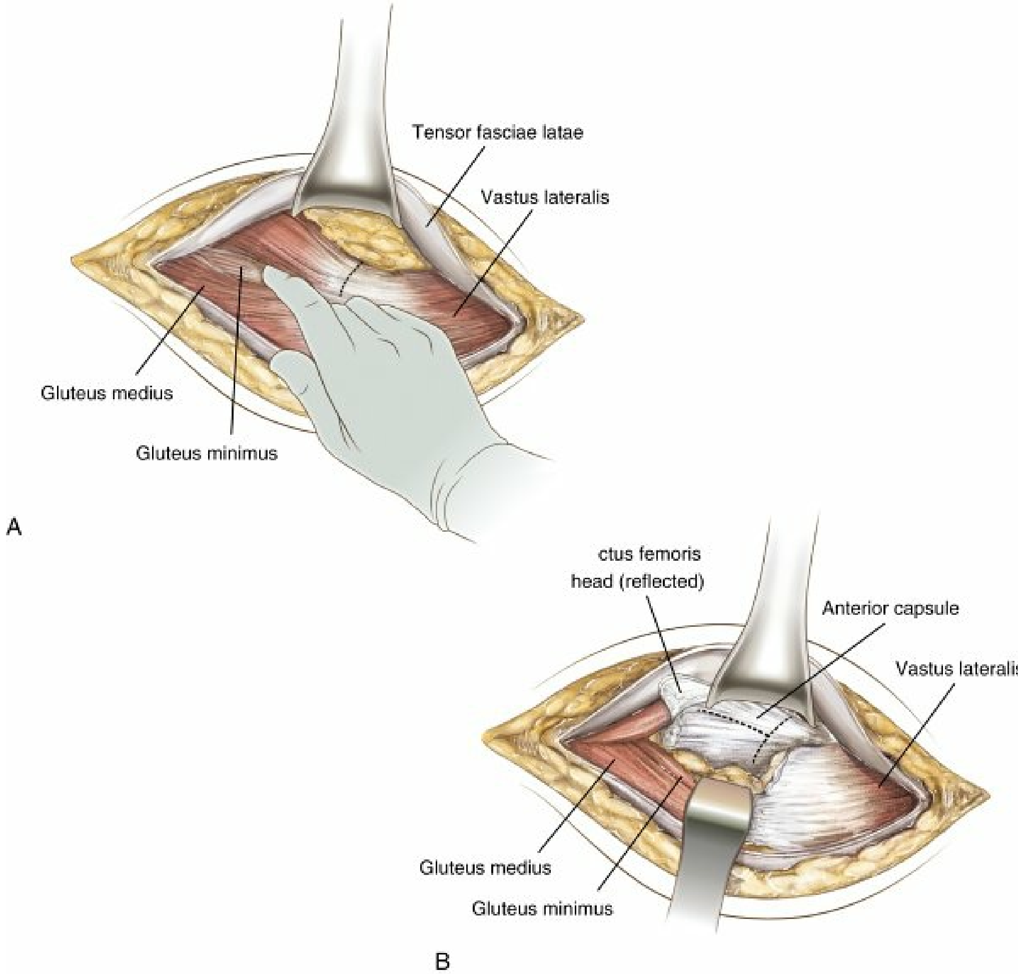


FIG. 2.83 Anterolateral (Watson-Jones) approach to the hip. (A) Superficial exposure. (B) Deep exposure.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures HP-80 and HP-81.

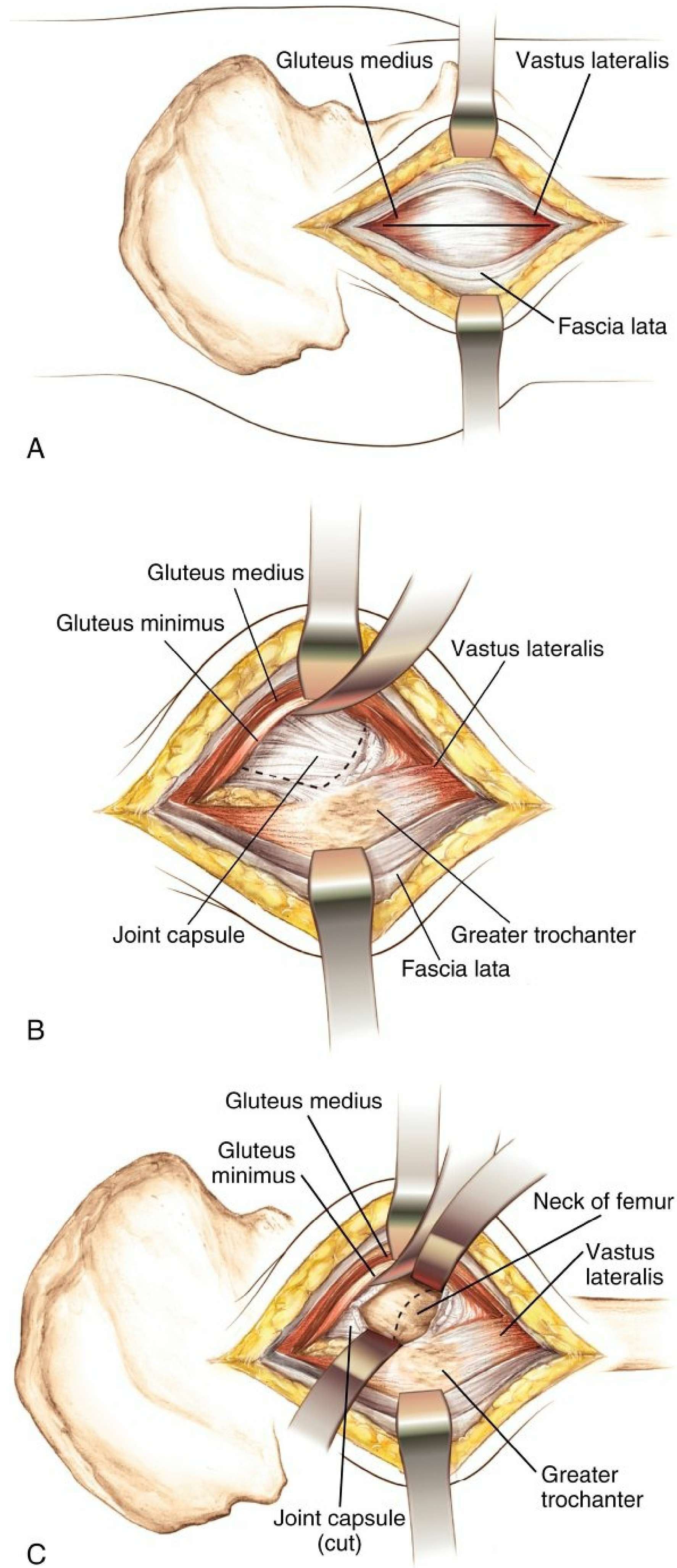

Gluteus medius
Vastus lateralis
Fascia lata
A
Gluteus medius
Gluteus minimus
Vastus lateralis
Joint capsule
Greater trochanter
Fascia lata
B
Gluteus medius
Gluteus minimus
Neck of femur
Vastus lateralis
Greater trochanter
Joint capsule (cut)
C

FIG. 2.84 Lateral (Hardinge) approach to the hip. (A) Superficial exposure. (B) Deep exposure. (C) Close-up view of deep exposure. From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures HP-72, HP-73, and HP-74.

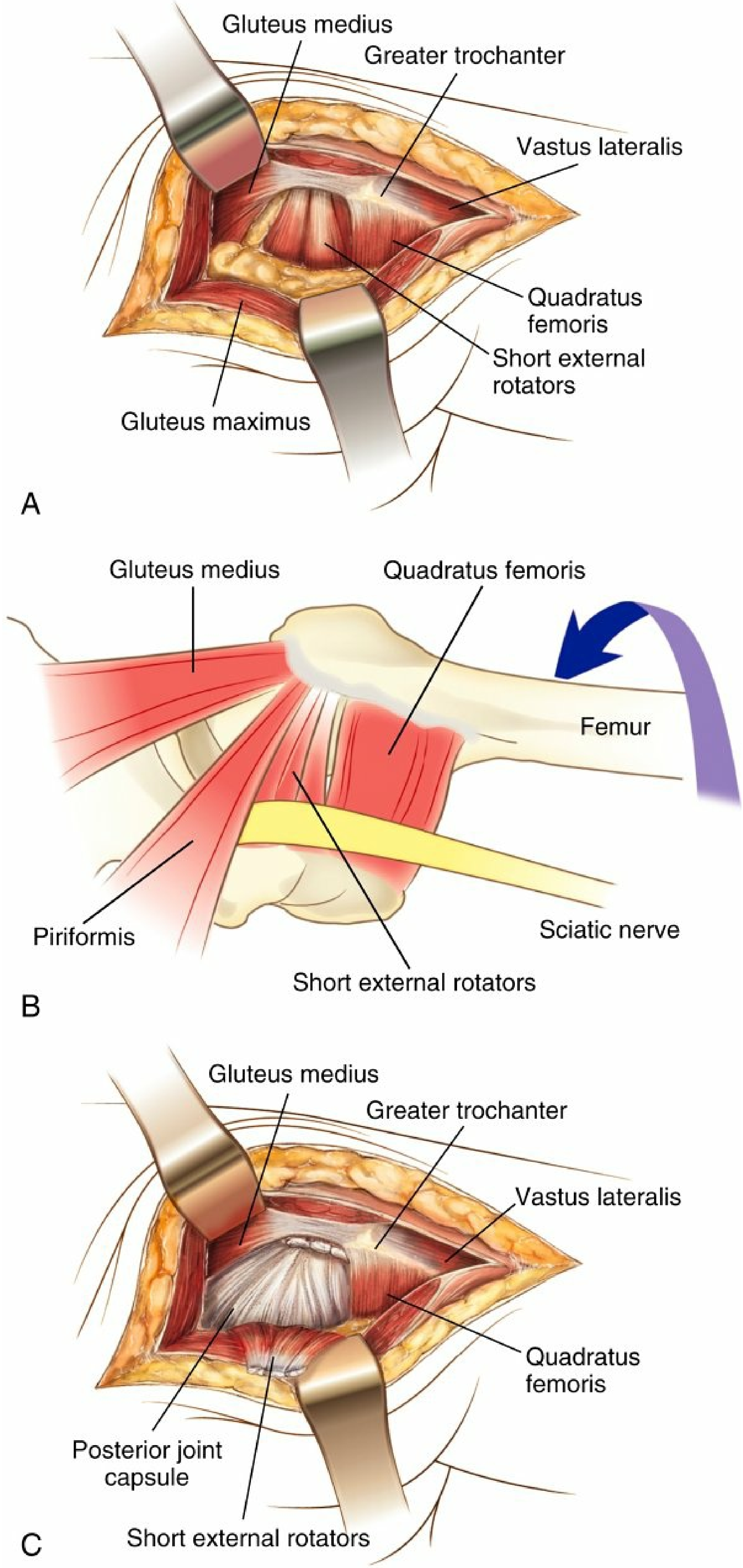

Gluteus medius
Greater trochanter
Vastus lateralis
Quadratus femoris
Short external rotators
Gluteus maximus
A
Gluteus medius
Quadratus femoris
Femur
Piriformis
Sciatic nerve
Short external rotators
B
Gluteus medius
Greater trochanter
Vastus lateralis
Quadratus femoris
Posterior joint capsule
Short external rotators
C

FIG. 2.85 Posterior (Moore or Southern) approach to the hip. (A) Superficial exposure. (B) Relationship of muscles to bones. Note that the femur is internally rotated *(blue arrow)* to improve exposure of the short external rotators. (C) Deep exposure.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders, Figures HP-58, HP-59, and HP-60.

        - Risks
            - Sciatic nerve: neurapraxia (usually peroneal division) may occur with retraction if not protected by the short external rotators; may be stretched with excessive lengthening.
            - Inferior gluteal artery: may be injured during splitting of the gluteus maximus
            - Medial femoral circumflex artery: may be damaged during takedown of external rotators from insertion
    - □ Medial (Ludloff) approach to the hip (Fig. 2.86)
        - Used for open reduction of congenital hip dislocation, psoas release
        - Interval: adductor longus and gracilis
        - Risks
            - Obturator nerve (anterior division) and medial femoral circumflex artery are between the adductor brevis and adductor magnus/pectineus.
            - Deep external pudendal artery (anterior to the pectineus near the adductor longus origin) is also at risk proximally for injury.
        - Trochanteric osteotomies are depicted in Fig. 2.87.
    - □ Knee
        - Anterior approach (medial parapatellar)
            - Dissection: midline skin incision and a medial parapatellar capsular incision
            - Risks
                - Infrapatellar branch of the saphenous nerve is sometimes cut with incisions that stray too far medially, leading to painful neuroma and anterolateral numbness.
                - Medial superior geniculate artery
        - Medial approach to the knee (Fig. 2.88)
            - Interval: between the sartorius and medial patellar retinaculum
            - Dissection: three layers are commonly recognized (from superficial to deep): (1) the pes anserinus

tendons, (2) the superficial MCL, and (3) the deep MCL and capsule.

- Risks
  - Saphenous nerve and vein must be identified and protected.
  - MCL should be protected to prevent valgus instability.

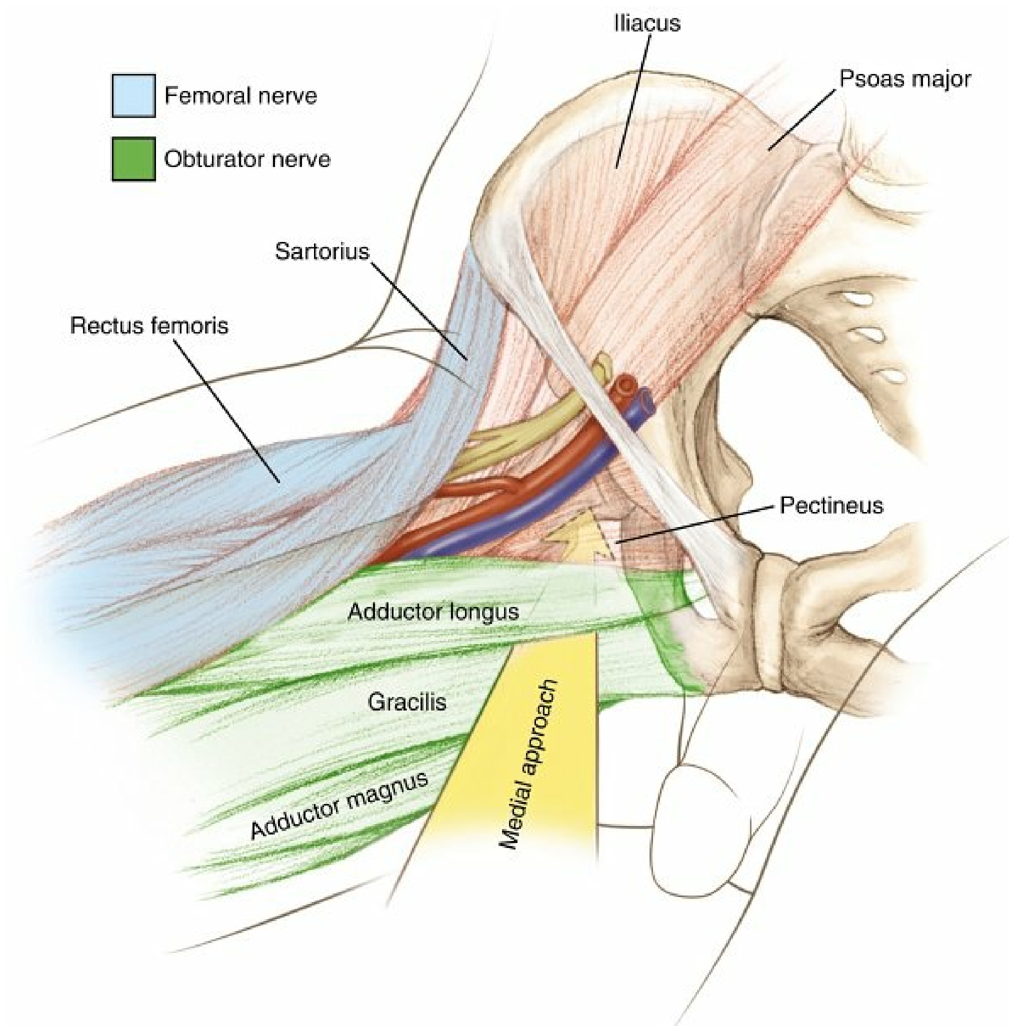
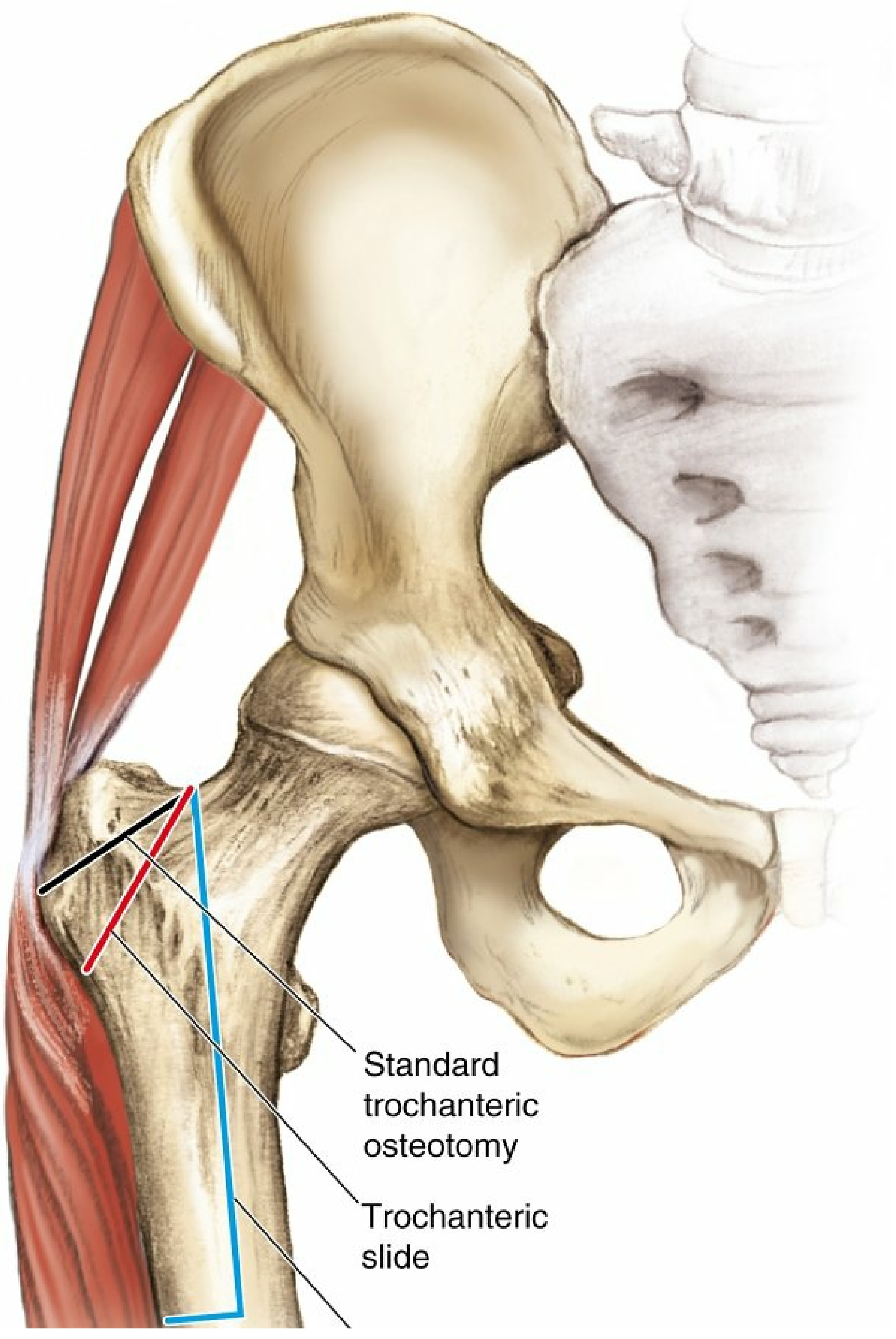


FIG. 2.86 Characterization of the plane exploited by the medial approach to the hip, represented by the yellow arrow.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 6-50.



Standard trochanteric osteotomy
Trochanteric slide

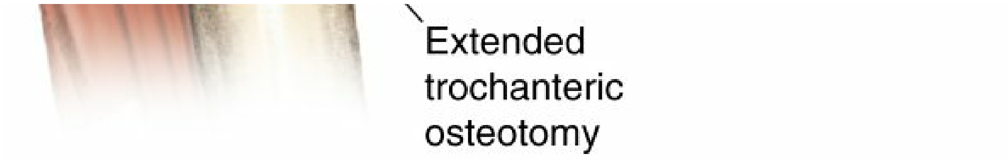


FIG. 2.87 Trochanteric osteotomies.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 6-96.

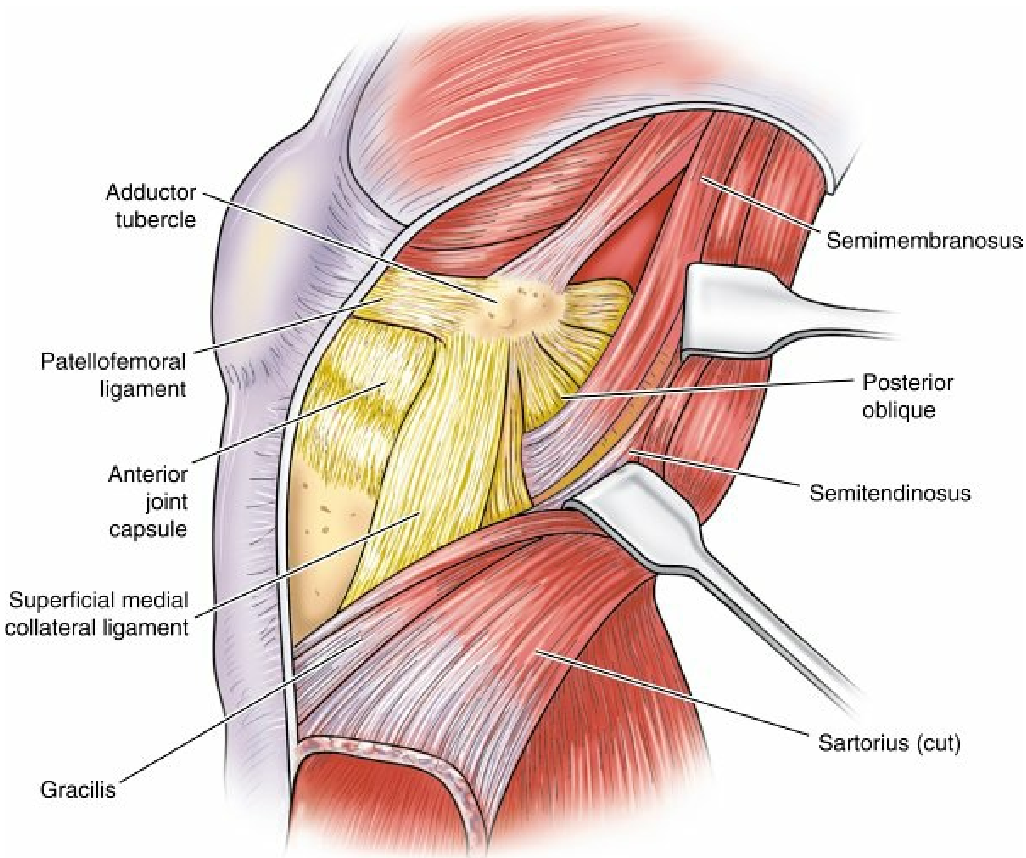


FIG. 2.88 Medial approach to the knee.
From Scott WN: *Insall & Scott surgery of the knee,* ed 5, Philadelphia, 2012, Elsevier, Figure 1-64.

- Lateral approach to the knee (Fig. 2.89)
    - Interval: either split IT band or approach between the IT band and the biceps (sciatic nerve).
    - Dissection
        - Develop interval between the IT band and biceps for identification of lateral collateral ligament (LCL) and popliteus.
        - Develop a second interval within the IT band to identify the lateral femoral epicondyle.
    - Risks
        - Common peroneal nerve (located near posterior border of biceps) must

be isolated and carefully retracted.
            - LCL and popliteus tendon are also at risk for injury and should be identified.
            - Superior lateral geniculate artery is located between the femur and vastus lateralis.
            - Inferior lateral geniculate artery is posterior to the LCL between the lateral head of the gastrocnemius and the posterolateral capsule.
    - Posterior approach to the knee
        - Dissection
            - S-shaped incision, beginning laterally and ending medially (distally)
            - Expose the popliteal fossa by using the small saphenous vein and medial sural cutaneous nerves as landmarks.
            - If greater exposure is necessary, detach the two heads of the gastrocnemius.
            - In an alternative approach, mobilize the medial head of the gastrocnemius (lateral to the semimembranosus) and retract it laterally, using its muscle belly to protect the neurovascular structures.
        - Risks: popliteal vessels and tibial nerve, common peroneal nerve, medial sural cutaneous nerve
- □ Foot and ankle
    - Anterior approach to the ankle
        - Interval: between the EHL and EDL or tibialis anterior (both deep peroneal nerve)
        - Dissection: before incising the extensor retinaculum, carefully protect the superficial peroneal nerve, which courses superficially.
        - Risks: deep peroneal nerve and anterior tibial artery, which lie directly in this interval, must be retracted medially along with the EHL.
    - Approach to the medial malleolus
        - Dissection
            - Because it is superficial, use an anterior or posterior approach.

- Posteromedial approach behind the medial malleolus through the tendon sheath of the posterior tibialis

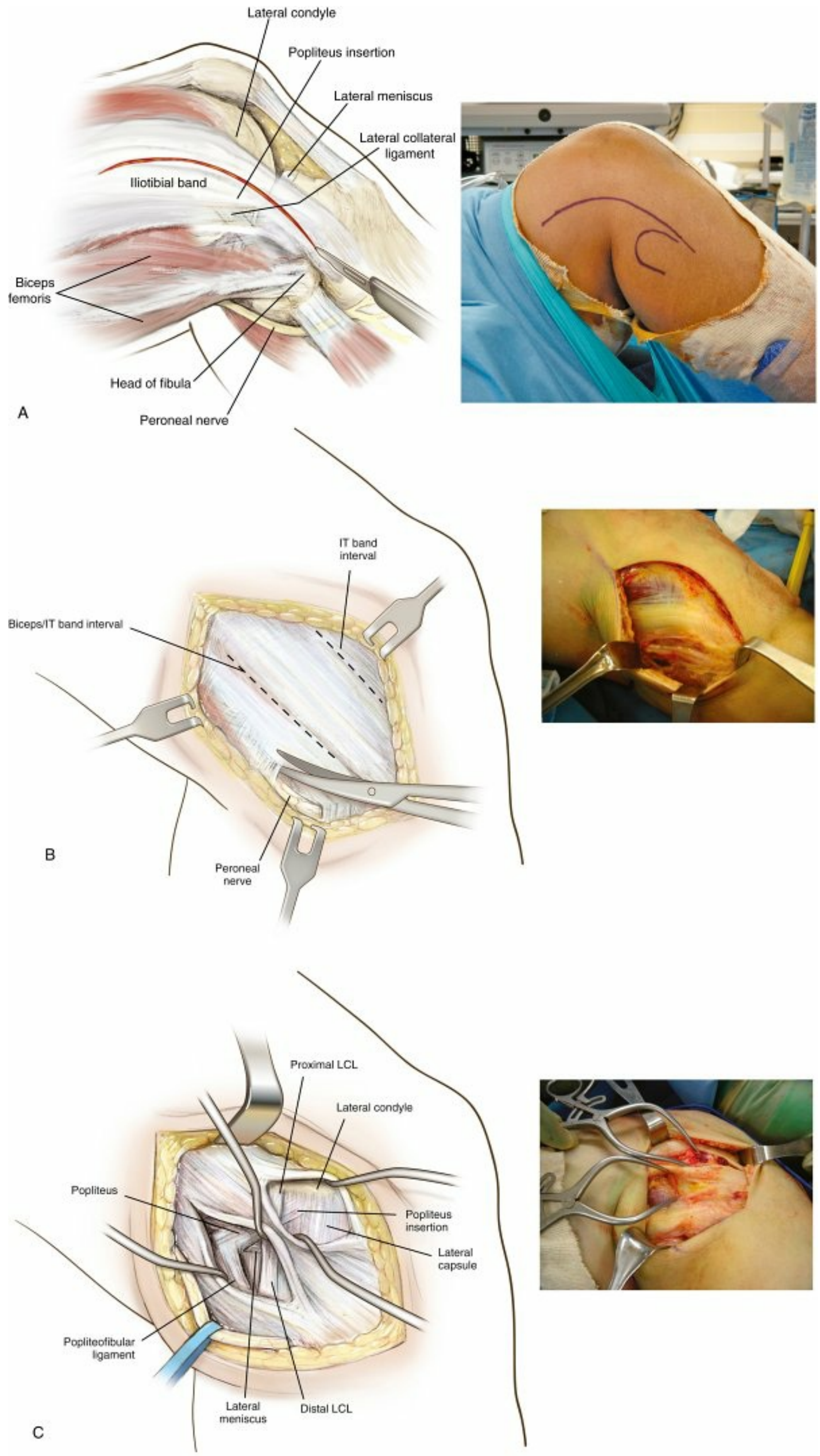


FIG. 2.89 Lateral approach to the knee. (A) Skin incision and superficial anatomy. (B) Deep interval. (C) The IT band interval and biceps/IT band interval are utilized to expose the proximal and distal LCL, respectively.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 7-31A.

- Risks
  - Anterior approach—saphenous nerve

        and the long saphenous vein
    - Posterior approach—posterior *t*ibial tendon, flexor *d*igitorum longus, posterior tibial *v*ein, posterior tibial *a*rtery, tibial *n*erve, and flexor *h*allucis longus (mnemonic: “Tom, Dick, and very angry nervous Harry”).
- Posteromedial approach to the ankle and foot: used for release of clubfoot in children
  - Dissection
    - Begin this approach medial to the Achilles tendon, and follow the curve distally along the medial border of the foot.
    - Use the posterior tibialis tendon as a landmark for the location of the subluxated navicular in the clubfoot.
  - Risks: posterior tibial nerve and artery and their branches
- Lateral approach to the ankle
  - Dissection: use a subcutaneous approach for ORIF of distal fibula fractures.
  - Risks: sural nerve (posterolateral) and the superficial peroneal nerve (anterior)
- Posterolateral approach to ankle
  - Interval: between the peroneus brevis and FHL
  - Dissection
    - Identify the peroneal tendons (brevis more muscular and anterior to longus directly behind the fibula).
    - Incise peroneal retinaculum to mobilize tendons laterally, thereby exposing the FHL.
    - Retract FHL medially to expose tibia and ankle joint.
  - Risks: lesser saphenous vein and sural nerve posterior to lateral malleolus
- Lateral approach to the hindfoot: used for triple arthrodesis
  - Interval: between the peroneus tertius (deep peroneal nerve) and peroneal tendons (superficial peroneal nerve)
  - Dissection: remove the fat pad covering the sinus tarsi, and reflect the EDB from its origin to expose

the joints.
- Risks
  - Lateral branch of the deep peroneal nerve (which supplies the EDB) must be protected in this approach.
  - Deep penetration with an instrument used in this approach can injure the FHL.
- Anterolateral approach to the midfoot
  - Dissection: approach commonly used for excision of a calcaneonavicular bar; release the EDB.
  - Risk: calcaneal navicular (spring) ligament may be injured.

▪ **Cross-sectional diagrams of the lower extremity with MRI are demonstrated in** Figs. 2.90 through 2.92.

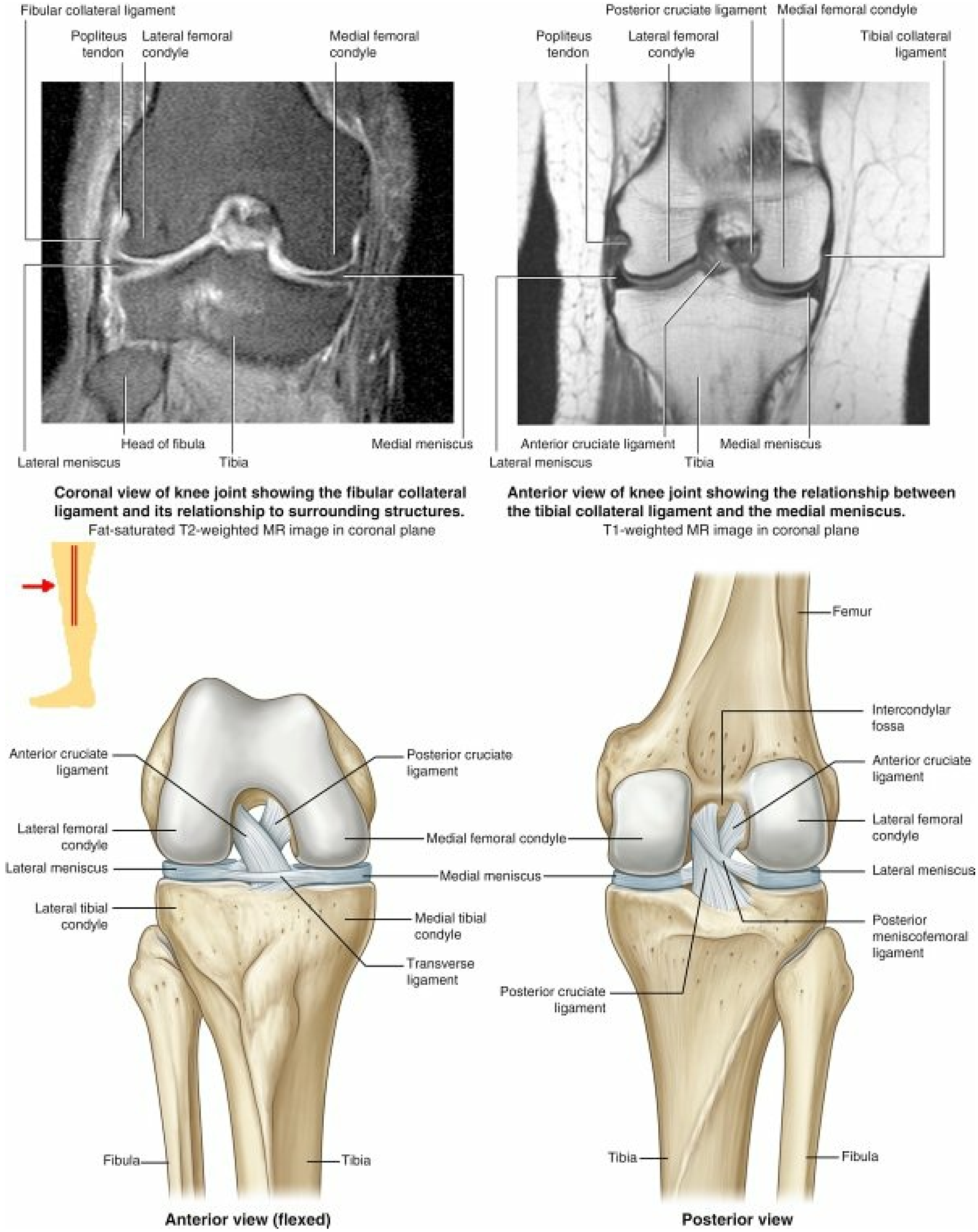


FIG. 2.90 Anterior and posterior views of the knee joint with corresponding imaging. From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

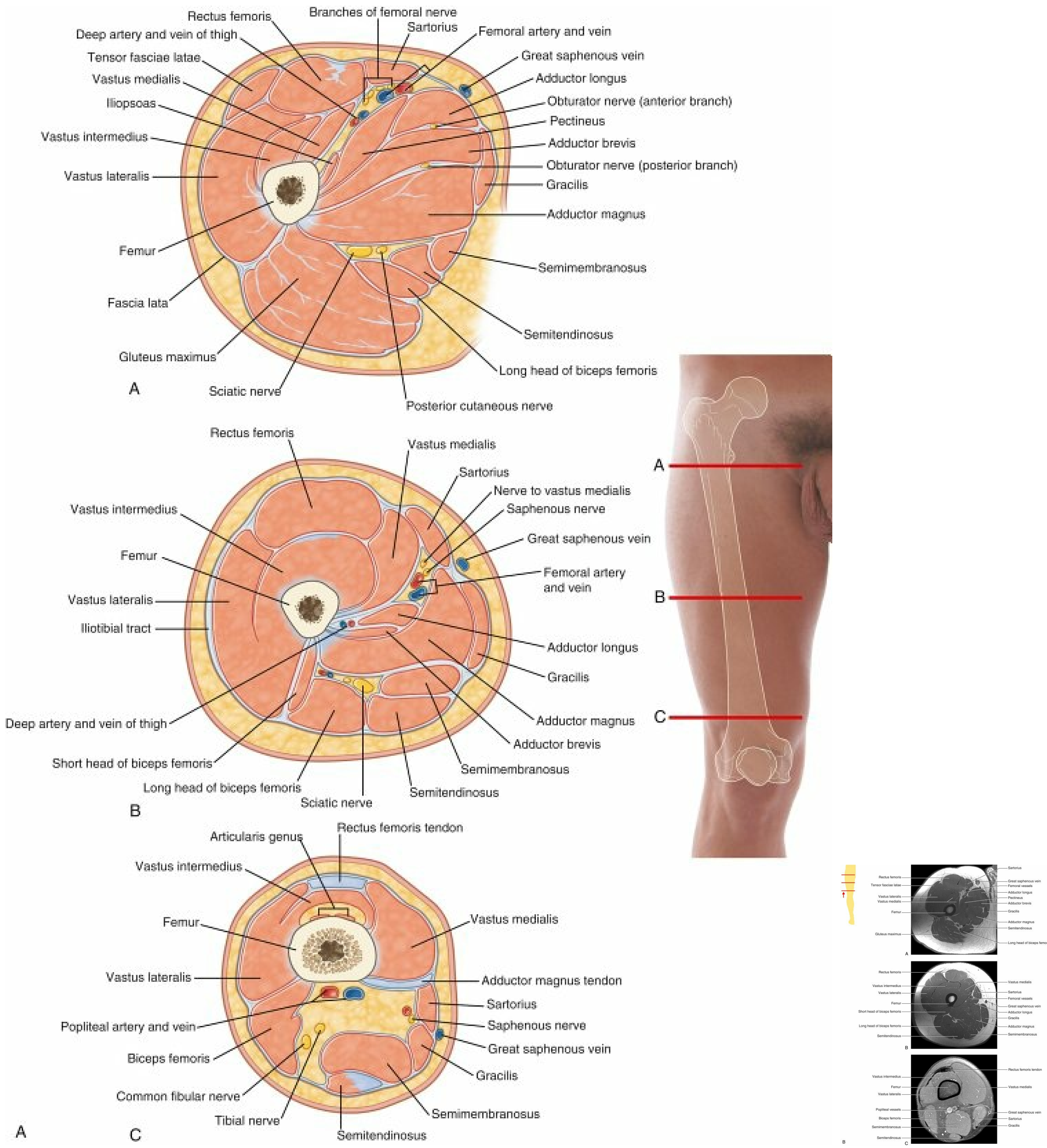


FIG. 2.91 Illustration (A) and imaging (B) of the cross-sectional anatomy of the thigh. From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

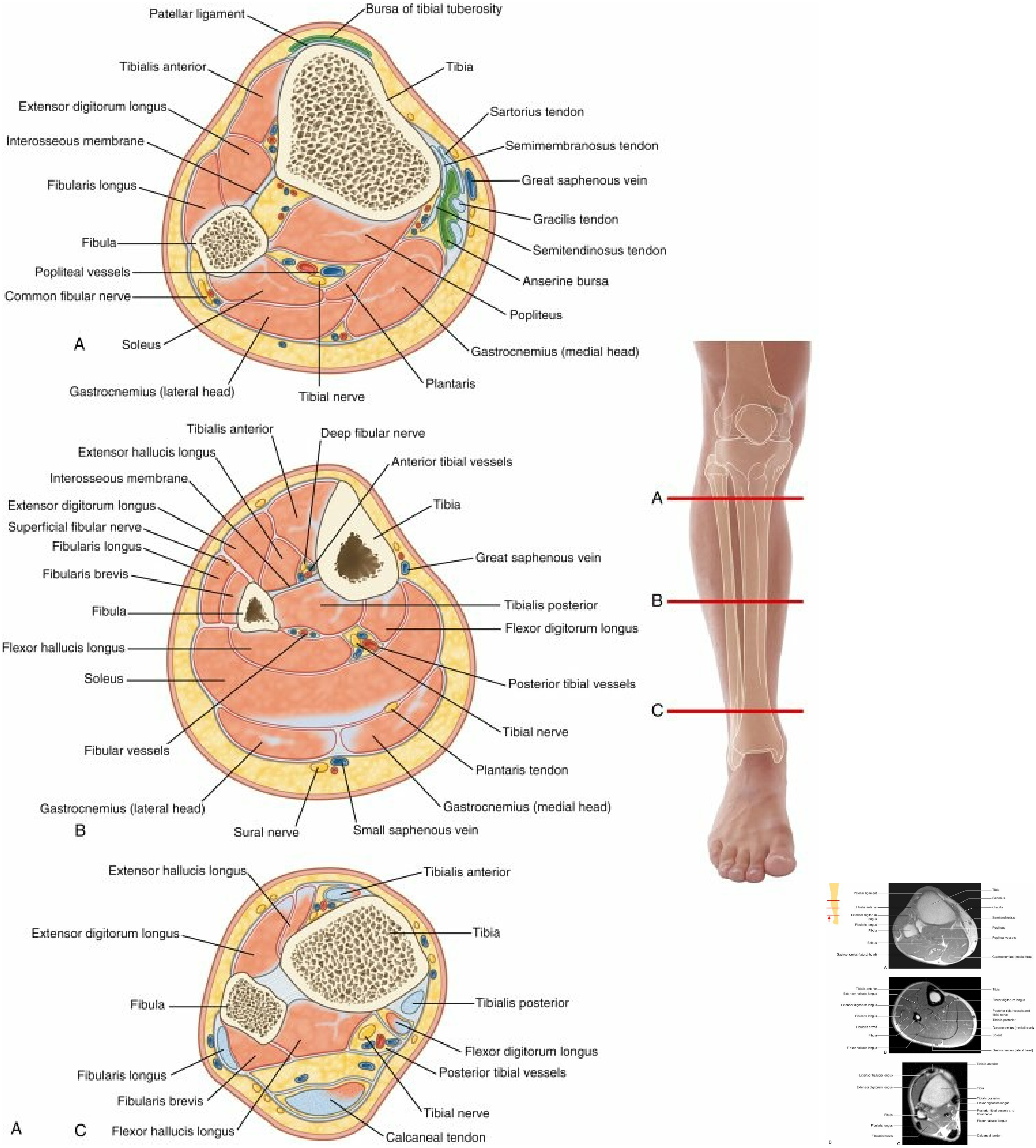


FIG. 2.92 Illustration (A) and imaging (B) of the cross-sectional anatomy of the lower leg. (From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.)

Section 4 Spine

Osteology

- **The spine has 33 vertebrae: 7 cervical, 12 thoracic, 5 lumbar, 5 fused sacral, and 4 fused coccygeal (** Fig. 2.93).
    - Normal curves are cervical lordosis, thoracic kyphosis, lumbar lordosis, and sacral kyphosis.

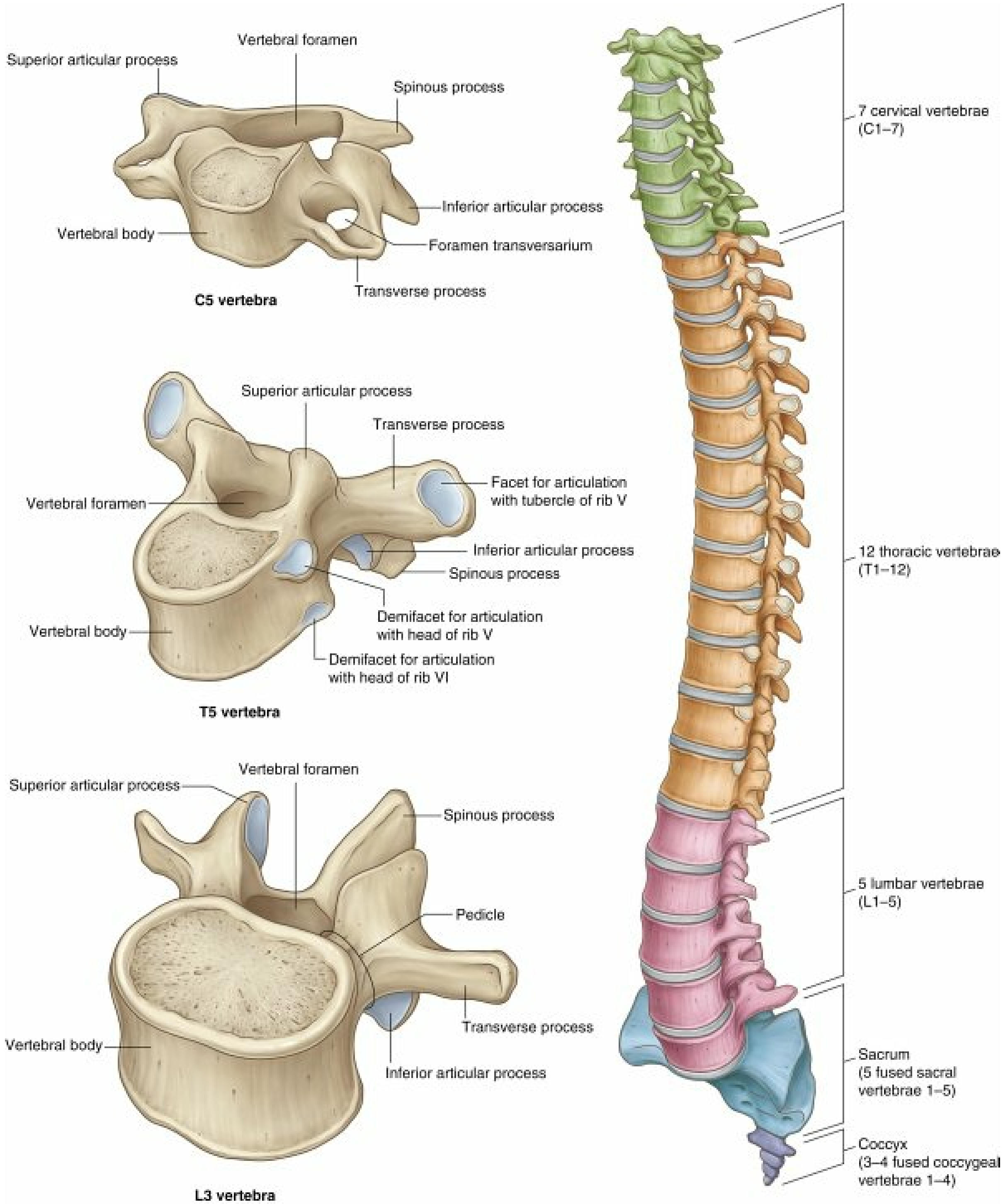


FIG. 2.93 Sections of the spine and corresponding vertebrae.

From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

Table 2.39

Spine Topographic Landmarks

Topographic Landmark	Spinal level
Mandible	C2–3
Hyoid cartilage	C3
Thyroid cartilage	C4–5
Cricoid cartilage	C6
Vertebra prominens	C7
Scapular spine	T3
Distal tip of scapula	T7
Iliac crest	L4–5

- **Plumb line from center of C7 to posterior superior corner of S1**
- ▫ Vertebral body width generally increases in a craniocaudad direction (except T1–3.)
- ▫ Important spine topographic landmarks are listed in Table 2.39.

▪ **Cervical spine (** Fig. 2.94)

- ▫ Atlas (C1) has no vertebral body and no spinous process.
  - Two concave superior facets that articulate with the occipital condyles
  - **50% of total neck flexion and extension occurs at occiput–C1 articulation**.
- ▫ Axis (C2) develops from five ossification centers, with an initial cartilaginous junction between the dens and vertebral body (subdental synchondrosis) that fuses at 7 years of age.
  - Base of the dens narrows because of the transverse ligament.
  - **50% of total neck rotation occurs at atlantoaxial (C1–2) articulation**
  - Atlantoaxial joint is diarthrodial.
    - *Pannus* in rheumatoid arthritis can affect this articulation and result in instability (see Chapter 8, Spine).
- ▫ C2–7 vertebrae have foramina in each transverse process and bifid spinous processes (except for the C7 nonbifid posterior spinous process [vertebral prominens]).
- ▫ Vertebral artery travels in the transverse foramina of C6 to C1 (not C7).
- ▫ Carotid (Chassaignac) tubercle is found at C6.
- ▫ Diameter of the cervical spine canal is normally 17 mm, and the cervical cord may become compromised when the diameter is reduced

to less than 13 mm (relative stenosis).

- **Thoracic spine (** Fig. 2.95)
  - Unique features include costal facets (present on all 12 vertebral bodies and the transverse processes of T1–9) and a rounded vertebral foramen.
  - Thoracic vertebral articulation with the rib cage makes this the most rigid region of the axial skeleton.
  - Narrowest pedicles at T5
- **Lumbar spine (** Fig. 2.96)
  - Lumbar vertebrae are the largest vertebrae and are higher anteriorly than posteriorly, significantly contributing to the lumbar lordosis.
  - Lumbar lordosis ranges from 55 to 60 degrees, with the apex at L3.
  - **66% of lordosis occurs in the region from L4 to the sacrum.**
  - Lumbar vertebrae contain short laminae and pedicles.
  - Mammillary processes (separate ossification centers) project posteriorly from the superior articular facets.
- **Sacrum**
  - Formed from the fusion of five spinal elements
  - Sacral promontory is an anterosuperior portion that projects into the pelvis.
  - Four pairs of pelvic sacral foramina located both anteriorly and posteriorly transmit respective ventral and dorsal branches of the upper four sacral nerves.
  - Sacral canal opens caudally into the sacral hiatus.
- **Coccyx**
  - Formed from the fusion of the lowest four spinal elements
  - Attachments dorsally to the gluteus maximus, external anal sphincter, and coccygeal muscles

Arthrology

- **Spinal ligaments (** Fig. 2.97)
  - Anterior longitudinal ligament (ALL)
    - Strong; thickest at center of vertebral body and thinnest at periphery
    - Characterized by separate fibers extending from one to five levels
    - Resists hyperextension
  - Posterior longitudinal ligament
    - Weaker than ALL
    - Extends from occiput (tectorial membrane) to posterior sacrum

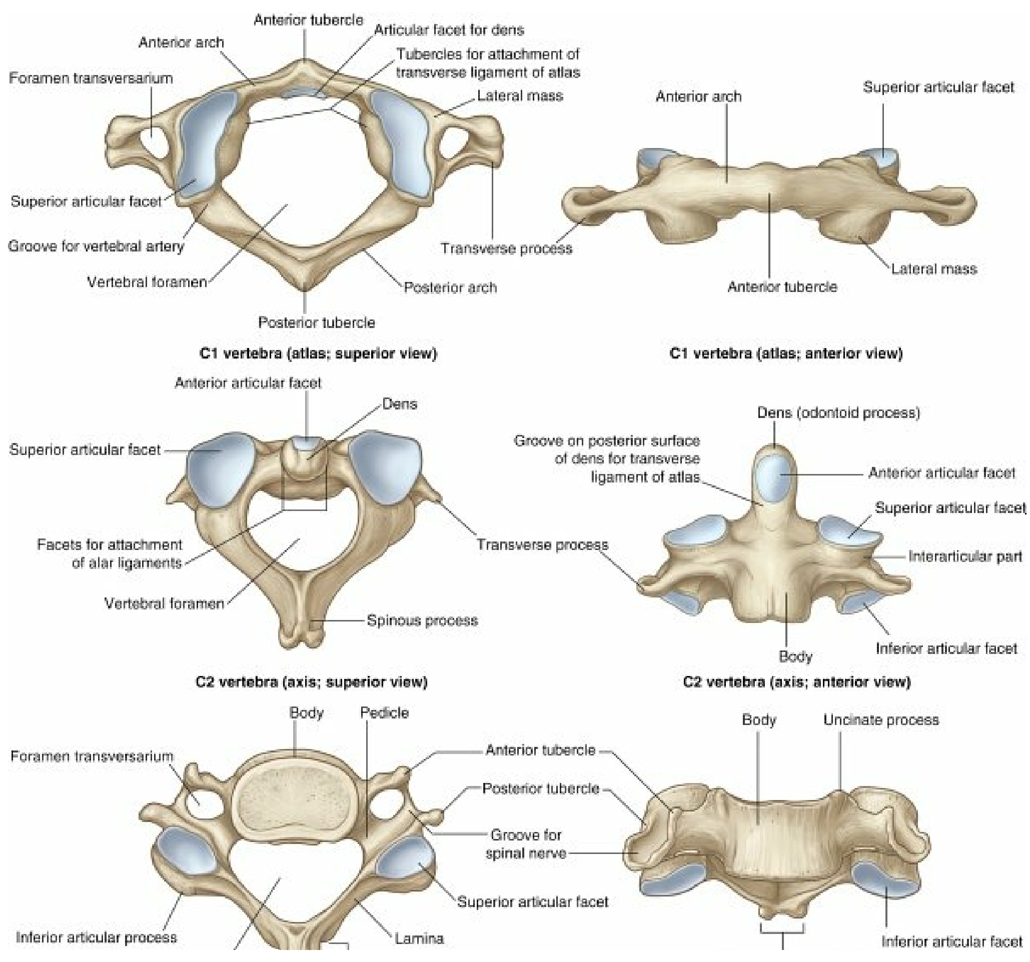
- Separated from the center of the vertebral body by a space that allows passage of the dorsal branches of the spinal artery and veins
- Hourglass shaped, with the wider (yet thinner) sections located over the discs; ruptured discs tend to be lateral to these expansions.

□ Ligamentum flavum

- Strong yellow elastic ligament connecting the laminae
- Runs from anterior surface of the superior lamina to posterior surface of the inferior lamina and is constantly in tension
- Hypertrophy may contribute to nerve root compression.

□ Supraspinous, interspinous, and intertransverse ligaments

- Ligamentous capsules overlying the zygapophyseal joints; the intertransverse ligaments contribute little to interspinous stability.
- Supraspinous ligament lies dorsal to the spinous processes, and interspinous ligament lies between the spinous processes.



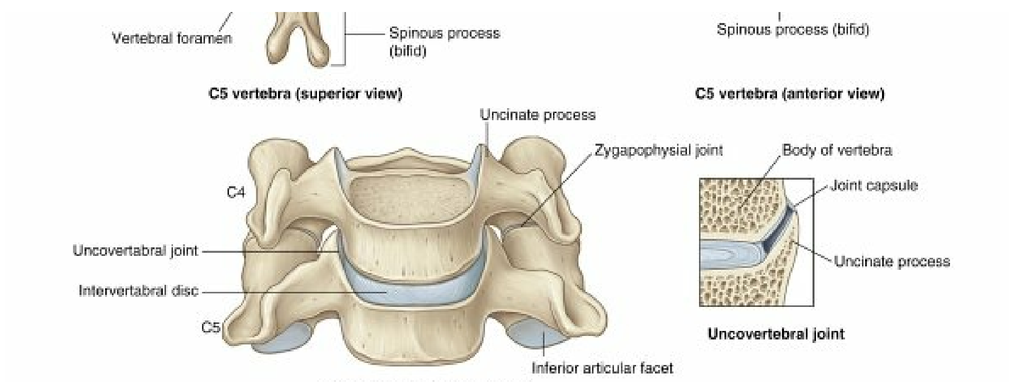


FIG. 2.94 Cervical vertebral anatomy.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

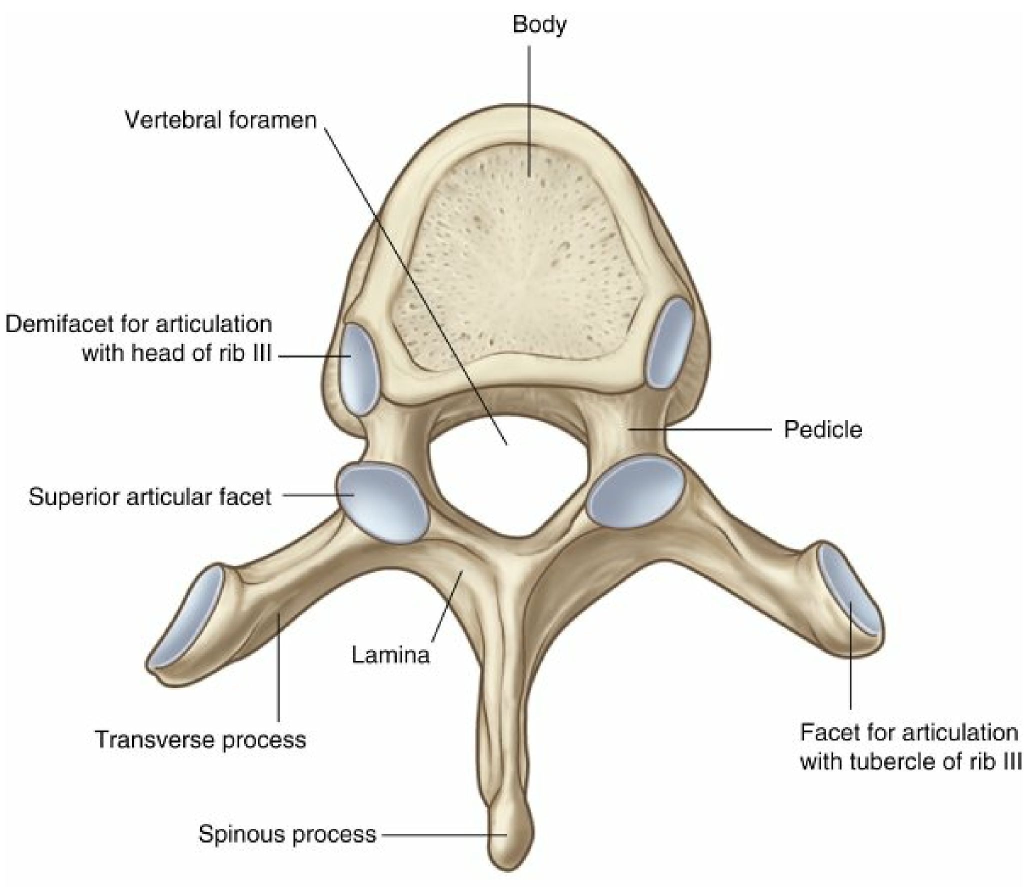


FIG. 2.95 Thoracic vertebral anatomy (superior view).
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

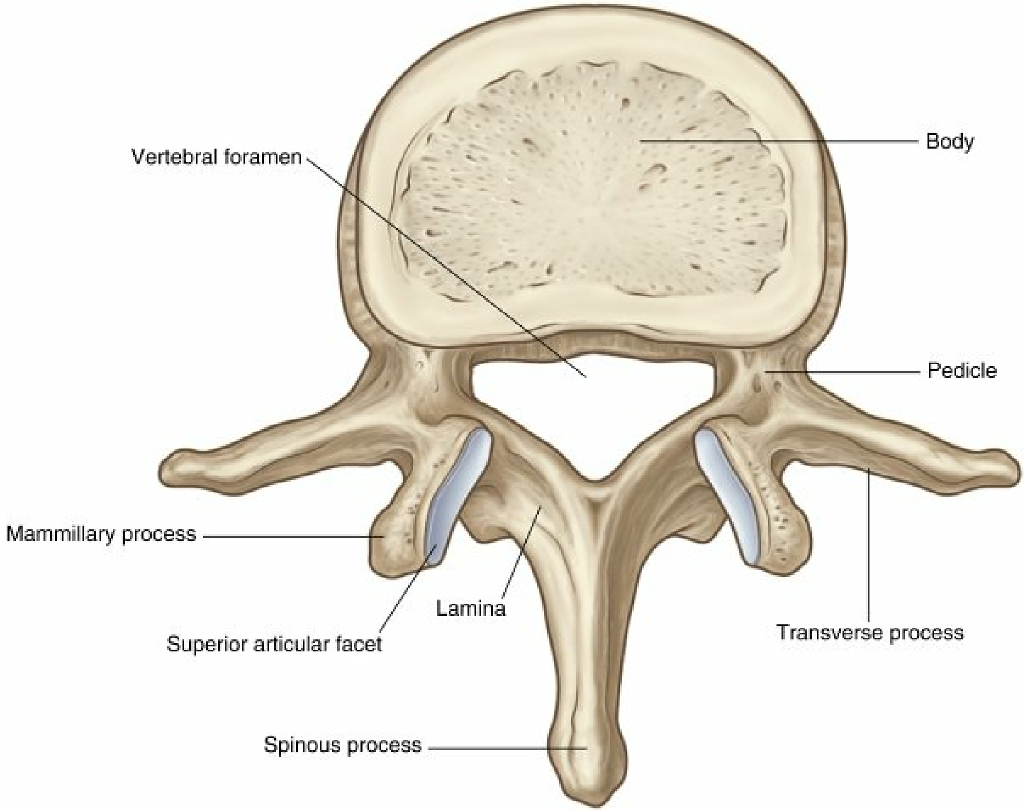
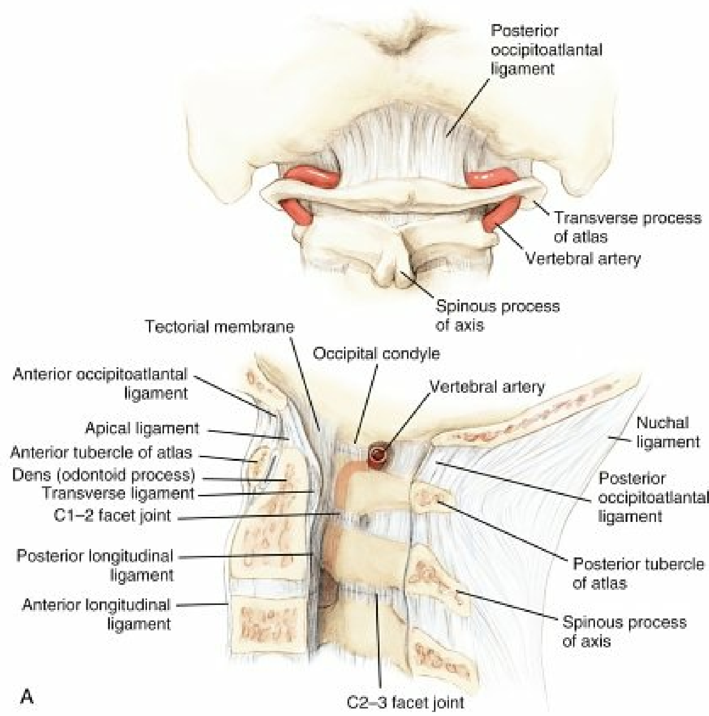
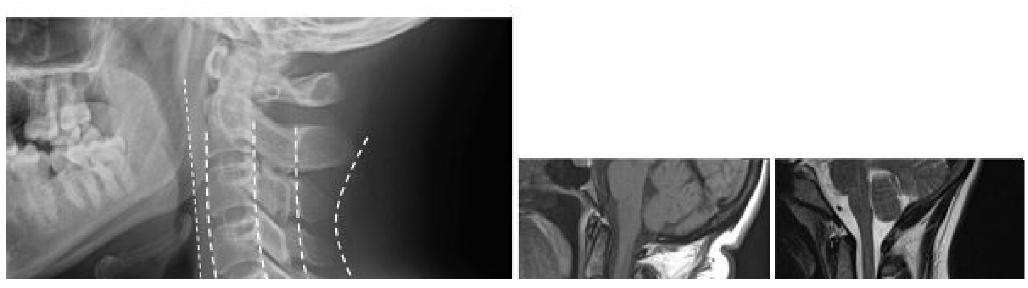


FIG. 2.96 Lumbar vertebral anatomy.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.





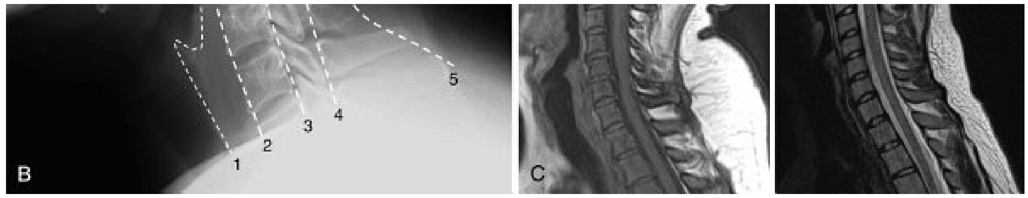


FIG. 2.97 The occipitocervical junction. (A) Anatomic diagram of the occipitocervical junction. Note the location and course of the vertebral artery. (B) Lateral cervical radiograph with important radiographic lines: *(1)* prevertebral soft tissue, *(2)* anterior vertebral body, *(3)* posterior vertebral body, *(4)* spinolaminar line, and *(5)* spinous process line. (C) Sagittal MRI of cervical spine.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 5-5A.

        - Supraspinous ligament begins at C7 and is in continuity with the ligamentum nuchae (which runs from C7 to occiput).
- **Spine stability (Denis model): the three-column system (** Fig. 2.98, Table 2.40)
- **Specialized ligaments**
    - □ Atlantooccipital joint
        - Composed of two articular capsules (anterior and posterior) and the tectorial membrane (cephalad extension of the posterior longitudinal ligament)
        - Further stabilization by the ligamentous attachments to the dens
    - □ Atlantoaxial joint (Fig. 2.99)
        - Transverse ligament is the major stabilizer of the atlantoaxial joint.
        - Further stabilized by the apical ligament (longitudinal), which together with the transverse ligament, compose the cruciate ligament
        - In addition, a pair of alar ("check") ligaments runs obliquely from the tip of the dens to the occiput.
    - □ Iliolumbar ligament
        - This stout ligament connects the transverse process of L5 with the ilium.
        - Tension on this ligament in patients with unstable vertical shear pelvic fractures can lead to avulsion fractures of the transverse process.
- **Facet (apophyseal) joints**
    - □ Orientation of the facets of the spine dictates the plane of motion at each relative level.
    - □ Facet orientation varies with the spinal level (Table 2.41).
    - □ Cervical spine—superior articular facet is anterior and inferior to the inferior articular process of the vertebra above; the nerve roots exit near the superior articulating process.
    - □ **Lumbar spine—the superior articular facet is anterior and lateral to the inferior articular facet.**

- **Intervertebral discs**
  - Account for 25% of the total height of the spinal column
  - Annulus fibrosus: type I collagen, obliquely oriented outer fibrous ring

Table 2.40

Denis Model of Spine Columns

Column	Composition
Anterior	Anterior longitudinal ligament, anterior two-thirds of annulus and vertebral body
Middle	Posterior third of body and annulus, posterior longitudinal ligament
Posterior	Pedicles, facets and facet capsules, spinous processes, posterior ligaments that include interspinous and supraspinous ligaments, ligamentum flavum

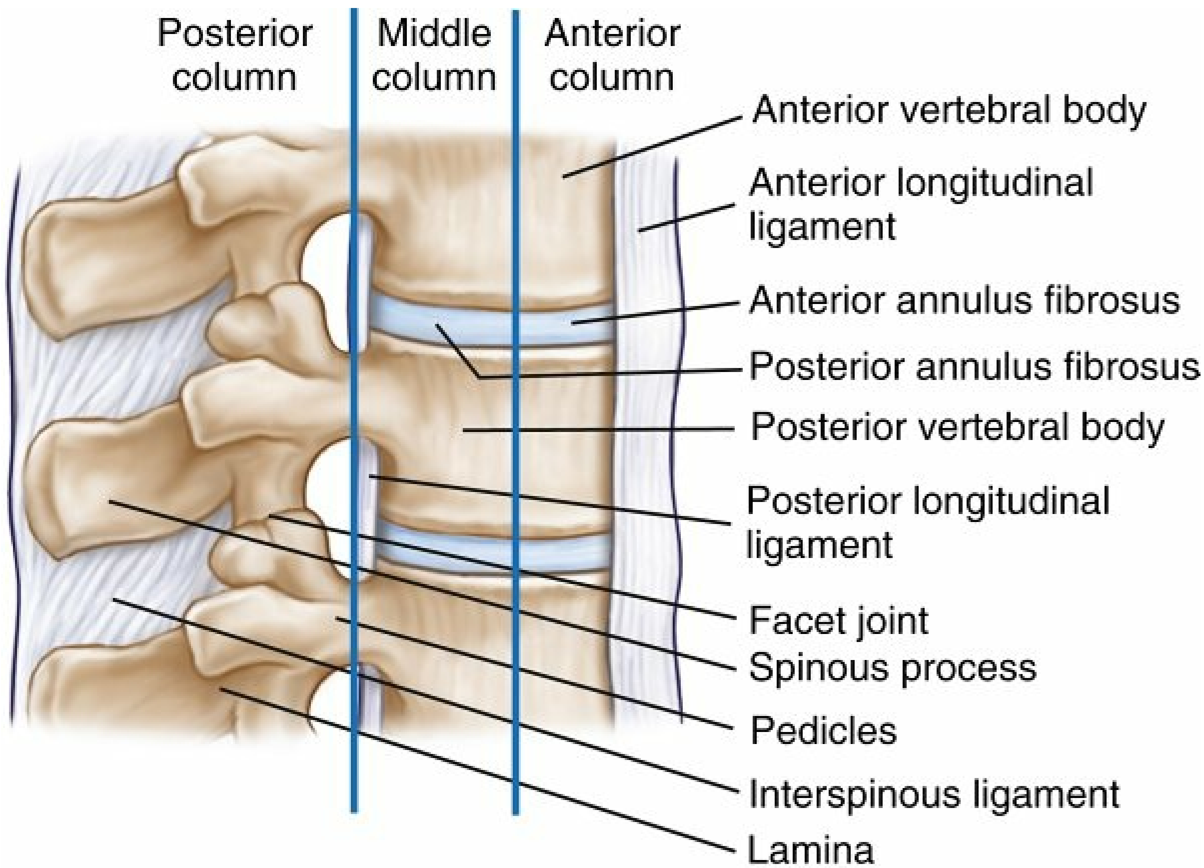


FIG. 2.98 Three-column system of spine stability (Denis model).
From Miller MD, Thompson SR, editors: *DeLee and Drez's orthopaedic sports medicine: principles and practice*, ed 4, Philadelphia, 2014, Saunders.

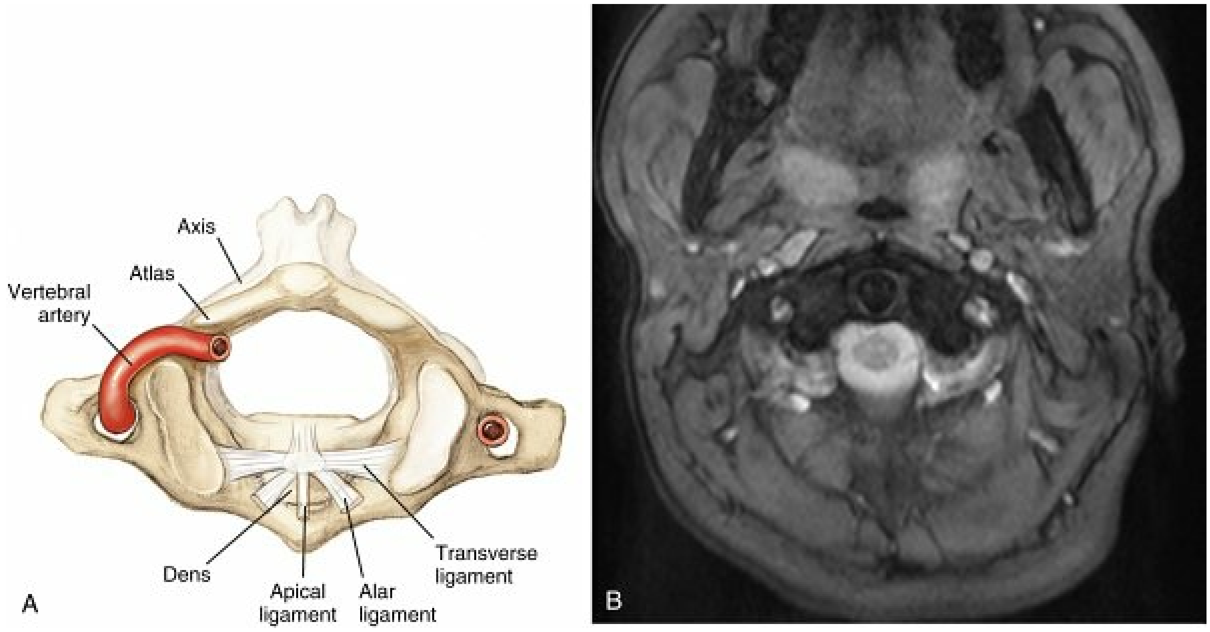


FIG. 2.99 Superior view of the atlantoaxial articulation. Note the relationship of the transverse ligament to C1–2.
From Miller MD et al: *Orthopaedic surgical approaches*, ed 2, Philadelphia, 2014, Saunders, Figure 5-6A.

Table 2.41

Spine Facet Orientation

Spinal Level	Orientation of Sagittal Facet	Orientation of Coronal Facet
Cervical	35 degrees at C2, increasing to 55 degrees at C7	Neutral, 0 degrees
Thoracic	60 degrees at T1, increasing to 70 degrees at T12	20 degrees posterior
Lumbar	137 degrees at L1, decreasing to 118 degrees at L5	45 degrees anterior

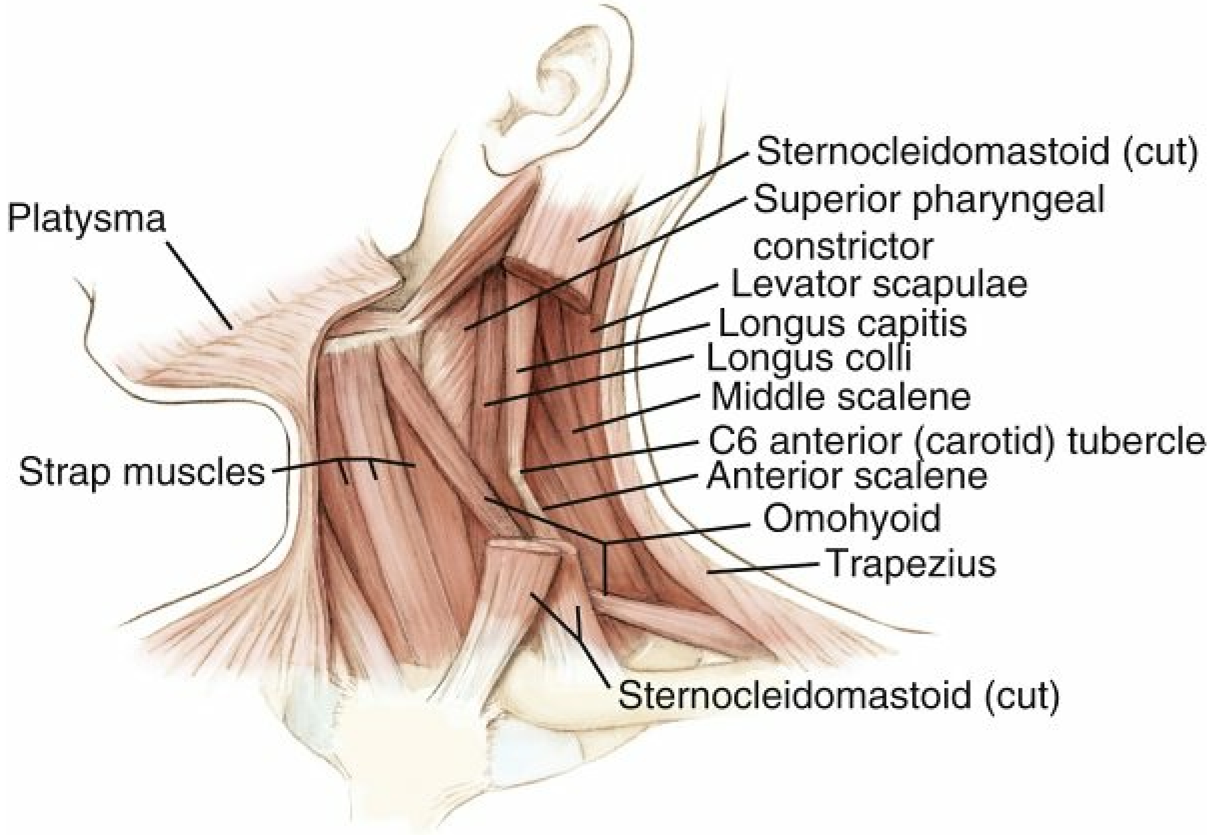


FIG. 2.100 Muscles of the anterior cervical spine.
From Miller MD et al: *Orthopaedic surgical approaches*, ed 2, Philadelphia, 2014, Saunders, Figure 5-10.

- □ Nucleus pulposus: type II collagen, softer internal structure of disc
  - High polysaccharide content (aggrecan), water (≈≈88%)
  - Aging results in the loss of water and conversion to fibrocartilage.
- □ **Intradisc pressure lowest in supine position and highest in the sitting position and flexed forward with weights on the hands.**

▪ **Muscles**

- □ Neck: functional classification (anterior and posterior regions)
  - Anterior neck region (Fig. 2.100)
    - Contains the superficial platysma muscle (cranial nerve VII innervated), stylohyoid and digastric muscles (cranial nerve VII innervated) above the hyoid, and "strap" muscles below the hyoid
    - Strap muscles include the sternohyoid and omohyoid in the superficial layer and the thyrohyoid and sternohyoid in the deep layer; all are innervated by the ansa cervicalis (C1–3).
    - Sternocleidomastoid muscle (cranial nerve XI and ansa) runs obliquely across the neck, rotating the head to the contralateral side.
    - Anterior triangle (borders: sternocleidomastoid, midline of the neck, and lower border of the

mandible) is the largest area.
            - Three smaller triangles are as follows:
                - Submandibular
                - Carotid (bordered by posterior aspect of the digastric and omohyoid and used for the anterior approach to C5)
                - Posterior (bordered by the trapezius muscle, sternocleidomastoid muscle, and clavicle)
        - Posterior neck region
            - Posterior neck muscles form the borders of the suboccipital triangle.
            - Superior and inferior heads of the obliquus capitis muscle and the rectus capitis posterior major muscle form this triangle.
            - Vertebral artery and the first cervical nerve are within this triangle; greater occipital nerve (C2) is superficial.
    - Back
        - Blanketed by the trapezius (superiorly) and latissimus dorsi (inferiorly)
        - Rhomboid muscles and levator scapulae are deep to this layer.
        - Deep muscles: the erector spinae and transversospinalis (Fig. 2.101)
            - Erector spinae run from the transverse and spinous processes of the inferior vertebrae to the spinous processes of the superior vertebrae.
            - They stabilize and extend the back.
            - All of the deep back musculature is innervated by dorsal primary rami of the spinal nerves.
- **Nerves**
    - Spinal cord
        - General anatomy
            - Spinal cord extends from the brainstem to the inferior border of L1, where it terminates as the conus medullaris.
            - Small filum terminale continues distal with the surrounding nerve roots contained within a common dural sac (cauda equina) to its termination in the coccyx.
            - Spinal cord is enclosed within the bony spinal canal, with variable amounts of space (greatest in

        the upper cervical spine).
        - Cord also varies in diameter (widest at the origin of the plexuses).
        - In cross section, the cord is observed to have both geographic and functional boundaries. It is divided in the midline anteriorly by a fissure and posteriorly by the sulcus.
    - Functional anatomy (Fig. 2.102): functions of the ascending (sensory) and descending (motor) tracts are summarized in Table 2.42.
        - Posterior funiculi (dorsal columns) are located dorsally and receive ascending fibers, which deliver deep tactile, proprioceptive, and vibratory sensations.
        - Lateral spinothalamic tract comprises ascending fibers that transmit sensations of pain and temperature.
        - Lateral corticospinal tract is composed of descending fibers for voluntary muscular contraction.
            - Sacral structures are the most peripheral in the lateral corticospinal tracts; cervical structures are more medial.
                - This is why central cord syndrome affects the upper extremities more than the lower extremities.
        - Ventral (anterior) spinothalamic tract comprises ascending fibers that transmit light tactile sensation.
        - Ventral (anterior) corticospinal tract comprises descending fibers for voluntary muscular contraction.
        - Incomplete spinal cord injury patterns are summarized in Table 2.43.
- □ Nerve roots (Fig. 2.103)
    - 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal (Co)

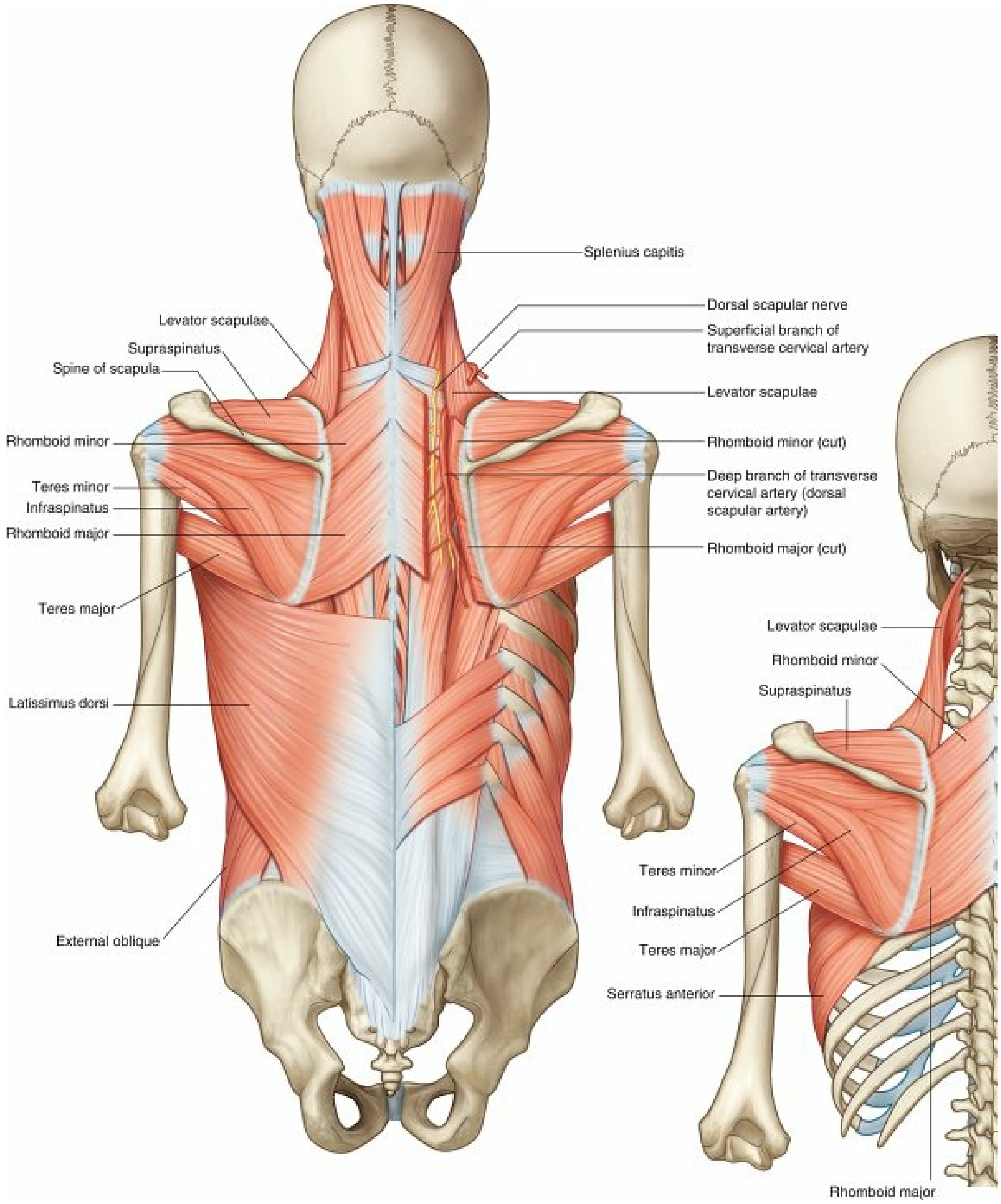


FIG. 2.101 Muscles of the back and shoulders.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

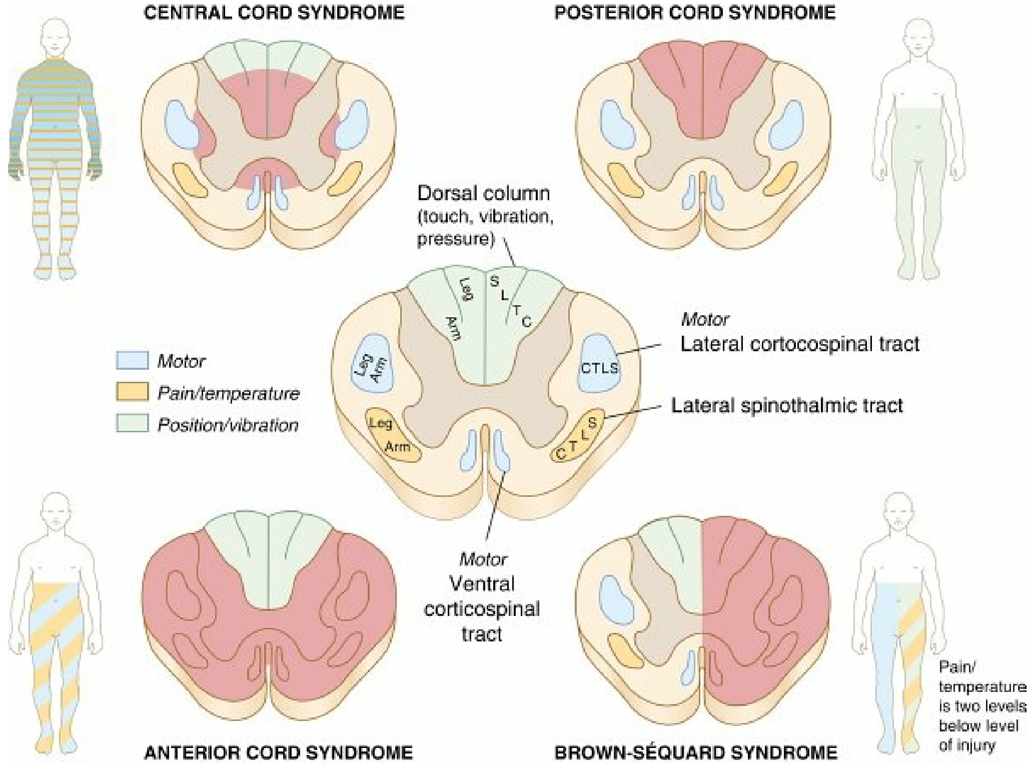


FIG. 2.102 Spinal cord anatomy and patterns of incomplete spinal cord injury syndromes. *C,* cervical; *L,* lumbar; *S,* sacral, *T,* thoracic.

Table 2.42

Spinal Cord Tracts

Direction	Tracts	Function
Ascending (sensory)	Dorsal columns	Deep touch, proprioception, vibratory
	Lateral spinothalamic	Pain and temperature
	Anterior spinothalamic	Light touch
Descending (motor)	Lateral corticospinal	Voluntary motor
	Anterior corticospinal	Voluntary motor

Table 2.43

Patterns of Incomplete Spinal Cord Injury

Pattern of Injury	Functional Deficit	Recovery
Central (most common)	Upper extremity affected more than lower extremity, usually quadriparetic with sacral sparing; flaccid paralysis of upper extremity and spastic paralysis of lower extremity	75%
Anterior	Complete motor deficit	10% (worst prognosis)
Brown-Séquard	Unilateral cord injury with ipsilateral motor deficit, contralateral pain and temperature deficits (two levels below injury)	>90%

- Within the subarachnoid space, the dorsal root (and ganglia) and ventral roots converge to form the spinal nerve.
    - Nerve becomes “extradural” as it approaches the intervertebral foramen (the dura becomes epineurium) at all levels above L1.
    - Below this level, the nerves are contained within the cauda equina.
- After exiting the foramen, the spinal nerve gives off dorsal primary rami, which supply the muscles and skin of the neck and back regions.
- Innervation of structures within the spinal canal—including the periosteum, meninges, vascular structures, and articular connective tissue—is from the sinuvertebral nerve.
- Ventral rami supply the anteromedial trunk and limbs.
- With the exception of the thoracic nerves, the ventral rami are grouped in plexuses before delivering sensorimotor functions to a general region.
- **In the cervical spine, the numbered nerve exits at a level above the pedicle of the corresponding vertebral level (e.g., the C2 nerve exits at the level of vertebrae C1–2) (Fig. 2.104).**
- **In the lumbar spine, the nerve root traverses the respective disc space above the named vertebral body and exits the respective foramen under the pedicle (see**

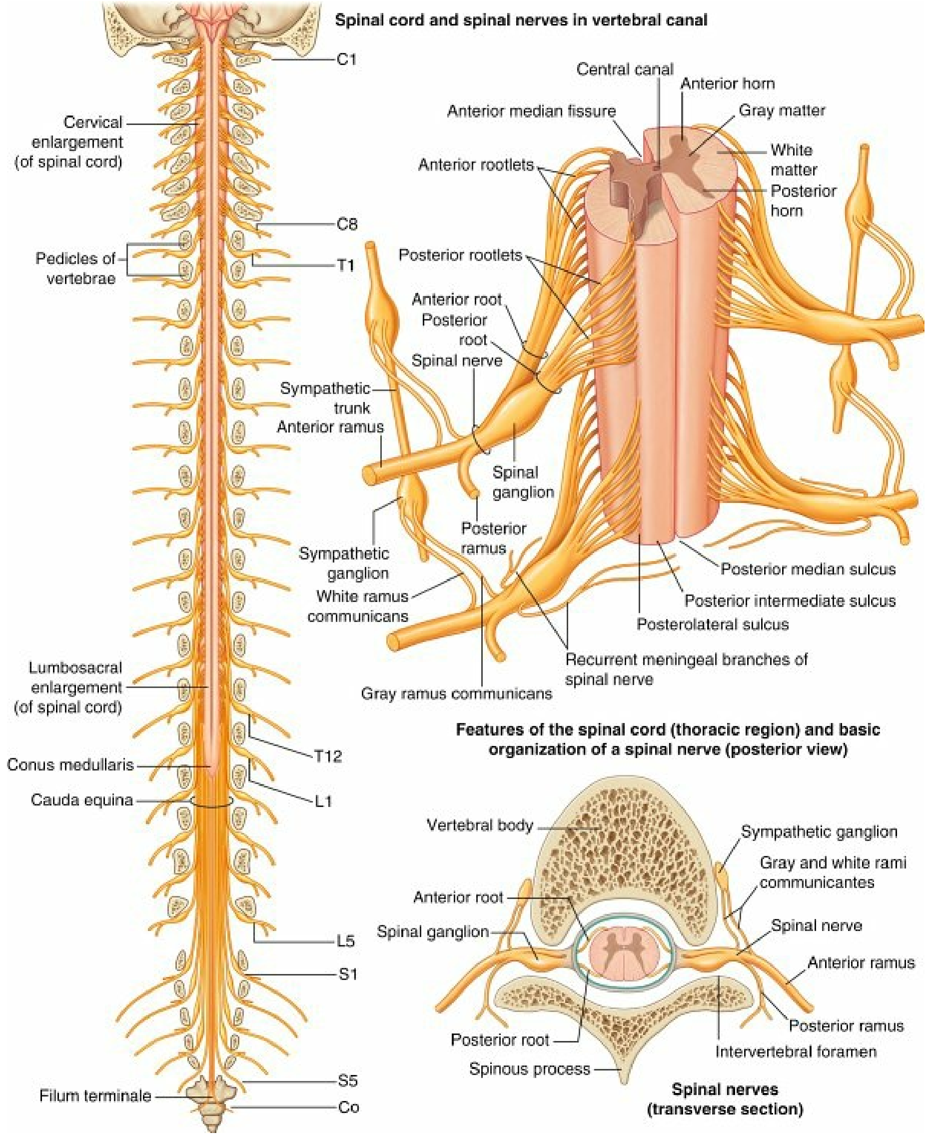


FIG. 2.103 Features of the spinal cord and basic organization of spinal nerves.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

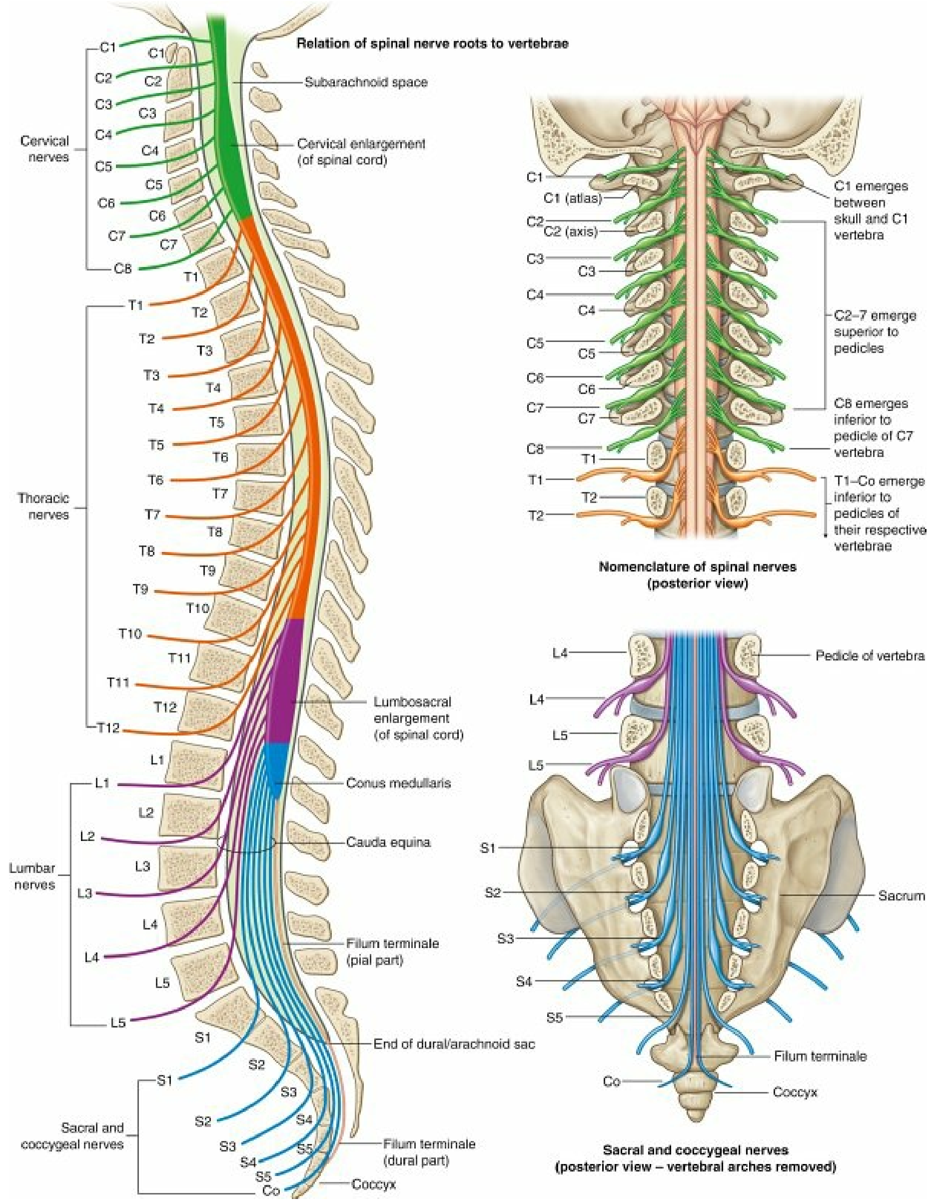


FIG. 2.104 Relation of spinal nerve roots to vertebrae.
From Drake RL et al, editors: *Gray's atlas of anatomy,* ed 2, Philadelphia, 2015, Churchill Livingstone.

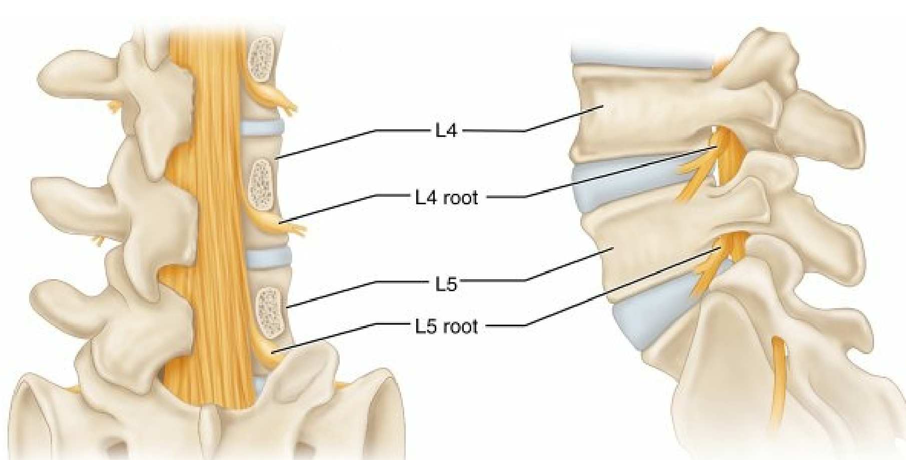


FIG. 2.105 Lumbar spine nerve roots.

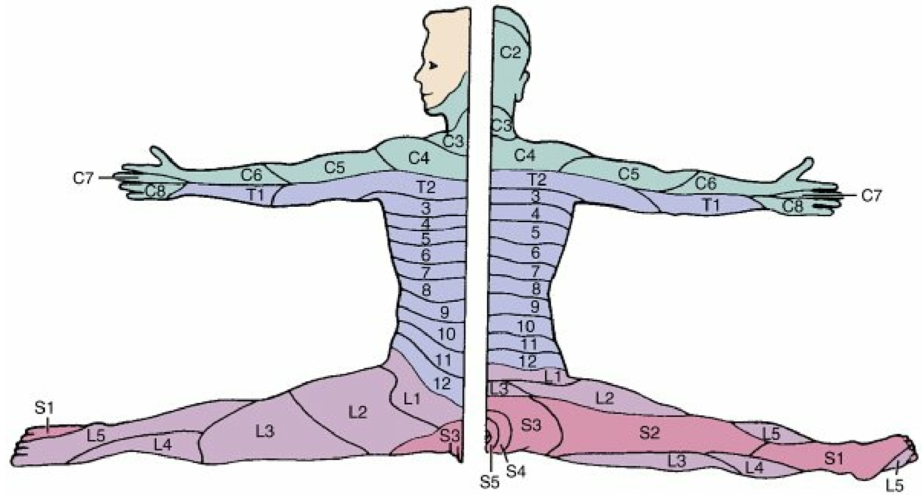


FIG. 2.106 Dermatome patterns.

Fig. 2.104).

- Herniated discs usually impinge on the traversing nerve root and facet joint (Fig. 2.105).
    - Example: a central disc herniation at the level of L4–5 would cause compression of the traversing L5 nerve root, resulting in a positive tension sign (straight-leg raise test), diminished strength in the hip abductors and EHL, and pain and numbness in the lateral leg to the dorsum of the foot.
    - Far lateral disc herniation at the L4–5 level would compress the exiting L4 nerve root, resulting in a positive tension sign (femoral nerve stretch test) and L4 nerve compromise.
- L5 nerve root is relatively fixed to the anterior sacral ala and can be damaged by sacral fractures and errant anteriorly placed iliosacral screws.
- Dermatomal patterns are depicted in Fig. 2.106.

Table 2.44

Key Testable Neurologic Levels

Neurologic Level	Representative Muscle	Reflex
C5	Deltoid	Biceps
C6	Wrist extensors	Brachioradialis
C7	Wrist flexors	Triceps
C8	Finger flexors	
T1	Interossei	
L4	Tibialis anterior	Patellar
L5	Toe extensors	
S1	Peroneal	Achilles

- Key testable neurologic levels are listed in Table 2.44.
- Nerve root compression: summary of nerve root compression is highlighted in Chapter 8, Spine.
- Sympathetic chain
    - Three ganglia of cervical sympathetic chain: superior, middle, and inferior (Table 2.45)
    - Cervical sympathetic chain posterior and medial to the carotid sheath
    - Anterior to the longus capitis muscle
    - Disruption of the inferior ganglia can lead to Horner syndrome (ptosis, miosis [pupillary constriction], and anhidrosis).
        - Can be seen with preganglionic brachial plexus lesions
    - Sympathetic ganglia: 11 in thoracic region, 4 in lumbar region, 4 in sacral region

Table 2.45

Cervical Sympathetic Ganglia

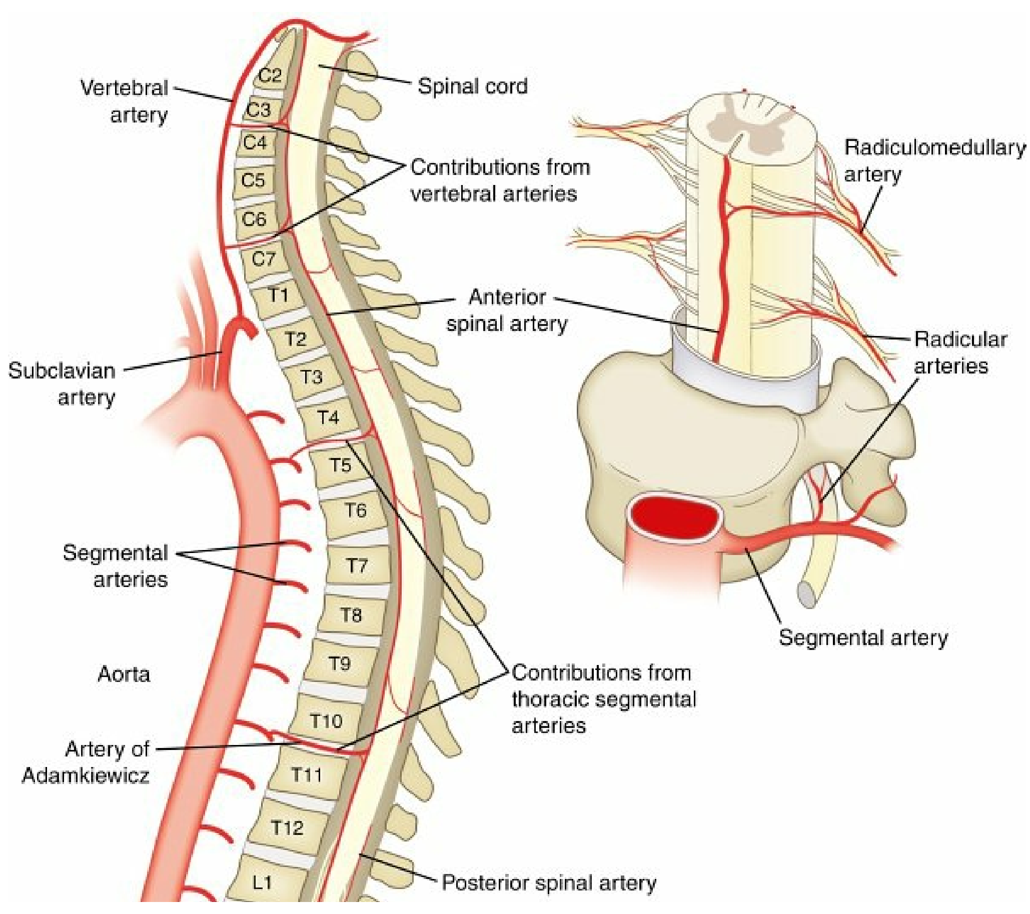
Ganglion	Location	Comments
Superior	C2–3	Largest
Middle	C6	Variable
Inferior	C7–T1	Stellate

- **Vessels (** Fig. 2.107)
    - Spinal blood supply from segmental arteries

- Located at vertebral midbodies via the aorta (which lies on the left side of the vertebral column; inferior vena cava and azygos vein are on the right)
- Primary supply to the dura and posterior elements is from the dorsal branches
- Ventral branches supply the vertebral bodies via the ascending and descending branches, which are delivered underneath the posterior longitudinal ligament in four separate ostia.

□ Vertebral artery (a branch of the subclavian artery)

- Ascends through the transverse foramina of C1 to C6 (anterior to and not through C7) posterior to the longus colli muscle and then posterior to the lateral masses; courses along the cephalic surface of the posterior arch of C1 (atlas); and passes ventromedially around the spinal cord and through the foramen magnum before uniting with its contralateral counterpart at the midline basilar artery



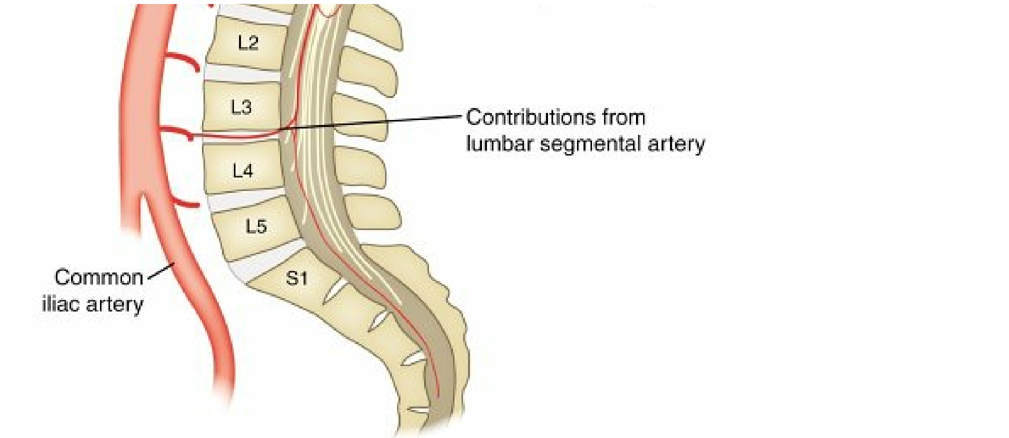


FIG. 2.107 Vascular anatomy of the spinal column.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 5-18.

- **The distance from the spinous process of C1 laterally to the vertebral artery is 2 cm (a safe distance for dissections would therefore be less than 2 cm).**

□ Artery of Adamkiewicz (great anterior medullary artery)

- Enters through the left intervertebral foramen in the lower thoracic spine from T8 to T12; supplies the interior two thirds of the anterior cord

□ Spinal cord arterial supply

- From the anterior and posterior spinal arteries and segmental branches of the vertebral artery and dorsal arteries, which travel via the dorsal and ventral rootlets to the respective dorsal and anterolateral portions of the cord
- Disruption of the anterior longitudinal artery can result in loss of function of the anterior two-thirds of the cord.

□ Venous drainage of the vertebral bodies

- Primarily through the central sinusoid located on the dorsum of each vertebral body

Surgical Approaches to the Spine (Table 2.46)

▪ **Cervical spine (** Fig. 2.108)

□ Anterior approach to the cervical spine

- Surface landmarks demonstrated in Fig. 2.109
- Incision: transverse and based on the desired level (e.g., for C5, the carotid triangle should be entered)

Table 2.46

Surgical Approaches to the Spine

Approach	Interval	Structures at Risk
Anterior cervical	Carotid sheath and the trachea	Recurrent laryngeal nerve Sympathetic ganglion
Posterior cervical	Midline approach between paracervical muscles	Vertebral artery
Anterior thoracic	Transverse between ribs two levels above surgical site	Intercostal neurovascular bundle; to avoid, dissect over top of rib
Posterior thoracolumbar	Midline approach over spinous processes	Posterior primary rami and segmental vessels; protect nerve root
Anterior lumbar (transperitoneal)	Between segmentally innervated rectus abdominis muscles	Presacral plexus of parasympathetic nerve

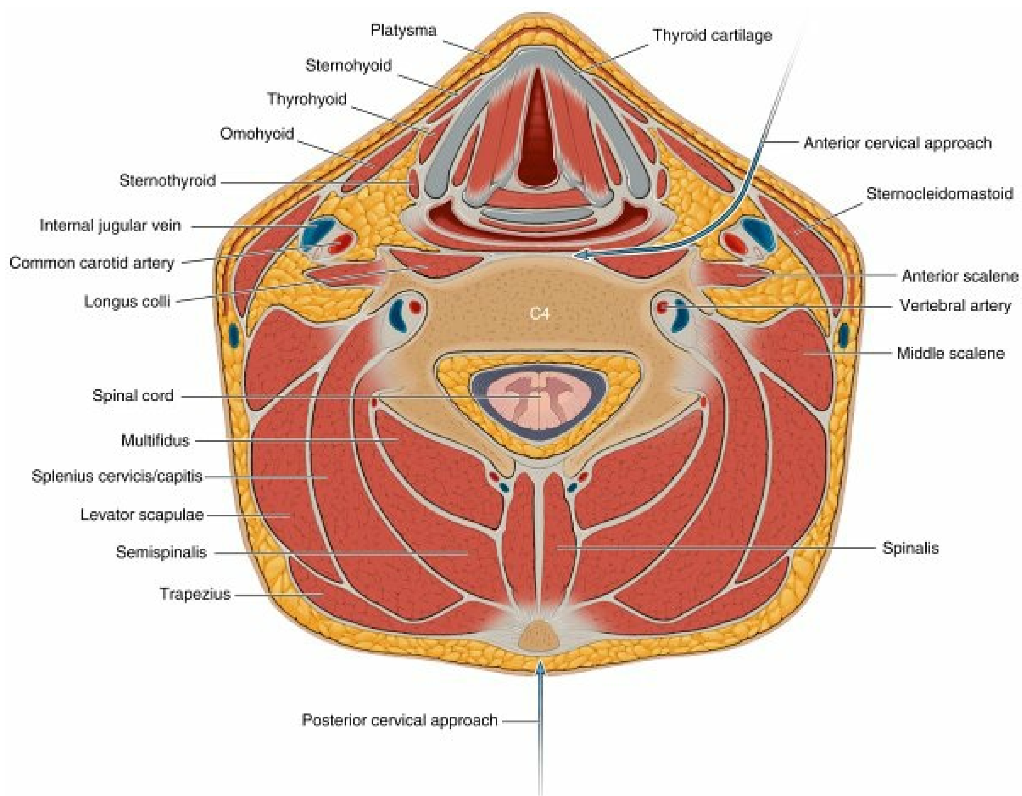


FIG. 2.108 Surgical intervals of the cervical spine.
From Miller MD et al: *Orthopaedic surgical approaches*, ed 2, Philadelphia, 2014, Saunders, Figure 5-16.

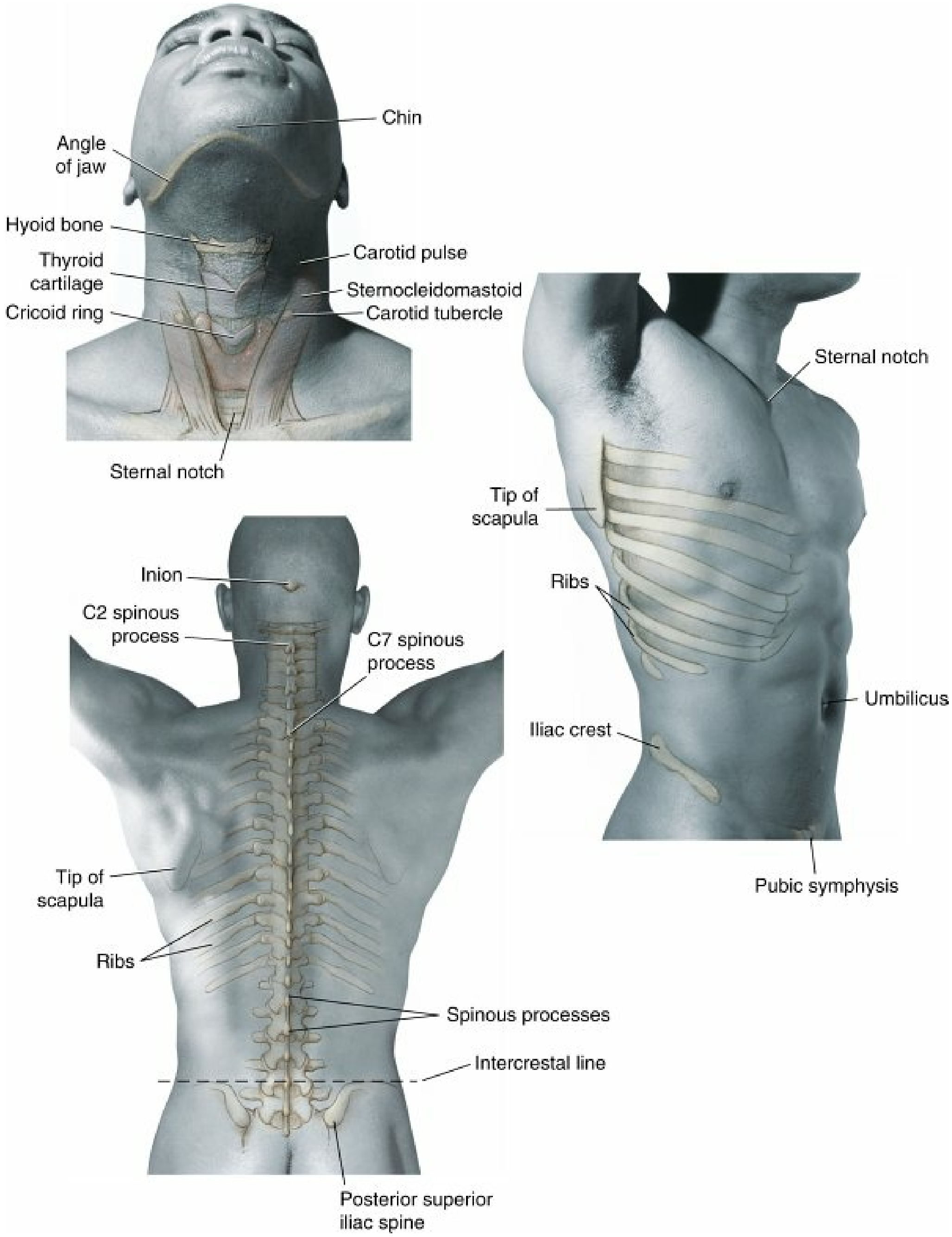


FIG. 2.109 Surface landmarks of the spine.
From Miller MD et al: *Orthopaedic surgical approaches*, ed 2, Philadelphia, 2014, Saunders, Figure 5-20.

- Dissection
    - Retract the platysma with the skin.
    - Expose the pretracheal fascia to explore the interval between the carotid sheath—which contains the internal and common carotid arteries, the internal jugular vein, and the vagus nerve (cranial nerve X)—and the trachea.
    - Incise the prevertebral fascia sharply, and then retract the longus colli muscle gently (protecting the recurrent laryngeal nerve, a branch of the vagus nerve that lies outside the sheath) to expose the vertebral body. The anterior surface of

the vertebral body is exposed.

- Risks
  - **Injury to the recurrent laryngeal nerve with right-sided approaches (paralysis is signified by a hoarse, scratchy voice caused by unilateral vocal cord paralysis, visualized with direct laryngoscopy)**
    - Recurrent laryngeal nerve arises from the vagus at the level of the subclavian artery on the right; the left arises at the level of the aortic arch.
  - Anterior cervical approaches from the lower left side increase the risk for injury to the thoracic duct, which is posterior to the carotid sheath.
  - When the longus muscles are dissected subperiosteally, the stellate ganglion is also protected (avoiding Horner syndrome).
  - Postoperatively, the upper airway is at risk for edema, vocal cord paralysis, and hematoma.

□ Posterior approach to the cervical spine

- Incision: midline
- Dissection
  - After a midline approach through the ligamentum nuchae, reflect the superficial (trapezius) and intermediate (splenius, semispinalis, longissimus capitis) layers laterally; the vertebrae are exposed.
  - Access to the spinal canal is through laminectomy or facetectomy.
- Risks
  - The vertebral artery is especially vulnerable as it leaves the foramen transversarium and travels superiorly and medially to pierce the atlantooccipital membrane at its lateral angle.
  - The greater occipital nerve (C2) and the third occipital nerve (C3) should also be protected in the suboccipital region.
  - Postoperative C5 palsy is the most common complication with a posterior approach.

□ Thoracic spine

- Anterior (transthoracic) approach to the thoracic spine
  - Incision: transverse, made approximately two ribs above the level of interest

        - Dissection
            - Dissect over the top of the rib to avoid injuring the intercostal neurovascular bundle (which lies on the inferior internal surface of the rib).
            - Further dissect the rib and remove it from the surgical field.
            - The right-sided approach is favored to avoid the aorta, segmental arteries, artery of Adamkiewicz, and thoracic duct (in the upper thoracic spine on the left side of the esophagus and behind the carotid sheath).
        - Risks
            - The esophagus, aorta, venae cavae, and pleura of the lungs should be identified and protected.
            - Intercostal neuralgia is the most common complication.
    - Posterior approach to the thoracolumbar spine
        - Incision: straight, midline, over the spinous processes and carried down through the thoracolumbar fascia
        - Dissection
            - Use the plane between the two segmentally innervated erector spinae muscles.
            - Subperiosteally dissect the paraspinal musculature from the attached spinous processes, thereby exposing the posterior elements.
            - Perform partial laminectomy to allow greater exposure of the cord and discs.
            - Place pedicle screws at the junction of the lateral border of the superior facet and the middle of the transverse process.
            - Angle these screws 15 degrees medially and in line with the slope of the vertebra, as seen on lateral radiographs.
        - Risks: injury to the posterior primary rami (near the facet joints) and segmental vessels (anterior to the plane connecting the transverse processes)
- **Lumbar spine (** Fig. 2.110)
    - Anterior approach to the lumbar spine (transperitoneal)

- Incision: longitudinal, from below the umbilicus to just above the pubic symphysis
- Dissection
    - Split the rectus abdominis muscles and incise the peritoneum.
    - Protect and retract the bladder distally and the bowel cephalad; incise the posterior peritoneum longitudinally over the sacral promontory.
    - The aortic bifurcation is revealed; ligate the middle sacral artery.
    - The L5–S1 disc space is exposed.
- Risks: injury to the lumbar plexus (particularly the superior hypogastric plexus of the sympathetic plexus that lies over the L5 vertebral body) can cause sexual dysfunction and retrograde ejaculation. (Ejaculation is predominantly a sympathetic nervous system function, and erection predominantly a parasympathetic nervous system function.)

□ Anterolateral approach to the lumbar spine (retroperitoneal)

- Incision: oblique, centered over the 12th rib to the lateral border of the rectus abdominis muscle
- Dissection
    - Incise the external oblique, internal oblique, and transversus abdominis muscles in line with the skin incision.
    - Elevate the retroperitoneal fat, thereby revealing the psoas major muscle and genitofemoral nerve.
    - Ligate the segmental lumbar vessels; mobilize the aorta and venae cavae to expose the desired vertebral level.
    - The great vessels typically bifurcate at the L4–5 disc level; therefore, use a larger area of dissection than would be used for operating on the L5–S1 disc level, which lies below the bifurcation of the aorta.
- Risks: injury to the sympathetic chain (medial to the psoas and lateral to the vertebral body) and ureters (between the peritoneum and psoas fascia)

□ Halo pin placement

- Safe zone for anterolateral halo pins is approximately 1 cm superior to the orbital rim in the outer two-thirds of the orbit below the equator of the skull (Fig. 2.111)
- With this pin position, the temporal fossa and temporalis muscle are situated laterally, and the supraorbital nerve,

supratrochlear nerve, and frontal sinus are situated medially.

- Supraorbital nerve is lateral to the supratrochlear nerve, which lies anterior to the frontal sinus.
- **Most commonly injured cranial nerve with halo traction is the abducens (cranial nerve VI); injury is recognized from the loss of lateral gaze.**

▪ **Cross-sectional anatomy of the spine is demonstrated in** Fig. 2.112.

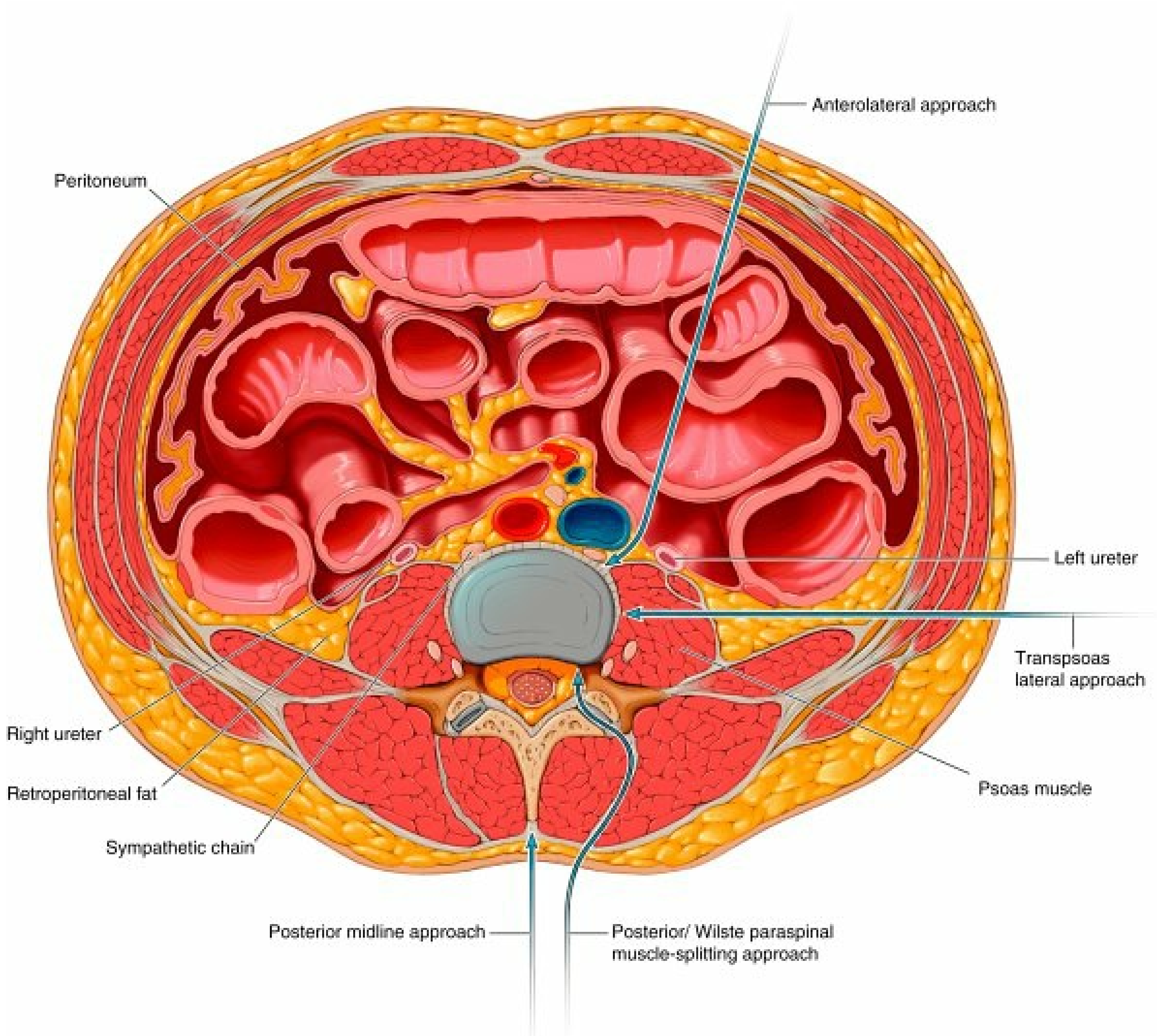


FIG. 2.110 Surgical intervals of the lumbar spine.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 5-17.

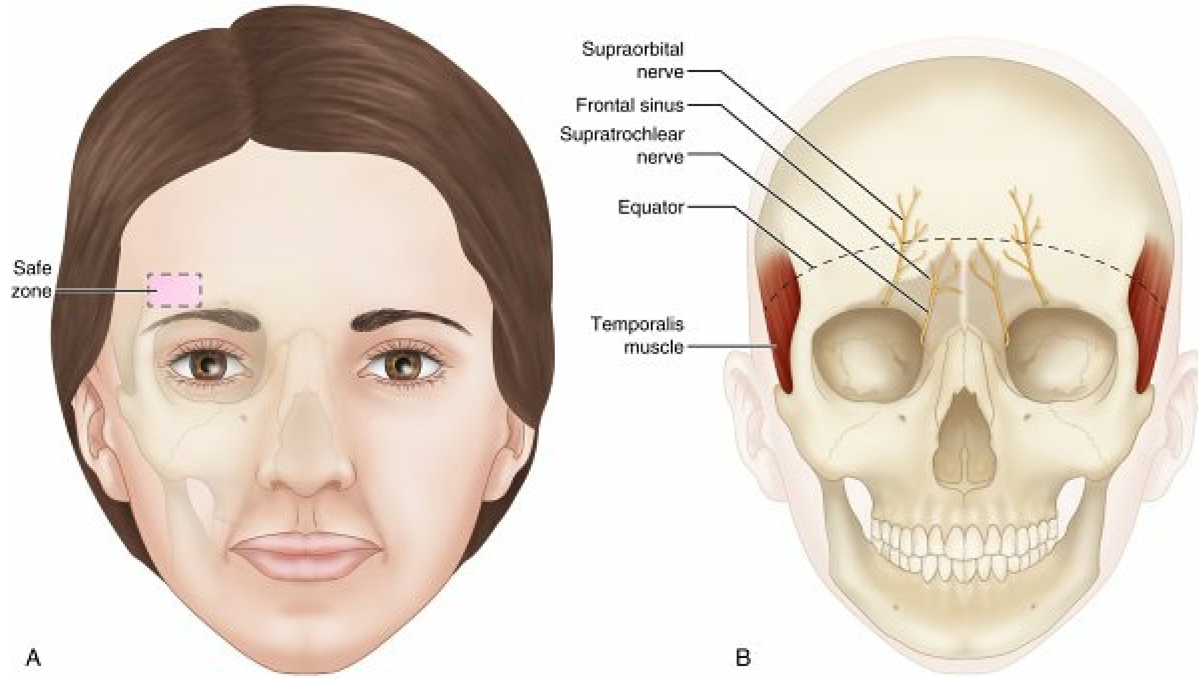
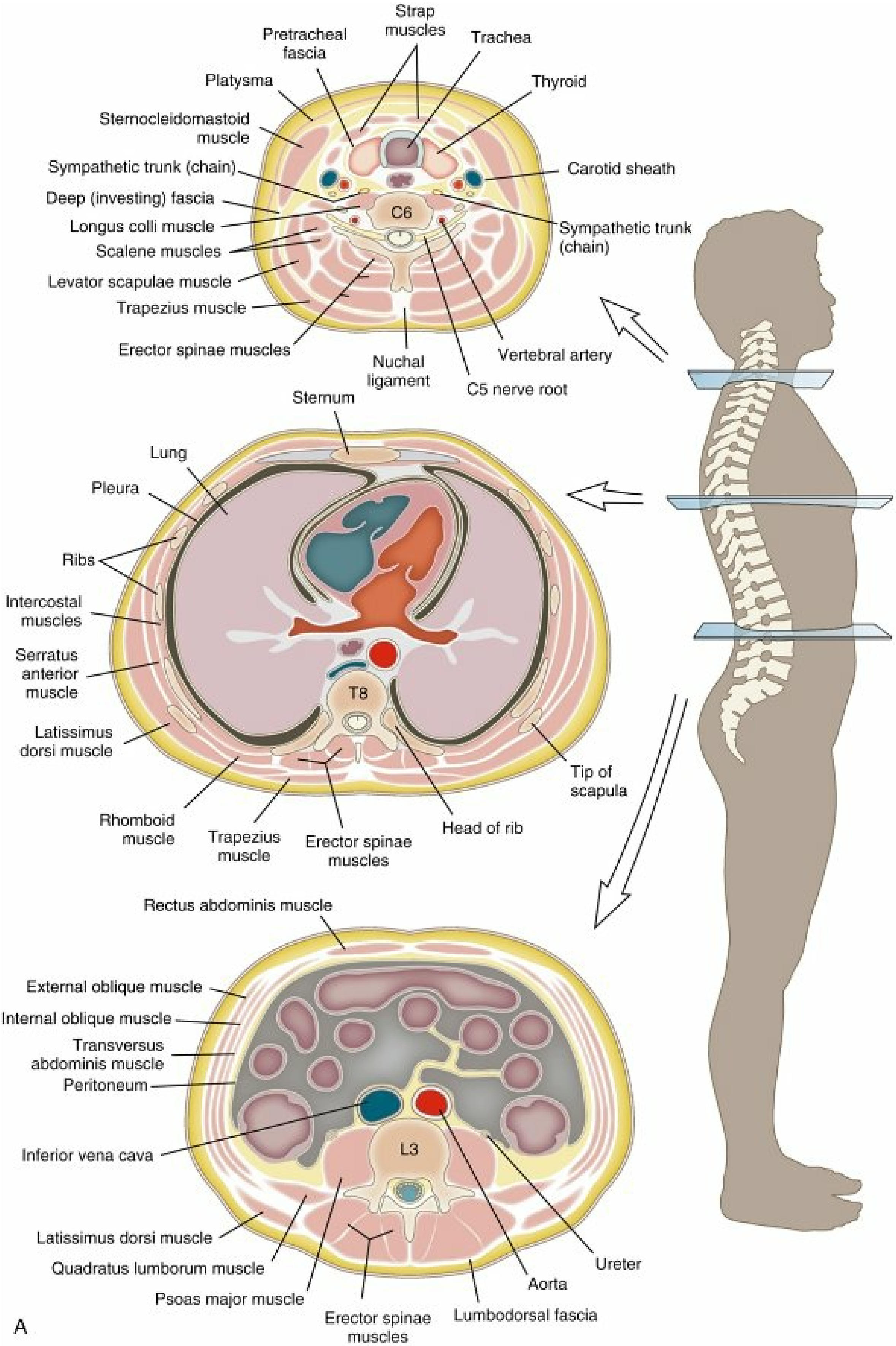


FIG. 2.111 Safe zone and surrounding nerves for Halo pin placement. Surface anatomy outlining the safe zone (A) and underlying nerve risks (B) for halo placement.



Strap muscles
Pretracheal fascia
Trachea
Platysma
Thyroid
Sternocleidomastoid muscle
Sympathetic trunk (chain)
Carotid sheath
Deep (investing) fascia
C6
Longus colli muscle
Sympathetic trunk (chain)
Scalene muscles
Levator scapulae muscle
Trapezius muscle
Erector spinae muscles
Vertebral artery
Nuchal ligament
C5 nerve root
Sternum
Lung
Pleura
Ribs
Intercostal muscles
Serratus anterior muscle
T8
Latissimus dorsi muscle
Tip of scapula
Rhomboid muscle
Trapezius muscle
Erector spinae muscles
Head of rib
Rectus abdominis muscle
External oblique muscle
Internal oblique muscle
Transversus abdominis muscle
Peritoneum
Inferior vena cava
L3
Latissimus dorsi muscle
Quadratus lumborum muscle
Psoas major muscle
Erector spinae muscles
Lumbodorsal fascia
Aorta
Ureter
A

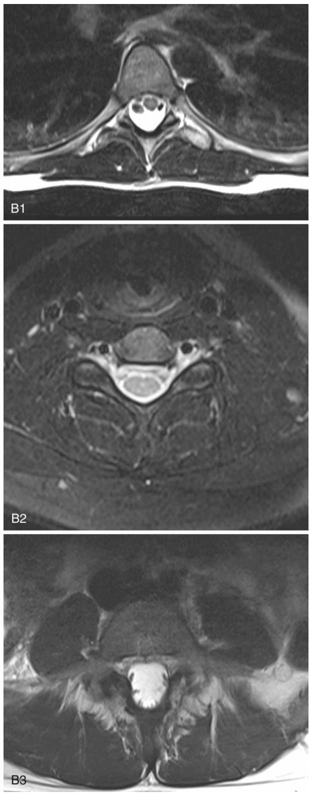


FIG. 2.112 Illustrations (A) and imaging (B) of the cross-sectional anatomy of the cervical (B1), thoracic (B2), and lumbar (B3) spine.
From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2014, Saunders, Figure 5-19A.

Testable Concepts

- The mnemonic "SAME" can be used to help understand the function of nerves: sensory = afferent; motor = efferent.

Section 2 Upper Extremity

- Suprascapular notch: suprascapular artery passes superior to transverse scapular ligament and suprascapular nerve passes inferior to ligament through notch (mnemonic: "Army over Navy" for *a*rtery over *n*erve).
- Coracoacromial ligament contributes to anterosuperior stability in rotator cuff deficiency and should be preserved with irreparable cuff tears to prevent anterosuperior escape.
- Use caution repairing anterosuperior glenoid labral variant—may cause loss of external rotation.
- Rotator cuff function: depress and stabilize the humeral head against the glenoid; force-couple larger shoulder muscles to maintain humeral head center of rotation.
- Radial head should line up with capitellum at all arm positions in all radiographic views.
- Radius and ulna connected by oblique interosseous membrane/ligament (disrupted in Essex-Lopresti injury), which transmits axial load from radius at wrist to ulna at elbow.
- Ossification of the bones of the wrist begins at the capitate (usually present at 1 year of age) and proceeds in a counterclockwise direction, according to posteroanterior radiographs of the right hand.
- Space of Poirier: central weak area in floor of carpal tunnel; implicated in volar dislocation of lunate in perilunate dislocation.
- At the level of the wrist, FDS to the middle and ring fingers are volar to FDS to index and small fingers.
- Four preclavicular brachial plexus branches: dorsal scapular, long thoracic, suprascapular, and nerve to subclavius. Look for these structures to be involved in preganglionic plexus injuries.
- All minor medial and lateral cord branches have *medial* or *lateral* in their names. Posterior cord branches do not.
- Innervation of all rotator cuff muscles derived from C5 and C6 of the brachial plexus
- Lateral winging due to spinal accessory nerve injury (cranial nerve XI) usually due to iatrogenic injury from neck surgery
- Axillary nerve passes anterior to subscapularis muscle and inferior to shoulder capsule, traveling from anterior to posterior through quadrangular space.

Anterior branch passes around humerus approximately 7 cm distal to acromion.

- Posterior interosseous nerve splits the supinator and supplies all of the extensor muscles except the mobile wad (brachioradialis, ECRB, ECRL).
- Superficial branch of the radial nerve emerges through antebrachial fascia approximately 6–9 cm proximal to the radial styloid. Runs between the brachioradialis and ERCL to supply sensation to the dorsal radial surface distal forearm and hand.
- Anterior interosseous nerve branches 4 cm distal to elbow and runs between the FPL and FDP; supplies all the deep flexors except the ulnar half of the FDP. Terminates in the PQ.
- Ulnar nerve enters the forearm between the two heads of the FCU (humeral and ulnar).
- Each part of the axillary artery has as many branches as the number of that part (e.g., the second part has two branches: thoracoacromial and lateral thoracic).
- Digital arteries arise from superficial palmar arch and run dorsal to digital nerves.
- During anterior approach to shoulder, watch out for musculocutaneous nerve piercing deep aspect of conjoint tendon about 5 cm distal to coracoid and axillary nerve traveling through quadrangular space.
- Keep dissection above teres minor during posterior approach to shoulder to avoid quadrangular space.
- Brachialis may be split because it has dual innervation (radial and musculocutaneous).
- Do not extend posterolateral (Kocher) approach to elbow distal to anular ligament to avoid risk of PIN injury.

Section 3 Lower Extremity

- Iliac spine separates greater and lesser sciatic notch; sacrospinous ligament (anterior sacrum to ischial spine) separates greater and lesser sciatic foramina.
- Pediatric femoral nail insertion at piriformis fossa threatens the posterosuperior retinacular vessels (potential for femoral head AVN).
- Slipped capital femoral epiphysis occurs through the femoral head physis (zone of hypertrophy).
- Shape of tibial plateau confers greater articular congruity medially than laterally (important when considering consequences of meniscectomy).
- Medial meniscus tears three times more often than the more mobile lateral meniscus.
- ACL has anteromedial (tight in flexion) and posterolateral (tight in extension) bundles; PL bundle assessed with pivot shift test.
- PCL has anterolateral (tight in flexion) and posteromedial (tight in extension) bundles.
- MPFL runs from proximal third of medial patella to Schottle point on the femur

(between adductor tubercle and medial epicondyle); just distal to vastus medialis obliquus

- Groove posterior for the tendon of the FHL. Os trigonum (if present) lateral to FHL.
- Primary blood supply to the talar body is from the artery of the tarsal canal (posterior tibial artery).
- Sustentaculum tali of calcaneus supports the middle articular surface above it and has an inferior groove for the FHL tendon.
- Intermediate cuneiform does not extend as far distally as the medial cuneiform, which allows the second metatarsal to “key” into place.
- Bony avulsion of AITFL in adolescents may result in a Tillaux fracture.
- Calcaneofibular ligament crosses both the ankle and the subtalar joint.
- Plantar calcaneonavicular ligament (spring ligament) supports head of talus; attenuated in pes planus deformity.
- Lisfranc ligament connects medial (shortest) cuneiform to second (longest) metatarsal. No ligamentous connection between first and second metatarsal bases.
- Digital nerve courses in a plantar direction under the transverse metatarsal ligament and is the spot where interdigital neuritis (Morton neuroma, usually the second or third interdigital space) occurs.
- L5 nerve root on anterior sacrum: at risk with anteriorly placed sacroiliac screw
- Mnemonic: “POP’S IQ” (nerves exiting below piriformis): *p*udendal, nerve to *o*bturator internus, *p*osterior femoral cutaneous, *s*ciatic, *i*nferior gluteal, nerve to *q*uadratus femoris
- Pudendal nerve, internal pudendal artery and vein, and nerve to obturator internus exit the greater sciatic foramen and reenter the lesser foramen.
- Femoral nerve lies between the iliacus and psoas muscles. Iliacus hematoma may irritate the femoral nerve because of its proximity.
- Pain from the hip can be referred to the knee as a result of the continuation of the obturator nerve anteriorly, which can provide sensation to the medial side of the knee.
- Sciatic nerve passes anterior to piriformis and posterior to obturator internus and short external rotators.
- Tibial nerve supplies all intrinsic foot muscles except the EDB (deep peroneal nerve) and plantar sensation.
- Most proximal branch of the lateral plantar nerve is the nerve to the abductor digiti quinti (Baxter nerve).
- Superior gluteal nerve approximately 5 cm proximal to greater trochanter. Injury leads to Trendelenburg gait from gluteal dysfunction.
- Obturator artery and vein jeopardized by anteroinferior screws and acetabular retractors.
- Corona mortis is an anastomotic connection between the inferior epigastric branch of the external iliac vessels and the obturator vessels in the obturator

canal.
- Ascending branch of lateral femoral circumflex artery (at risk for injury during anterolateral approaches) proceeds to greater trochanteric region between TFL and rectus femoris.

Section 4 Spine

- Normal spine sagittal alignment: plumb line from center of C7 to posterior superior corner of S1.
- 50% of total neck flexion and extension occurs at occiput–C1 articulation; 50% of total neck rotation occurs at atlantoaxial (C1–2) articulation.
- Vertebral artery travels in the transverse foramina of C6 to C1 (not C7).
- 66% of lordosis occurs in the region from L4 to the sacrum.
- Lumbar spine—the superior articular facet is anterior and lateral to the inferior articular facet.
- Intradiscal pressure lowest in supine position and highest in the sitting position and flexed forward with weights on the hands.
- In cervical spine, numbered nerve exits above the pedicle of the corresponding vertebral level. In the lumbar spine, the nerve exits under the pedicle.
- The distance from the spinous process of C1 laterally to the vertebral artery is 2 cm (a safe distance for dissections would therefore be less than 2 cm).
- Injury to the recurrent laryngeal nerve with right-sided approaches (paralysis is signified by a hoarse, scratchy voice caused by unilateral vocal cord paralysis, visualized with direct laryngoscopy).
- Most commonly injured cranial nerve with halo traction is the abducens (cranial nerve VI); injury is recognized from the loss of lateral gaze.

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CHAPTER 3

Pediatric Orthopaedics

Matthew R. Schmitz, and Jeremy K. Rush

Upper Extremity Problems *

Brachial Plexus Palsy

- **Clinical features**
  - In 2 per 1000 births, an injury is still associated with stretching or contusion of the brachial plexus.
  - Typically manifests as internal rotation shoulder contracture and elbow and wrist flexion contractures
    - **Progressive glenoid hypoplasia occurs in 70% of children with significant internal rotation contracture.**
  - Hand function varies with level of brachial plexus deformity.
  - Three types commonly recognized (Table 3.1):
    - **Erb-Duchenne (C5, C6)—best prognosis, most common**
    - **Klumpke (C8, T1)—poor prognosis**
    - **Total plexus palsy (C5–T1)—worst prognosis**
- **Causes**
  - Large size of neonate, shoulder dystocia, forceps delivery, breech position, prolonged labor
  - Radiographic studies
  - Investigations have focused on the position of the humeral head within the glenoid.
  - Posterior subluxation with erosion of the glenoid should be prevented.
  - Axillary lateral view of the shoulder should be obtained to evaluate position of humeral head.
  - If surgical reconstruction is planned, computed tomography (CT) scanning instead of magnetic resonance imaging (MRI) of the shoulder should be considered.
- **Treatment**
  - Key to success of therapy consists of maintaining passive range of movement (ROM) and awaiting return of motor function (up to 18 months).
    - Parents should focus on passive elbow motion and shoulder elevation, abduction, and external rotation.
  - More than 90% of cases eventually resolve without intervention.
    - **Lack of biceps function 6 months after injury and the presence of Horner syndrome carry a poor prognosis.**
  - Options: early surgery to address nerve function, late surgery to address deformities
    - Microsurgical nerve grafting
    - Latissimus and teres major transfer to shoulder external rotators (L'Episcopo)

- Tendon transfers for elbow flexion (Clark pectoral transfer and Steindler flexorplasty)
- Pectoral and subscapularis release for internal rotation contracture and secondary glenoid hypoplasia (<5 years old)
- Proximal humerus rotational osteotomy (>5 years old)

□ Release of the subscapularis tendon for internal rotation contracture, if performed by age 2 years, may result in improved active external rotation of the shoulder, with muscle transfer to assist in active external rotation.

Sprengel Deformity

- **Clinical features**
  - Undescended scapula often associated with winging, hypoplasia, and omovertebral connections (30% of cases; Fig. 3.1)
  - Most common congenital anomaly of the shoulder in children
  - Affected scapulae are usually small, relatively wide, and medially rotated.
  - Associated diseases:
    - **Klippel-Feil syndrome (Sprengel deformity in one-third of cases**)
    - Kidney disease
    - Scoliosis
    - Diastematomyelia
- **Treatment**
  - Surgery for cosmetic or functional deformities (decreased abduction)
    - Distal advancement of associated muscles and scapula (Woodward procedure) *or*
    - Detachment and movement of scapula (Schrock and Green procedures)
    - Both can improve abduction by 40–50 degrees

Table 3.1

Brachial Plexus Palsy.

Type	Roots	Deficit	Prognosis
Erb-Duchenne palsy	C5, C6	Deltoid, cuff, elbow flexors, wrist and hand dorsiflexors; waiter's tip deformity	Best
Total plexus	C5–T1	Sensory and motor; flaccid arm	Worst
Klumpke palsy	C8, T1	Wrist flexors, intrinsic muscles; Horner syndrome	Poor

FIG. 3.1 Sprengel shoulder: clinical photographs of a child affected with Sprengel deformity on the left side. Note the elevation and rotation of the scapula.
From Jones KL: *Smith's recognizable patterns of human malformation,* Philadelphia, 2006, Elsevier Saunders, p 716.

- Clavicular osteotomy is often needed to avoid brachial plexus injury caused by stretch.
- Surgery is best done when patients are 3–8 years of age.

Fibrotic Deltoid Problems

- **Clinical features**
  - Short fibrous bands replace the deltoid muscle and cause abduction contractures at the shoulder, with elevation and winging of the scapula when the arms are adducted.
- **Treatment**
  - Surgical resection of these bands is often required.

Congenital Pseudarthrosis of the Clavicle

- **Clinical features**
  - **Failure of union of medial and lateral ossification centers of right clavicle**
    - Bilateral in less than 10%; left side if situs inversus
  - Manifests as an enlarging, painless, nontender mass
- **Causes**
  - May be related to pulsations of the underlying subclavian artery
- **Radiographic findings**
  - Anteroposterior (AP) view of the clavicle reveals rounded sclerotic bone at the pseudarthrosis site.
- **Treatment**
  - Usually asymptomatic and does not require treatment
  - Surgery (open reduction and internal fixation [ORIF] with bone grafting) is indicated for unacceptable cosmetic deformities or significant functional symptoms (mobility of fragments and winging of scapula) at age 3–6 years.
  - Successful union is predictable (in contrast to congenital pseudarthrosis of tibia).

Poland Syndrome

- **Clinical features**
  - Unilateral chest wall hypoplasia (**sternocostal head of pectoralis major absent**)
  - Hypoplasia of hand and forearm
  - Symbrachydactyly and shortening of middle fingers—simple syndactyly of ulnar digits, absence of shortening of middle digits
- **Examination findings**
  - Chest deformities: chest wall hypoplasia, Sprengel deformity, scoliosis
  - Hand deformities
    - Absence or hypoplasia of metacarpals and phalanges
    - Carpal bone abnormalities
    - Absence of flexor and extensor tendons
    - Can be associated with radioulnar synostosis
- **Treatment: syndactyly release; caution should be taken about possible lack of soft tissue coverage requiring full-thickness skin graft**

Apert Syndrome

- **Autosomal dominant due to mutation in** *FGFr2* gene
- **Characteristics**
  - Bilateral complex syndactyly of hands and feet

- Craniosynostosis—premature closure of cranial sutures—flattened skull with broad forehead
- Ankylosis of interphalangeal joints (symphalangism)
- Radioulnar synostosis
- Glenoid hypoplasia
- Decreased mental capabilities

▪ **Treatment**

- Surgical release of border digits done at 1 year of life
- Digital reconstruction of middle digits to turn 3 digits into 2 digits done at 2 years old

Lower Extremity Problems: General

Rotational Problems of the Lower Extremities

- **Introduction**
  - In-toeing usually attributable to metatarsus adductus (in infants), internal tibial torsion (in toddlers), and femoral anteversion (in children <10 years)
  - Out-toeing typically a result of external rotation hip contracture (in infants) and external tibial torsion and external femoral torsion (in older children and adolescents)
  - All these problems may be a result of intrauterine positioning.
  - Deformities usually bilateral; clinician should be wary of asymmetric findings.
  - Evaluation should include measurements listed in Table 3.2 and illustrated in Fig. 3.2.
- **Metatarsus adductus**
  - Clinical features
    - Forefoot adducted at tarsal-metatarsal joint
    - Lateral border of foot is convex instead of straight
    - Usually seen during first year of life
    - May be associated with hip dysplasia (10%–15% of cases)
    - Approximately 85% of cases resolve spontaneously.
  - Treatment
    - Nonoperative
      - Stretching exercises are used for feet that can be passively corrected to neutral position (heel bisector line aligns with second metatarsal).
      - Feet that cannot be passively corrected (rare situation) usually respond to serial casting, with mixed results.
    - Surgery
      - Lateral column shortening and medial column lengthening if patient older than 5 years old (mixed results)
- **Internal tibial torsion**
  - Clinical features
    - Most common cause of in-toeing
    - Usually seen during second year of life and can be associated with metatarsus adductus and developmental dysplasia of the hip (DDH)
    - Internal rotation of tibia causes pigeon-toed gait.

• Transmalleolar axis is internal.
• Thigh-foot axis of −10 degrees

□ Treatment

• Resolves spontaneously with growth

Table 3.2

Evaluation of Rotational Problems of the Lower Extremities.

Measurement	Technique	Normal Values (degrees)	Significance
Foot-progression angle	Foot vs. straight line	−5 to +20	Nonspecific rotation
Medial rotation	Prone hip ROM	20–60	>70 degrees: femoral anteversion
Lateral rotation	Prone hip ROM	30–60	<20 degrees: femoral anteversion
Thigh-foot angle	Knee bent; foot up	0–20	<−10 degrees: tibial torsion
Foot lateral border	Convex; medial crease	Straight; flexible	Metatarsus adductus

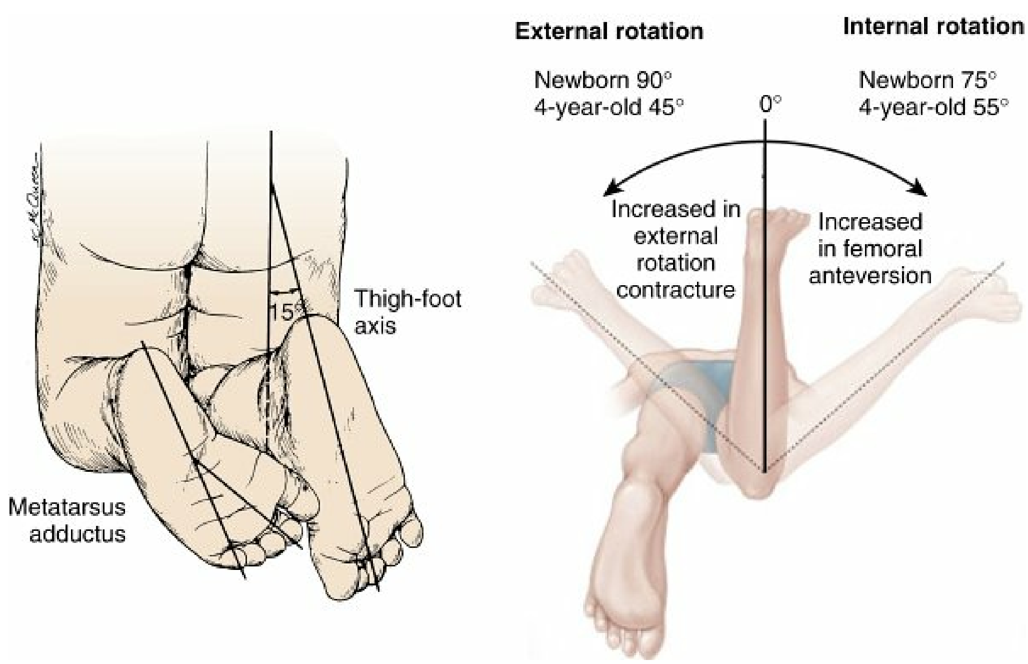


FIG. 3.2 Hip internal and external rotation to estimate femoral anteversion; thigh-foot axis to estimate tibial torsion.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics*, ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 4-5.

• Operative correction is rarely necessary except in severe case, which is addressed with a supramalleolar osteotomy when child is between 7 and 10 years of age.

▪ **External tibial torsion**

- Clinical features
  - Cause of out-toeing; may cause disability and decrease physical performance
  - Can worsen with growth—normal increase in external torsion
  - Associated with increased femoral anteversion (miserable malalignment syndrome), early degenerative joint disease, neuromuscular conditions
  - Manifests as knee pain due to patellofemoral malalignment
  - Thigh-foot axis > 40
- Treatment
  - Rest, rehabilitation
  - Supramalleolar osteotomy if child older than 8–10 years and external tibial torsion more than 40 degrees

- **Femoral anteversion**
  - Clinical features
    - Internal rotation of femur; seen in 3- to 6-year-olds
    - Children with this problem classically sit with the legs in a W shape.
    - If associated with external tibial torsion, may lead to patellofemoral problems
  - Treatment
    - Disorder usually corrects spontaneously by age 10
    - Special shoes, therapy, and derotational braces have never been shown to improve rates of remodeling.
    - In older children with less than 10 degrees of external rotation, femoral derotational osteotomy (intertrochanteric is best) may be considered for cosmesis, although this is not a functional problem.

Leg Length Discrepancy

- **Clinical features**
  - Many potential causes
    - Congenital disorders (e.g., hemihypertrophy, dysplasias, proximal femoral focal deficiency [PFFD], DDH)
    - Paralytic disorders (e.g., spasticity, polio)
    - Infection (disruption of physis)
    - Tumors
    - Trauma
  - Long-term problems associated with leg length discrepancy (LLD) include inefficient gait, equinus contractures of ankle, postural scoliosis and low back pain, possible hip osteoarthritis with

uncovering of the femoral head of the long leg.

- Discrepancy must be measured accurately (e.g., with blocks of set height under affected side; with scanography).
  - Lateral CT scanography—more accurate than conventional scanography if there are soft tissue contractures of hip, knee, or ankle
  - Can be tracked with Green-Anderson data, Moseley graph (with serial leg length radiographs or CT scanograms and with bone age determinations) or the Paley multiplier method (most accurate for congenital deformities)
  - A gross estimation of LLD can be made under the following assumption of growth per year up to age 16 in boys and age 14 in girls (Fig. 3.3):
    - Distal femur: ⅛ inch (9 mm) per year
    - Proximal tibia: ¼ inch (6 mm) per year
    - Proximal femur: ⅛ inch (3 mm) per year
    - More accurate results with Moseley graph

- **Treatment**
  - In general, projected discrepancies at maturity of less than 2 cm are observed or treated with shoe lifts.
    - More than 50% of population have up to 2 cm of LLD and are asymptomatic.
  - Discrepancies of 2 to 5 cm
    - Epiphysiodesis of the long side
    - Shortening of the long side (ostectomy)
    - Lengthening of the short side
  - Discrepancies of more than 5 cm are generally treated with lengthening.
    - With use of standard techniques, lengthening of 1 mm a day is typical.
    - Ilizarov principles are followed, including metaphyseal corticotomy (preserving medullary canal and blood supply) followed by gradual distraction.
    - On rare occasions, physeal distraction (chondrodiastasis) can be considered.
      - This procedure must be performed in patients near skeletal maturity, because the physis almost always closes after this type of limb lengthening.

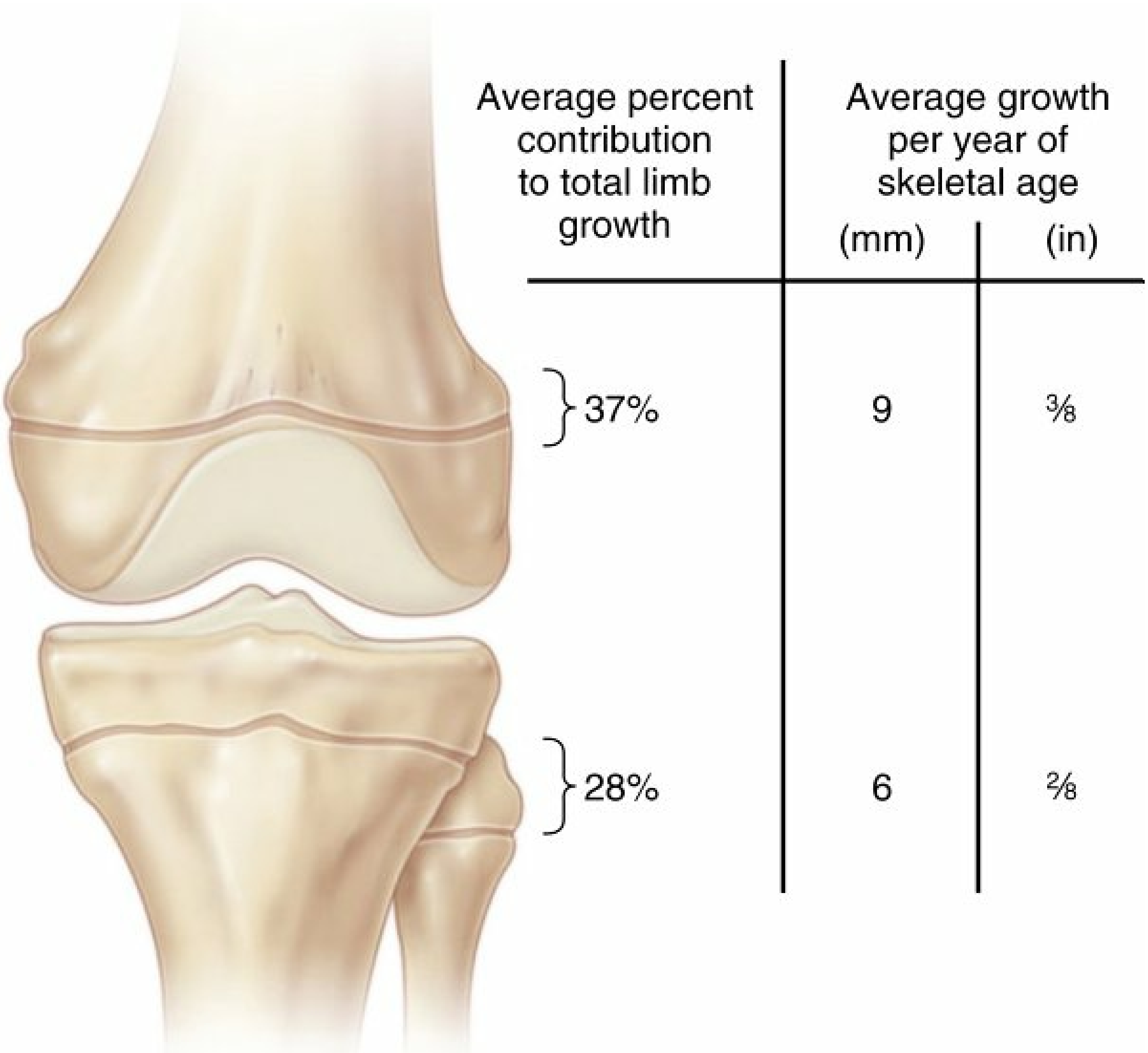


FIG. 3.3 Approximate percentage of contribution to total leg length increase and average growth per skeletal year of maturation (in millimeters and inches) of the distal femoral and proximal tibial physes.

From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders, Fig. 24-16.

Hip and Femur

Developmental Dysplasia of the Hip

- **Introduction**
  - Represents abnormal development or dislocation of the hip secondary to capsular laxity and mechanical factors (e.g., intrauterine positioning)
- **Spectrum of disease**
  - Dysplasia—shallow acetabulum
  - Subluxation
  - Dislocation
  - Teratologic—dislocated in utero and irreducible; associated with neuromuscular conditions and genetic abnormalities
  - Late dysplasia (adolescent and adult)
- **Risk factors**
  - Breech positioning, positive family history (ligamentous laxity), female sex, and being a firstborn child (in that order)
  - Less intrauterine space accounts for increased incidence of DDH in firstborn children.
  - DDH is observed most often in the left hip (67% of cases), in girls (85%), in infants with a positive family history (≥20%), in the presence of increased maternal estrogens, and in breech births (30%–50%).
  - Also associated with postnatal positioning such as swaddling with the hips in extension
- **Clinical features**
  - Associated with other problems related to intrauterine positioning, such as torticollis (20% of cases) and metatarsus adductus (10%); no association with clubfoot
  - If left untreated, muscles about the hip become contracted, and the acetabulum becomes more dysplastic and filled with fibrofatty tissue (pulvinar).
  - Potential obstructions to obtaining a concentric reduction in DDH:
    - Iliopsoas tendon
    - Pulvinar
    - Hypertrophied ligamentum teres
    - Contracted inferomedial hip capsule
    - Transverse acetabular ligament
    - Inverted labrum
  - The teratologic form is most severe and usually necessitates early surgery.
    - A pseudoacetabulum is present at or near birth.

- Teratologic hip dislocations commonly manifest in association with syndromes such as arthrogryposis and Larsen syndrome.

- **Diagnosis**
  - Physical examination
    - Early diagnosis possible with Ortolani test (elevation and abduction of femur relocates a dislocated hip) and Barlow test (adduction and depression of femur dislocates a dislocatable hip)
    - All children should undergo screening via physical examination.
    - Advanced screening is controversial, but screening ultrasound should be done for children with significant risk factors (breech position, family history).
    - Three phases are commonly recognized:
      - *Dislocated* (positive result of Ortolani test early; negative result of Ortolani test late, when femoral head cannot be reduced)
      - *Dislocatable* (positive result of Barlow test)
      - *Subluxable* (suggestive result of Barlow test)
    - Subsequent diagnosis is made with limitation of hip abduction in the affected hip as the laxity resolves and stiffness becomes more clinically evident.
      - Caution: abduction may be decreased symmetrically with bilateral dislocations.
    - Galeazzi sign—demonstrated by the clinical appearance of foreshortening of the femur on the affected side.
      - Performed with the patient's feet held together and knees flexed (a congenitally short femur can also cause the Galeazzi sign)
    - Other clinical findings associated with DDH include asymmetric gluteal folds (less reliable) and Trendelenburg stance (in older children), increased lumbar lordosis, and pelvic obliquity.
    - Repeated examinations, especially in an infant, are important because a child's irritability can prevent proper evaluation.
  - Radiography
    - Dynamic ultrasonography is useful for making the diagnosis in young children before ossification of the femoral head (which occurs at age 4–6 months) (Fig. 3.4).
      - Also useful for assessing reduction in a Pavlik harness and diagnosing acetabular dysplasia or capsular laxity

        - Success dependent on operator's skill
        - On the coronal view, the normal α angle is greater than 60 degrees, and the femoral head is bisected by the line drawn down the ilium.
    - Radiographic studies and findings (Fig. 3.5)
        - Used in older children (after age 4 months)
        - Measurement of the acetabular index (normal <25 degrees)
        - Measurement of the Perkin line (normally the ossific nucleus of the femoral head is medial to this line)
        - Evaluation of the Shenton line useful
        - Later, delayed ossification of the femoral head on the affected side may be visible (femoral head ossification begins to show between 4 and 6 months).
    - Arthrography used to help judge closed reduction and possible blocks to reduction
    - Advanced imaging (CT, MRI) helpful after closed reduction to determine concentric reduction
- □ Treatment (Fig. 3.6)
    - Based on achieving and maintaining early "concentric reduction" to prevent future degenerative joint disease. Specific therapy is determined by the child's age.
    - Birth to 6 months
        - In hips that have normal examination findings but abnormal ultrasound findings, treatment recommendations are uncertain
            - Children should have close follow-up.
            - Repeat ultrasound at age 6 weeks, with treatment if continued signs of dysplasia

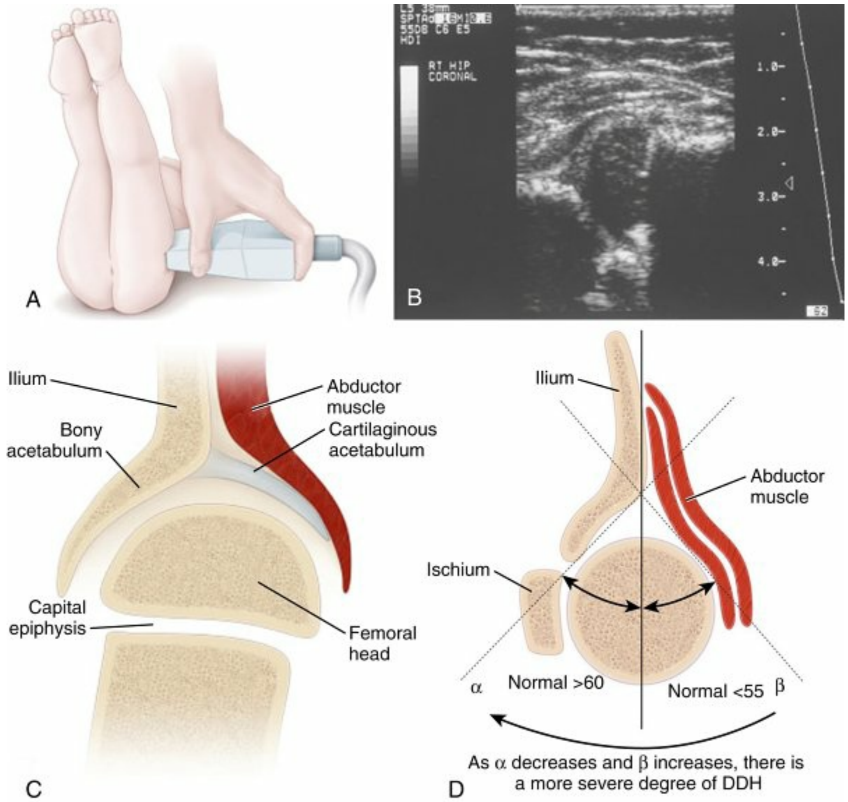


FIG. 3.4 Ultrasound evaluation of the neonate's hip. (A) Positioning of ultrasound transducer on a normal hip. (B) Ultrasonogram. (C) Illustration of ultrasound findings of a dislocated hip with poor bony roof. (D) Graphic illustration of the dislocated hip.

From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders.

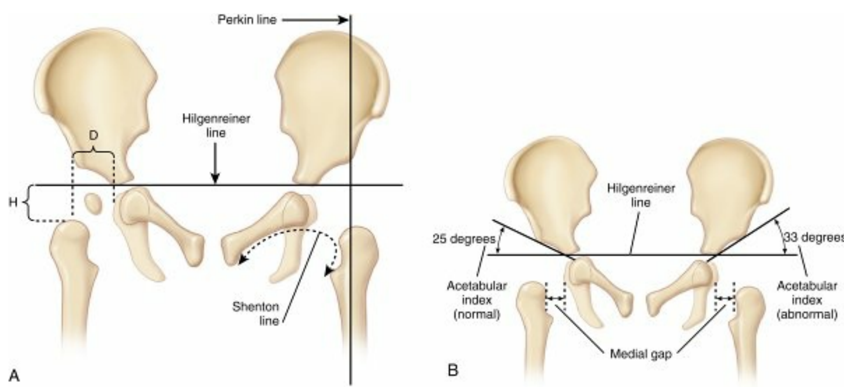


FIG. 3.5 (A and B) Drawings of the common radiographic measurements used to evaluate developmental dysplasia of the hip, anterior view. Note the delayed ossification, disruption of the Shenton line, and increased acetabular index on the left hip, which is dislocated.

From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders.

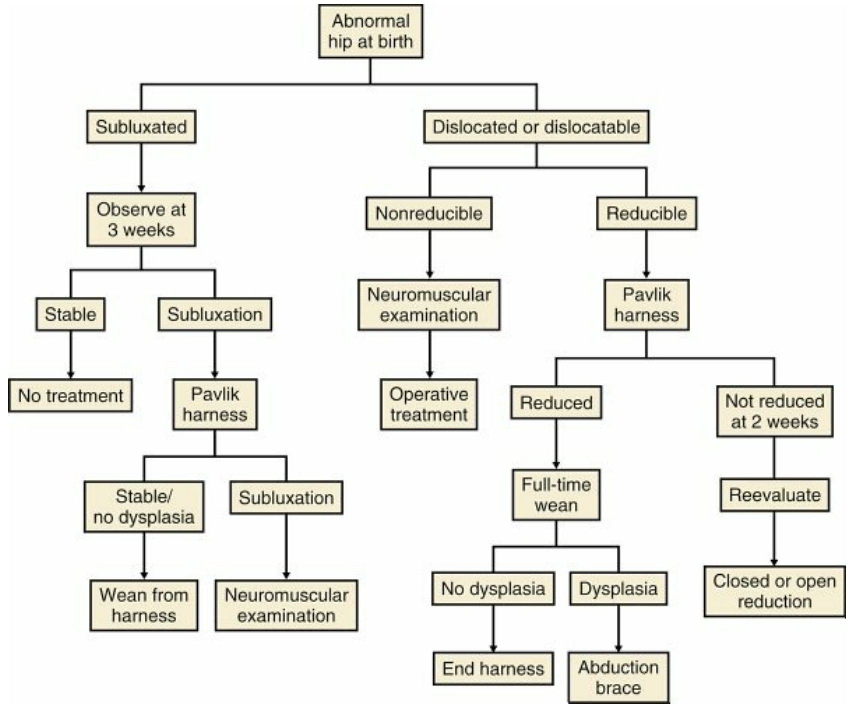


FIG. 3.6 Algorithm for the treatment of developmental dysplasia of the hip.
Redrawn from Guille JT et al: Developmental dysplasia of the hip from birth to 6 months, *J Am Acad Orthop Surg* 8:232–242, 2000.

- Pavlik harness
  - All Ortolani-positive (dislocated but reducible) hips should be treated with Pavlik harness.
  - Barlow-positive (reduced but dislocatable) hips may stabilize without treatment but should be watched closely; many writers advocate treating with Pavlik harness with observation.
  - If dislocated, reduction should be checked weekly with ultrasonography for 3 weeks.
    - Not reduced: transition to rigid abduction orthosis versus closed reduction, arthrography, and spica casting should be considered.
    - Reduced: continue harness until findings of examination and ultrasonography are normal.

- 6 to 18 months:
    - Hip arthrography, percutaneous adductor tenotomy, closed reduction, and spica casting
    - Postreduction CT or MRI used to confirm concentric reduction
    - If closed reduction fails: open reduction
- 18 months to 3 years:
    - Open reduction
- 3 to 8 years:
    - Osteotomy
        - Salter, Dega, Pemberton, or Staheli procedure
- Older than 8 years:
    - Osteotomy
        - Growth plate open: triple (Steele), double pelvic (Southerland), Staheli procedure
        - Growth plate closed: Ganz and Chiari procedures
    - Total hip arthroplasty is performed when the child is an adult.
- Specific treatment modalities
    - Pavlik harness
        - Designed to maintain reduction in infants (<6 months) in about 100 degrees of flexion and mild abduction (the "human position" [Salter position])
        - Confirm reduction by radiographs or ultrasound after placement of harness and brace adjustment.
        - Position of the hip should be within the safe zone of Ramsey (between maximum adduction before redislocation and excessive abduction, which increases risk of avascular necrosis [AVN]).
        - Impingement of the posterosuperior retinacular branch of the medial femoral circumflex artery has been implicated in osteonecrosis associated with DDH treated in an abduction orthosis.

        - Pavlik harness treatment is contraindicated in teratologic hip dislocations.
        - In a patient with a narrow safe zone (<40 degrees), adductor tenotomy should be considered.
        - Excessive flexion may result in transient femoral nerve palsy.
        - "Pavlik disease"—if attempts to reduce a hip do not succeed in 3 weeks, harness should be discontinued to prevent erosion of the pelvis superior to the acetabulum and subsequent difficulty with closed reduction and casting.
        - The Pavlik harness is usually worn 23 hours a day for at least 6 weeks after a reduction has been achieved and then an additional 6 to 8 weeks part time (nights and during naps).
        - Risk factors for Pavlik harness failure:
            - Patient older than 7 weeks at initiation of treatment
            - Bilateral dislocations
            - Absence of Ortolani sign
    - Closed and open reduction
        - Closed reduction
            - Performed for patients for whom Pavlik treatment fails and for patients 6 to 18 months of age
            - Performed using general anesthesia; procedure includes a physical examination, arthrography to assess reduction (look for thorn sign on arthrogram, indicating normal labral position),

and hip spica casting with the legs flexed to at least 90 degrees and in the stable zone of abduction
    - CT or MRI often performed to confirm that hip is well reduced, especially in questionable cases
- Open reduction
    - Reserved for children 6 to 18 months old in whom closed reduction fails, who have an obstructive limbus, or who have an unstable safe zone
    - Initial treatment for children 18 months and older.
    - Anterior approach, especially for patients older than 12 months (less risk to medial femoral circumflex artery)
    - Capsulorrhaphy, adductor tenotomy, and femoral shortening can be performed to take tension off the reduction, along with an acetabular procedure if severe dysplasia is present
    - Obstacles to reduction: transverse acetabular ligament, pulvinar, infolded labrum, inferior capsular restriction, hypertrophied

ligamentum teres, and psoas tendon
        - Medial open reduction can be performed in children up to 12 months of age.
        - Less blood loss
        - Directly addresses obstacles to reduction
        - Does not provide access for a capsulorrhaphy
        - More often associated with osteonecrosis
    - Surgical risks
    - Osteonecrosis—the major risk associated with both open and closed reductions; caused by direct vascular injury or impingement versus disruption of circulation from osteotomies
    - Damage to medial femoral circumflex can occur with medial approach to hip; close association to psoas, which undergoes a tenotomy because it is a block to reduction.
    - Failure of open reduction is difficult to treat surgically because of the high rates of complication after revision surgery (osteonecrosis in 50% and pain and stiffness in 33% according to one study)
    - Diagnosis after age 8 (younger in patients with bilateral DDH) may contraindicate reduction because the acetabulum has little chance to remodel, although reduction may be indicated in conjunction with salvage procedures.
- Osteotomy
    - Indications
        - May be required in toddlers and school-age children, usually for

residual and persistent acetabular dysplasia

- Osteotomies should be performed only after a congruent reduction is confirmed on an abduction–internal rotation view, with satisfactory ROM, and after reasonable femoral sphericity is achieved by closed or open methods.

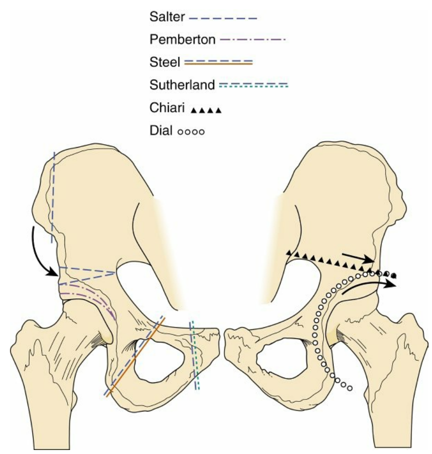


FIG. 3.7 Common pelvic osteotomies for the treatment of developmental dysplasia of the hip. Both the Steel and Sutherland cuts use the Salter cut in addition to another cut.

- The choice of femoral versus pelvic osteotomy (Fig. 3.7) is sometimes a matter of the surgeon's preference.
- Pelvic osteotomies should be performed in a child in whom severe dysplasia is accompanied by significant radiographic

changes on the acetabular side (i.e., increased acetabular index, failure of lateral acetabular ossification), whereas changes on the femoral side (e.g., marked anteversion, coxa valga) are best treated by femoral osteotomies.
    - Table 3.3 lists common reconstructive osteotomies.
- Procedures
    - Salter osteotomy: redirectional; may lengthen the affected leg up to 1 cm
    - Pemberton acetabuloplasty: volume reducing; good choice for residual dysplasia (bends on triradiate cartilage)
    - Acetabular reorientation procedures in older patients include the triple innominate osteotomy (Steel or Tönnis procedure)
    - Dega-type osteotomies: volume reducing; often favored for paralytic dislocations and in patients with posterior acetabular deficiency
    - Ganz periacetabular osteotomy: redirectional; provides improved three-dimensional correction because the cuts are

close to the acetabulum, allow immediate weight bearing, spare stripping of the abductor muscles, allow for a capsulotomy to inspect the joint, and are performed through a single incision. However, the triradiate cartilage must be closed.

- Chiari osteotomy: salvage procedure when a concentric reduction of the femoral head within the acetabulum cannot be achieved. This osteotomy shortens the affected leg and requires periarticular soft tissue metaplasia for success. It depends on metaplastic tissue (fibrocartilage) for a successful result.

Table 3.3

Common Pelvic Osteotomies, Procedures,

Osteotomy	Procedure	Requ
WITH CONCENTRIC REDUCTION		
Femoral	Intertrochanteric osteotomy (varus derotation osteotomy)	Con b
Salter	Open-wedge osteotomy through ileum	Con b

Pemberton	Through acetabular roof to triradiate cartilage; does not enter sciatic notch	Con b
Dega	Through lateral ilium above acetabulum to triradiate cartilage; incomplete cuts through innominate bone	Con f v a c
Sutherland (double)	Salter and pubic osteotomy	C C
Steel (triple)	Salter and osteotomy of both rami	C C
Ganz	Periacetabular osteotomy	S C
WITHOUT CONCENTRIC REDUCTION		
Chiari	Through ilium above acetabulum (makes new roof)	Non a
Shelf	Slotted lateral acetabular augmentation	Non a

- Lateral shelf acetabular augmentation procedure: salvage procedure for patients older than 8 years with inadequate lateral coverage or trochanteric advancement and increased trochanteric overgrowth (improves hip abductor biomechanics). It does not require concentric reduction. Success of this procedure depends on metaplastic tissue (fibrocartilage).

Congenital Coxa Vara

- **Clinical features**
  - □ Bilateral in a third to half of cases
  - □ Coxa vara can be congenital (noted at birth and differentiated from DDH on MRI), developmental (autosomal dominant, progressive), acquired (e.g., trauma, Legg-Calvé-Perthes disease, slipped capital femoral epiphysis [SCFE]), or associated with skeletal dysplasia (cleidocranial dysplasia, spondyloepiphyseal dysplasia, metaphyseal dysplasia).
  - □ May manifest as waddling gait (bilateral) or painless limp (unilateral)
- **Radiographic findings**
  - □ Triangular ossification defect in the inferomedial femoral neck in developmental coxa vara is common.
  - □ Neck-shaft angle is decreased as a result of a defect in ossification of the femoral neck.
  - □ Evaluation of the Hilgenreiner epiphyseal angle (angle between Hilgenreiner line and a line through proximal femoral physis) is the key to treatment (Fig. 3.8).
- **Treatment**
  - □ Based on Hilgenreiner epiphyseal angle (normal <25 degrees)
    - Less than 45 degrees: spontaneously corrects
    - 45–60 degrees: requires close observation
    - More than 60 degrees (with neck-shaft angle <110 degrees): usually necessitates surgery
  - □ Surgical treatment is a corrective valgus osteotomy of the proximal femur.
  - □ Subtrochanteric valgus osteotomy with or without derotation (Pauwels)

is indicated for a neck-shaft angle of less than 90 degrees, a vertically oriented physeal plate, progressive deformities, or significant gait abnormalities.

- Distal transfer of the greater trochanter may restore more normal hip abductor mechanics.

Legg-Calvé-Perthes Disease (Coxa Plana)

- **Clinical features**
  - Noninflammatory deformity of proximal femur secondary to vascular insult of unknown origin, leading to osteonecrosis of proximal femoral epiphysis
  - Pathologically, osteonecrosis is followed by revascularization and resorption through creeping substitution that eventually allows remodeling.
  - Most common in boys 4–8 years of age with delayed skeletal maturation who are very active
  - Increased incidence with a positive family history, low birth weight, and abnormal birth presentation (associated with delayed bone age and attention deficit hyperactivity disorder [ADHD])
  - Symptoms include pain (often knee pain), effusion (from synovitis), and a limp.
  - Decreased hip ROM (especially abduction and internal rotation) and a Trendelenburg gait are also common.
  - Bilateral involvement may be seen in 12%–15% of cases.
    - Bilateral cases usually not simultaneous
    - Bilateral involvement may mimic multiple epiphyseal dysplasia (MED) and warrants a skeletal survey.
  - Differential diagnosis includes septic arthritis, blood dyscrasias, hypothyroidism, and epiphyseal dysplasia.
- **Radiographic findings**
  - Vary with stage of disease but include cessation of growth of the ossific nucleus, medial joint space widening, and development of a crescent sign that represents subchondral fracture

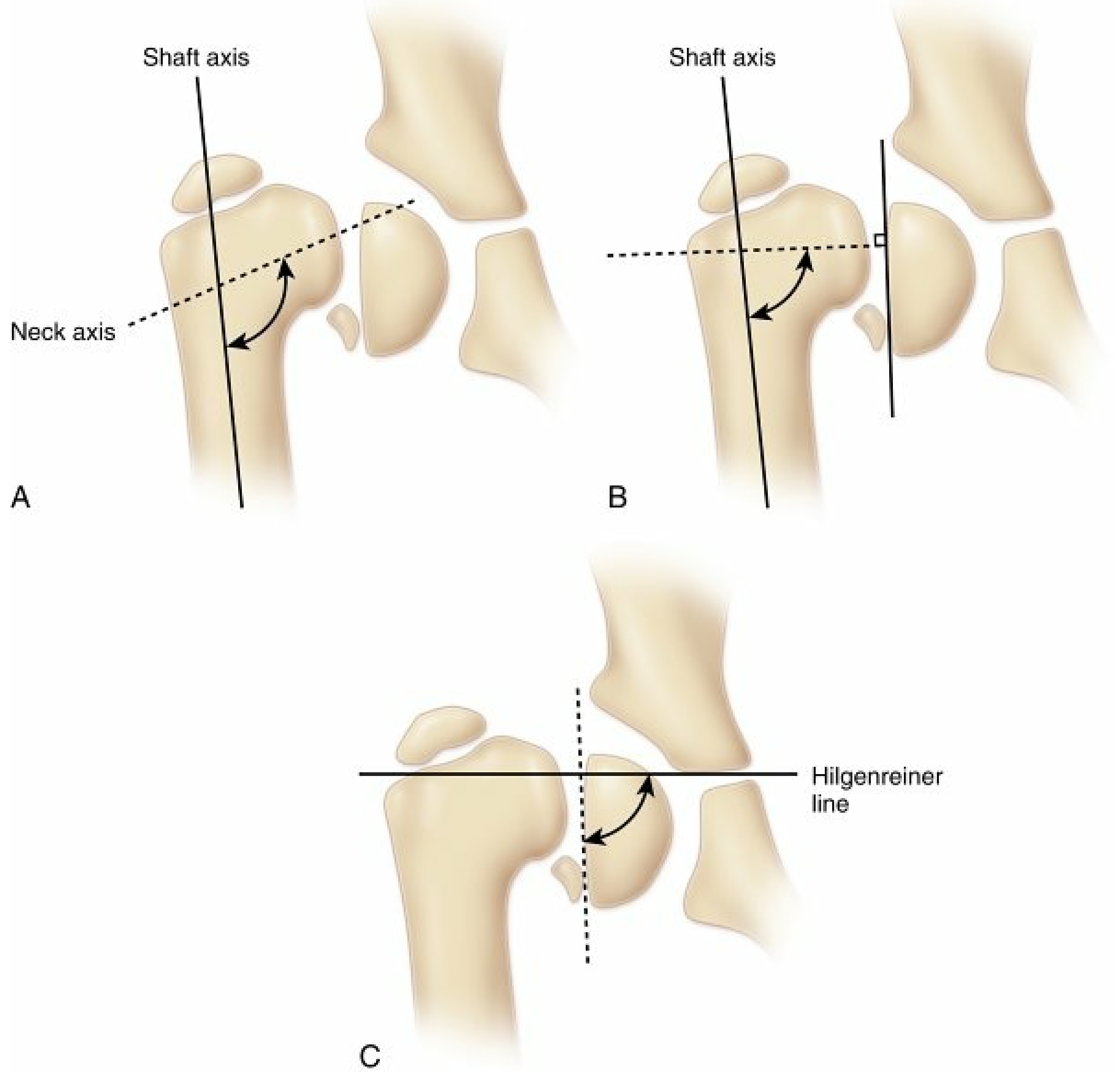


FIG. 3.8 Quantification of the extent of radiographic deformity of the proximal femur in developmental coxa vara. (A) The neck–shaft angle is the angle between the axis of the femoral shaft and the axis of the femoral neck. (B) The head–shaft angle is the angle between the axis of the femoral shaft and an imaginary perpendicular line to the base of the capital femoral epiphysis. (C) The Hilgenreiner–epiphyseal angle is the angle between the Hilgenreiner line and an imaginary line parallel to the capital femoral physis.

From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 3, Philadelphia, 2002, WB Saunders, p 767.

- □ Classification
  - Waldenström classification determines the four stages all cases follow:
    - Initial—sclerotic epiphysis with joint widening (x-rays may not show changes for 4–6 months)
    - Fragmentation—due to bone resorption and collapse (lateral pillar classification based on this stage)
    - Reossification—new bone appears (may last up to 18 months)
    - Healed or reossified—continued remodeling until

maturity

- Most prognostic classification is Herring, or lateral pillar, classification
  - Based on involvement of lateral pillar of capital femoral epiphysis during the fragmentation stage (Fig. 3.9, Table 3.4)

▪ **Prognosis**

- □ Maintaining sphericity of femoral head is the most important factor in achieving a good result.
- □ Early degenerative hip joint disease results from aspherical femoral heads.
- □ Poor prognosis is associated with older age at onset (bone age >6 years), female sex, lateral column C classification (regardless of age), and decreased hip ROM (decreased abduction).
- □ Radiographic findings associated with poor prognosis (Catterall head-at-risk signs):
  - Lateral calcification
  - Gage sign (V-shaped defect at lateral physis)
  - Lateral subluxation
  - Metaphyseal cyst formation
  - Horizontal growth plate

▪ **Treatment**

- □ Goals: relief of symptoms, restoration of ROM, and containment of the hip
- □ Use of outpatient or inpatient traction, antiinflammatory medications, and partial weight bearing with crutches for periods of 1 or 2 days to several weeks is helpful for relieving symptoms.
- □ ROM is maintained with traction, muscle release, exercise, use of a Petrie cast, or a combination of these measures.
- □ Herring described a treatment plan based on age and the lateral pillar classification of disease involvement.
  - Surgical treatment may improve radiographic outcome at skeletal maturity for older patients (chronologic age >8 years or bone age >6 years) with lateral pillar groups B and B/C hips

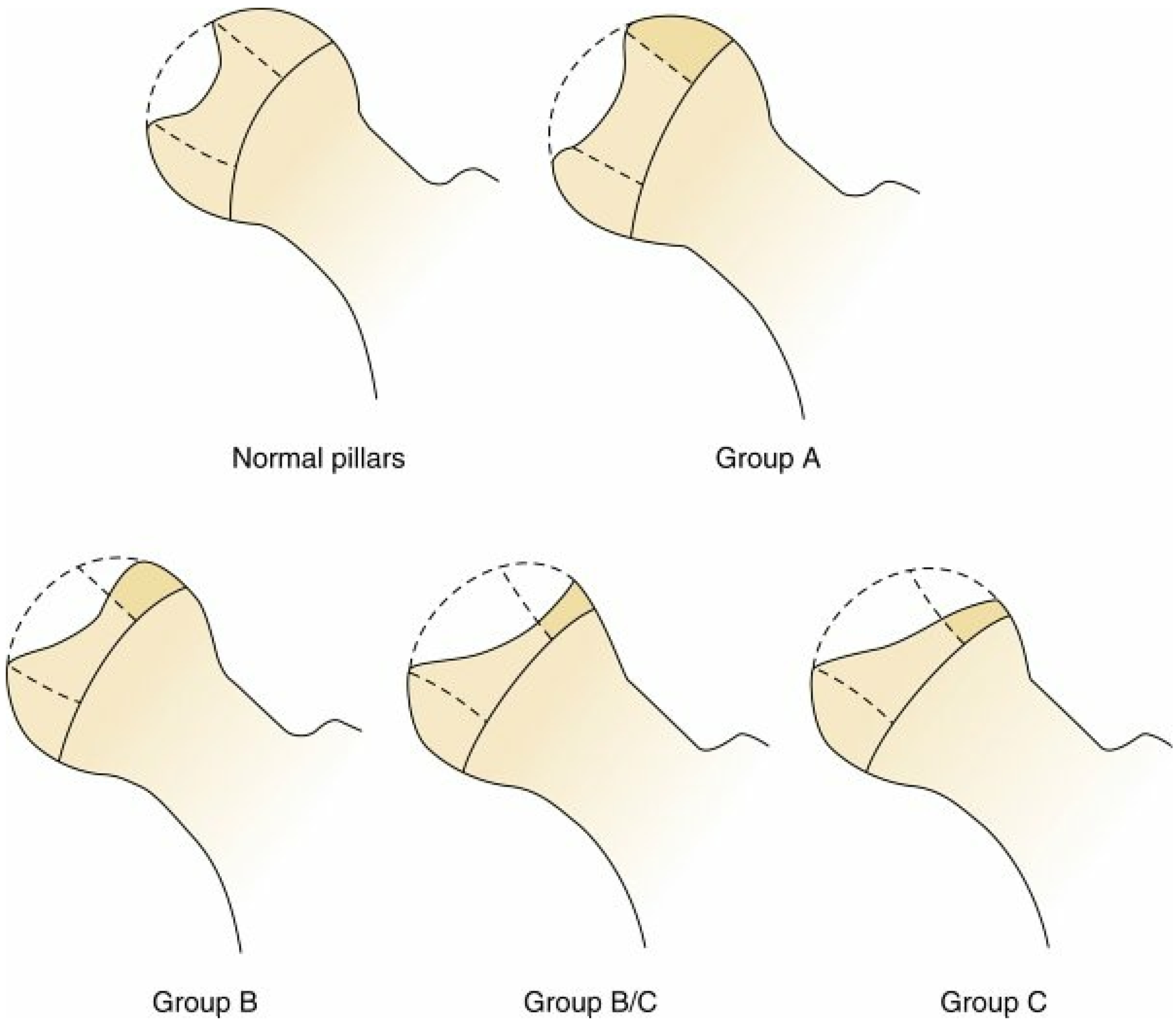


FIG. 3.9 Lateral pillar classification of Legg-Calvé-Perthes disease. Researchers derived the definition of normal pillars by noting the lines of demarcation between the central sequestrum and the remainder of the epiphysis on the anteroposterior radiograph. In group A, normal height of lateral pillar is maintained. In group B, more than 50% of height of lateral pillar is maintained. In group B/C (borderline), lateral pillar is 50% or less in height, but (1) it is very narrow (2 to 3 mm wide), (2) it has very little ossification, or (3) it has depressions in comparison with the central pillar. In group C, less than 50% of height of lateral pillar is maintained.
Adapted from Herring JAet al: The lateral pillar classification of Legg-Calvé-Perthes disease, *J Pediatr Orthop* 12:143–150, 1992.

Table 3.4

Lateral Pillar Classification.

Group	Pillar Involvement	Prognosis
A	Little or no involvement of the lateral pillar	Uniformly good outcome
B	>50% of lateral pillar height maintained	Good outcome in younger patients (bone age <6 yr) but poorer outcome in older patients
C	<50% of lateral pillar height maintained	Poor prognosis in all age groups

□ Containment

- Femoral osteotomy—proximal femoral varus osteotomy
- Pelvic osteotomy—Salter, triple, Dega, Pemberton
  - Shelf osteotomy to prevent lateral subluxation and lateral epiphyseal overgrowth

- ☐ Salvage
  - Valgus femoral osteotomy for hinge abduction
  - Chiari and/or shelf pelvic osteotomies for hips that can no longer be contained

Slipped Capital Femoral Epiphysis

- **Clinical features**
  - ☐ Disorder of proximal femoral epiphysis caused by weakness of perichondrial ring and slippage through hypertrophic zone of the growth plate
  - ☐ Epiphysis remains in the acetabulum, and the neck is displaced anteriorly and rotates externally.
  - ☐ SCFE is seen most often in obese adolescent African American boys during their rapid growth spurt (10–16 years of age); occasional patients have a positive family history.
  - ☐ From 17% to 50% of cases are bilateral (25% is safe estimate).
  - ☐ Patients presenting when younger than 10 years should undergo an endocrine workup.
  - ☐ SCFE may be associated with hormonal disorders in young children, such as hypothyroidism (most common), growth hormone deficiency, and renal osteodystrophy.
  - ☐ Patients present with an antalgic externally rotated gait, decreased internal rotation, thigh atrophy, and hip, thigh, or knee pain.
    - Diagnosis is missed when patients present with knee pain with pain and activation of the medial obturator nerve.
  - ☐ In all patients, physical examination reveals obligate external rotation with flexion of the hip.
- **Classification**
  - ☐ Stability
    - Prognostic for the severe complication of osteonecrosis of the femoral head
    - Stable: weight bearing with or without crutches possible
    - Unstable: weight bearing not possible because of severe pain
    - Osteonecrosis does not develop in patients with stable slippages, but does develop in 47% of patients with unstable slips.
  - ☐ Temporal: no prognostic information

- Acute: symptoms less than 3 weeks
- Chronic: symptoms more than 3 weeks

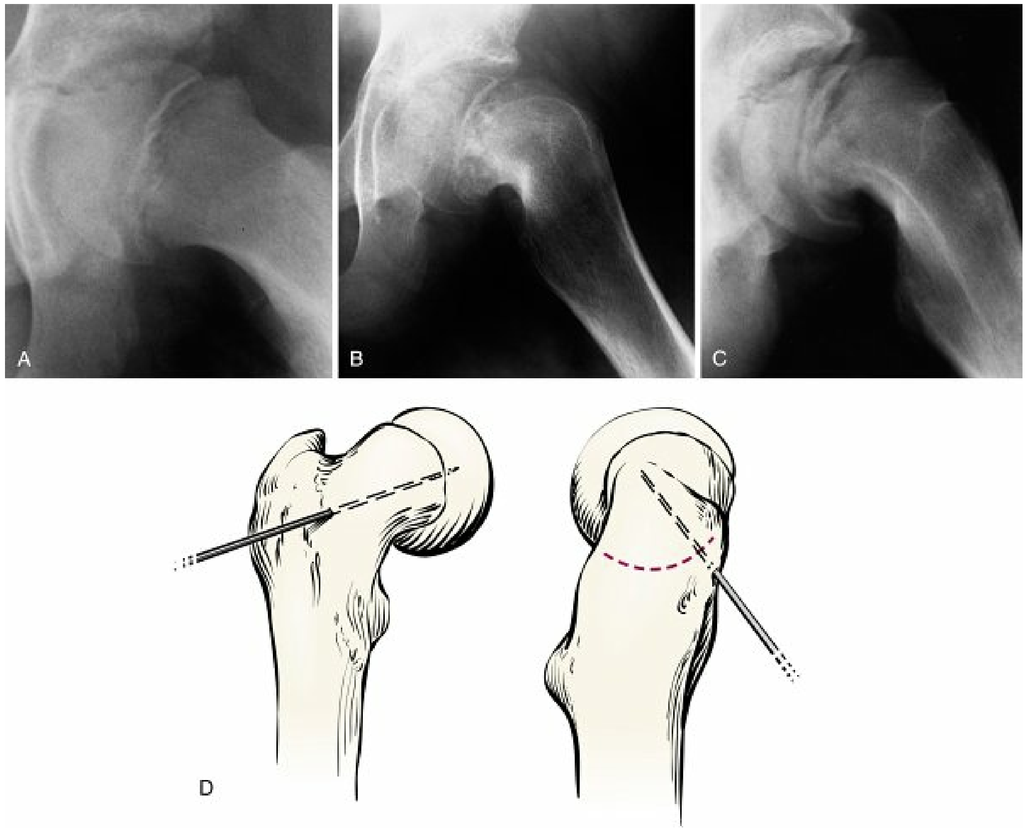


FIG. 3.10 Slipped capital femoral epiphysis. (A) Acute SCFE with no remodeling present. (B) Chronic SCFE showing adaptive changes including callus in the junction of the metaphysis and epiphysis. (C) Acute-on-chronic changes with both sequelae of chronic SCFE (callus) and acute worsening displacement of the epiphysis. (D) Drawings of correct pin placement for guiding of percutaneous in situ screw fixation of SCFE; note that the starting point is anterior on the femoral neck to account for the posteriorly displaced epiphysis.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 18-1 and Plate 18-1.

- Acute on chronic: exacerbation of chronic symptoms

- **Radiographic studies**
  - AP and frog-leg pelvic views are needed for comparison.
  - If the slippage is unstable, a cross-table lateral view is required.
  - SCFE can be graded on the basis of the percentage of slippage
    - Grade I: 0%–33% slippage
    - Grade II: 34%–50% slippage
    - Grade III: more than 50% slippage
  - In mild cases, loss of the lateral overhang of the femoral ossific nucleus (Klein line) and blurring of the proximal femoral metaphysis may be all that is visible on the AP radiograph.
- **Treatment**
  - Recommended treatment for stable and unstable slippages is pinning in situ.

- Positioning on the table may partially reduce the acute component of an unstable slippage.
- Forceful reduction before pinning is not indicated—can cause AVN.
- A single pin can be placed percutaneously (Fig. 3.10).
- The pin should be started anteriorly on the femoral neck and should end in the central portion of the femoral head.
- Goal of treatment: stabilize epiphysis and promote closure of proximal femoral physis
- Prophylactic pinning of the opposite hip is controversial but is generally recommended in a patient with an endocrinopathy or in a child who is young (<10 years) or whose triradiate cartilage is open.

□ Emerging techniques for unstable severe SCFE include surgical hip dislocation with modified Dunn technique (Fig. 3.11).

- Protection of femoral head blood supply via surgical dislocation technique and creation of periosteal flaps on the femoral neck
- Allows acute correction of deformity with femoral neck shortening and reorientation of proximal femoral epiphysis
- Initial results have low rates of AVN; follow-up results show AVN rates approaching 25%.

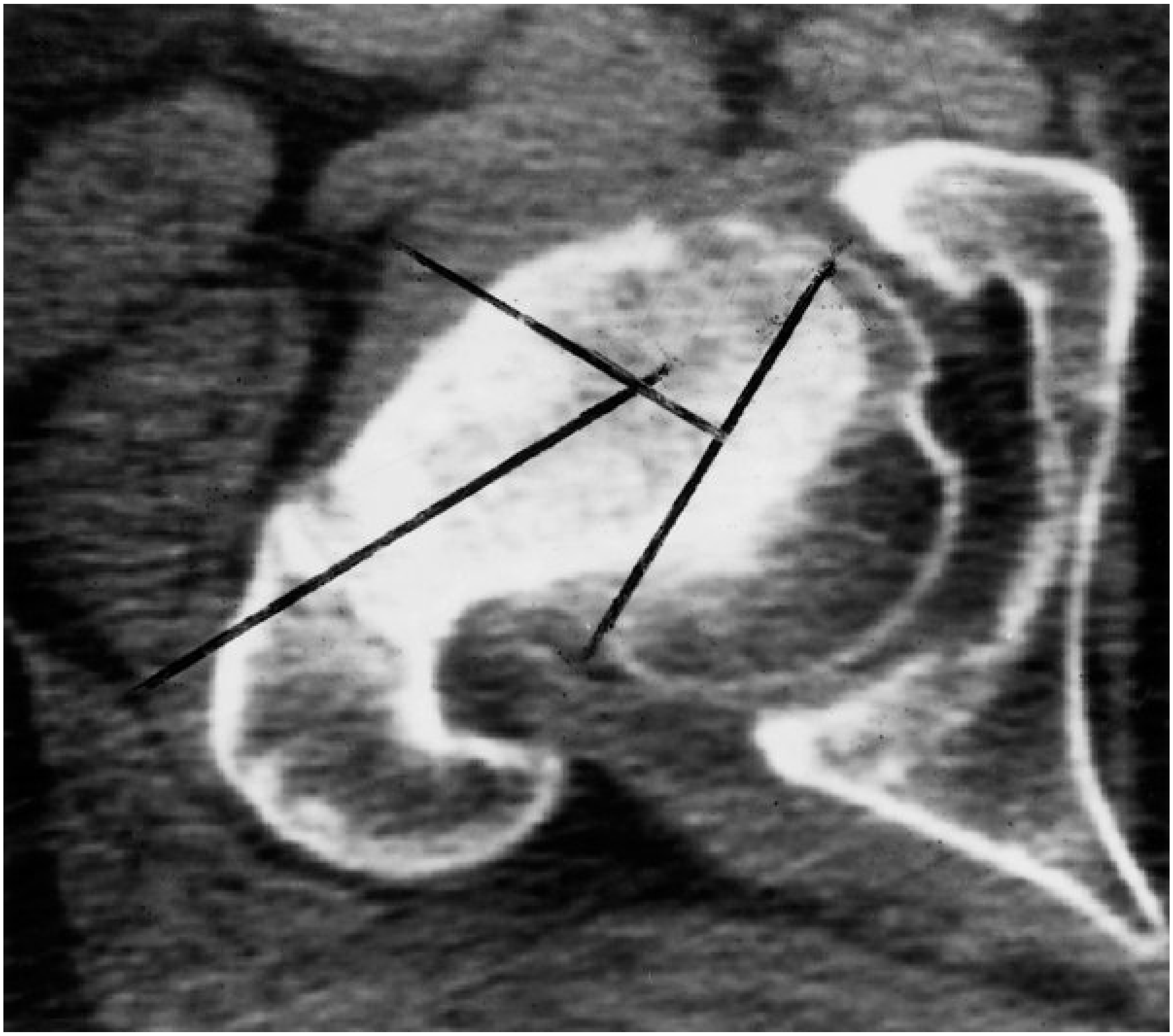


FIG. 3.11 Unstable slipped capital femoral epiphysis can be treated with a surgical hip dislocation and acute correction of the proximal epiphyseal displacement through creation of periosteal flaps that protect the blood supply to the epiphysis while the femoral neck is shortened.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Plate 18-3.

- **Prognosis and complications**
  - In severe SCFE, the residual proximal femoral deformity may partially remodel with the patient's remaining growth.
  - Intertrochanteric (Kramer) or subtrochanteric (Southwick) osteotomies may be useful in treating the deformities caused by SCFE that fail to remodel.
  - Cuneiform osteotomy at the femoral neck has the potential to correct severe deformity but remains controversial because of the reported high rates of osteonecrosis (37% of cases) and future osteoarthritis (37%).
  - Complications associated with SCFE:
    - Osteonecrosis
      - Unstable slippage is the most accurate predictor.
    - Chondrolysis
      - Characterized by narrowed joint space, pain, and

decreased motion
        - Pin placement into the anterior superior quadrant of the femoral head has the highest rate of joint penetration.
        - Associated with inadvertent pin penetration into the joint
    - Degenerative joint disease
        - Pistol-grip deformity of the proximal femur
    - Slip progression—occurs in up to 2% of cases treated with in situ pinning

Bladder Exstrophy

- **Congenital disorder involving both musculoskeletal and genitourinary systems**
- **Altered migration of sclerotomes that make up the pubis**
- **Presentation**
    - Exposed bladder
    - Acetabuli are externally rotated.
    - Can manifest as an externally rotated foot progression
- **Treatment involves staged multidisciplinary approach.**
    - Closure of bladder in newborn
    - Genitourinary repair in males during years 1 to 2
    - Bladder neck reconstructions (4 years old)
    - Pelvic osteotomies may be performed at any stage of process but are most commonly performed during bladder reconstruction in the newborn.

Proximal Femoral Focal Deficiency

- **Clinical features**
    - Developmental defect of the proximal femur recognizable at birth
    - The patient with PFFD has a short, bulky thigh that is flexed, abducted, and externally rotated.
    - PFFD often associated with coxa vara or fibular hemimelia (50% of cases)
    - Congenital knee ligamentous (anterior cruciate ligament [ACL] deficiency) and contracture also common
    - Bilateral in 50% of cases
    - Associated with sonic hedgehog *(SHH)* gene
- **Classification**
    - A: femoral head present with normal acetabulum
    - B: femoral head present with dysplastic acetabulum

- C: femoral head absent with markedly dysplastic acetabulum
- D: both femoral head and acetabulum absent

- **Treatment**
  - Individualized on basis of:
    - LLD
    - Adequacy of musculature
    - Proximal joint stability
    - Presence or absence of foot deformities
  - In general, prosthetic management with foot amputation is used when femoral length is less than 50% that of the opposite side, whereas lengthening with or without contralateral epiphysiodesis is used when the femoral length is more than 50% that of the opposite side.
  - Percentage of shortening remains constant during growth
  - Aiken classification
    - In PFFD classes A and B, presence of the femoral head potentially allows for reconstructive procedures that include limb lengthening.
    - In PFFD classes C and D, the femoral head is absent; treatment includes amputation, femoral-pelvic fusion (Brown procedure), Van Ness rotationplasty, and limb lengthening.

Lower Extremity Inflammation and Infection (See Chapter 1, Basic Science) (Table 3.5)

- **Transient synovitis**
  - Clinical features
    - Most common cause of pain in hips during childhood, but the diagnosis is one of exclusion. In many cases, septic arthritis should be considered.
    - Can be related to viral infection, allergic reaction, or trauma; true cause unknown
    - Onset can be acute or insidious.
    - Symptoms, which are self-limiting, include muscle spasm and voluntary limitation of motion.
    - With transient synovitis, erythrocyte sedimentation rate (ESR) is usually less than 20 mm/hr.

Table 3.5

Causative Organisms for Musculoskeletal Infections and Empirical Antibiotic Regimens Based on Patient Age and Risk Factors.

Patient

Characteristics	Causative Organisms	Empirical Antibiotics
AGE GROUP		
Neonatal (birth to 8 wk)		
Nosocomial infection	*Staphylococcus aureus, Streptococcus* spp., Enterobacteriaceae, *Candida* spp.	Nafcillin or oxacillin plus gentamicin *or* cefotaxime (or ceftriaxone) plus gentamicin
Community-acquired infection	*S. aureus*, group B streptococci, *Escherichia coli, Klebsiella* spp.	Nafcillin or oxacillin plus gentamicin *or* cefotaxime (or ceftriaxone) plus gentamicin
Infantile (2–18 mo)	*S. aureus, Kingella kingae, Streptococcus pneumoniae, Neisseria meningitidis*	Immunized: nafcillin, oxacillin, or cefazolin
	Haemophilus influenzae **type b (nonimmunized)**	Nonimmunized: nafcillin or oxacillin plus cefotaxime, *or* cefuroxime
Early childhood (18 mo–3 yr)	*S. aureus, K. kingae, S. pneumoniae, N. meningitidis*	Immunized: nafcillin, oxacillin, or cefazolin
	H. influenzae **type b (nonimmunized)**	Nonimmunized: nafcillin or oxacillin plus cefotaxime, *or* cefuroxime
Childhood (3–12 yr)	*S. aureus*, group A beta-hemolytic streptococci (GABHS)	Nafcillin, oxacillin, or cefazolin
Adolescent (12–18 yr)	*S. aureus*, GABHS, *Neisseria gonorrhoeae*	Nafcillin, oxacillin, or cefazolin; ceftriaxone and doxycycline for disseminated gonococcal infection

RISK FACTOR		
Sickle cell disease	*Salmonella* spp., *S. aureus, S. pneumoniae*	Ceftriaxone
Foot puncture wound	*Pseudomonas aeruginosa, S. aureus*	Ceftazidime or piperacillin-tazobactam and gentamicin
Human immunodeficiency virus	*S. aureus, Streptococcus* spp., *Salmonella* spp., *Nocardia asteroides, N. gonorrhoeae,* cytomegalovirus, *Aspergillus, Toxoplasma gondii, Torulopsis glabrata, Cryptococcus neoformans, Coccidioides immitis*	Broad-spectrum antibiotics per infectious disease recommendations
Chronic granulomatous disease	*Aspergillus* spp., *Staphylococcus* spp., *Burkholderia cepacia, Nocardia* spp., *Mycobacterium* spp.	Nafcillin, oxacillin, or cefazolin

From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders, Table 35-2.

- See the section “Septic arthritis” for Kocher criteria that suggest an infectious etiology.

□ Imaging studies
- Entire limb
- Consideration of spine radiographs
- Hip ultrasonography
- Consideration of MRI to evaluate persistent pain

□ Treatment
- If Kocher criteria not met, one can consider not aspirating the joint.
- Aspiration of synovial fluid with culture required if any doubt about criteria or with mixed findings
- If findings are negative for sepsis, the patient may be observed during a trial of NSAIDs.
- Symptoms should improve within 24 to 48 hours with NSAIDs.

▪ **Osteomyelitis**

□ Clinical features
- Occurs more often in children because of their rich metaphyseal blood supply and thick periosteum
- More common in boys
- Pathology
    - Most common organism is *Staphylococcus aureus*

- With the advent of the *Haemophilus influenzae* vaccination, *H. influenzae* is now much less commonly found in musculoskeletal sepsis.
- *Kingella kingae* infection is becoming more common in younger age groups and is thought to be potential cause of culture-negative infections—the organism is difficult to isolate; blood culture medium needed.

- History of trauma common in children with osteomyelitis
- Osteomyelitis in children usually begins with hematogenous seeding of a bony metaphysis.
    - Small arterioles just beyond the physis
    - Blood flow becomes sluggish and phagocytosis is poor.
    - Bone abscess can be created (Fig. 3.12).
        - Pus lifts the thick periosteum and puts pressure on the cortex, causing coagulation.
        - Chronic bone abscesses may become surrounded by thick fibrous tissue and sclerotic bone (Brodie abscess).
- Manifests as a tender, warm, sometimes swollen area over a long-bone metaphysis
- Fever may or may not be present.
- Methicillin-resistant *S. aureus* (MRSA) with a *PVL* gene mutation is associated with deep venous thrombosis and septic emboli.

□ Diagnosis

- Laboratory tests may be helpful (blood cultures, white blood cell [WBC] count, ESR, C-reactive protein [CRP]).
- Imaging studies
    - Radiographs show soft tissue edema early, metaphyseal rarefaction late.
    - Periosteal new bone appears at 5 to 7 days.
    - Osteolysis—30%–50% loss of bone mineral—may not appear until 10 to 14 days.
    - MRI examination is key to evaluate for abscess (either intraosseous or subperiosteal).
- Definitive diagnosis is made with aspiration or positive clinical picture with convincing MRI evidence (≥50% of affected patients have positive blood culture results).

□ Treatment

- Intravenous antibiotics are the best initial treatment if osteomyelitis is diagnosed early.

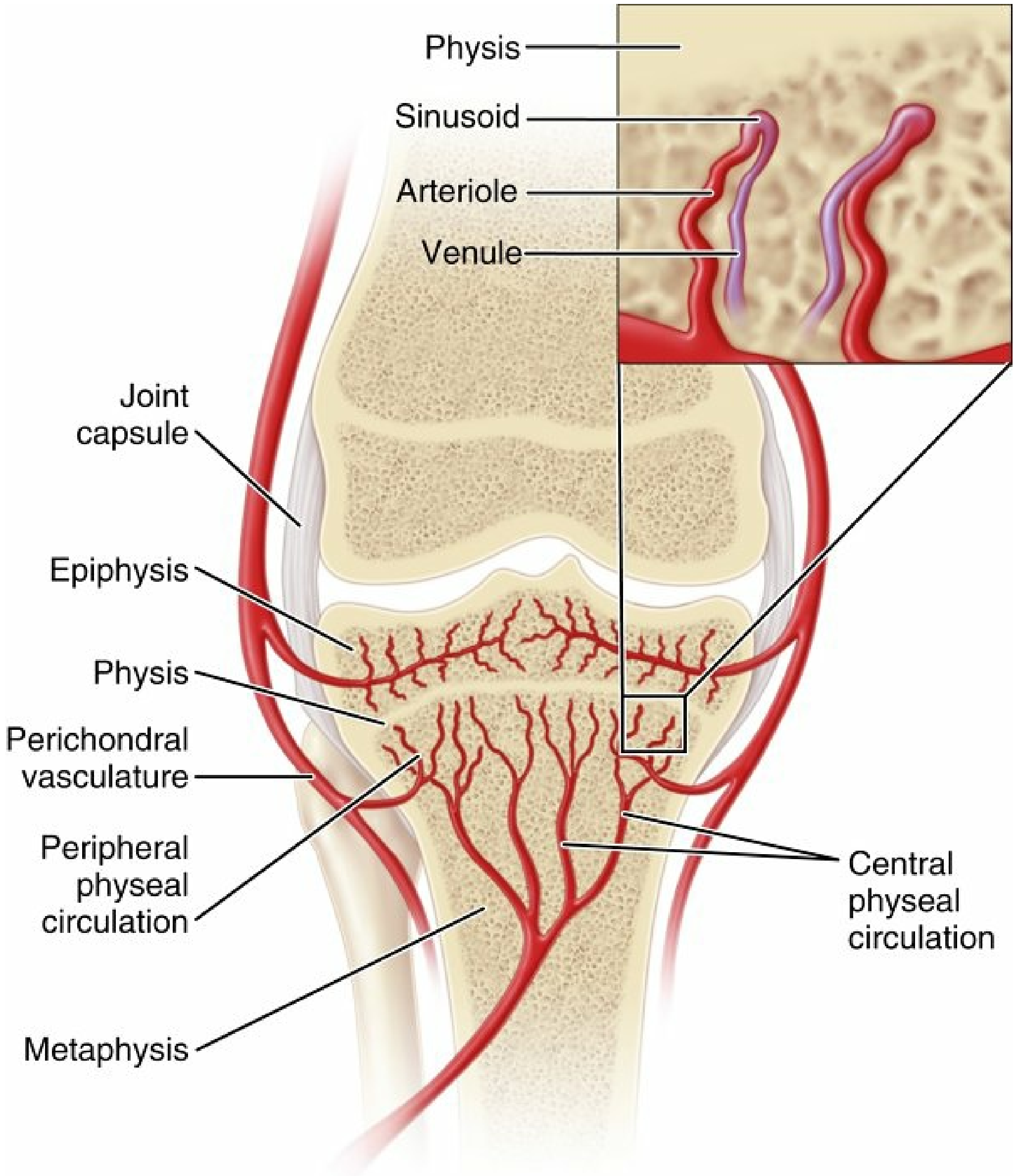


FIG. 3.12 Metaphyseal sinusoids, where sluggish blood flow increases susceptibility to osteomyelitis.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders.

    - If no subperiosteal abscess or abscess within the bone
- Broad-spectrum antibiotics are initially chosen, followed by antibiotics specific for the organism cultured from percutaneous aspiration/biopsy.
- CRP measurements can be used to monitor the therapeutic response to antibiotics.
    - Failure to decline within 48–72 hours warrants alteration in treatment.
- Failure to respond to antibiotics, appearance of frank pus on

MRI, or presence of a sequestered abscess (not accessible to antibiotics) necessitates operative drainage and débridement.

    - Drilling the metaphysis can assist in draining some of the infection.
    - Specimens should be sent for histologic study and culture.

  - Antibiotics should be continued until the ESR (or CRP level) returns to normal, usually at 4 to 6 weeks.

- **Septic arthritis**
  - Clinical features
    - Can develop from osteomyelitis
      - Especially in neonates, in whom transphyseal vessels allow proximal spread into the joint in joints with an intraarticular metaphysis (hip, elbow, shoulder, ankle) (Fig. 3.13)
    - Septic arthritis can also occur as a result of hematogenous spread of infection.
    - Because pus is chondrolytic, septic arthritis in children is an acute surgical emergency.
    - Most commonly occurs in children younger than 2 years

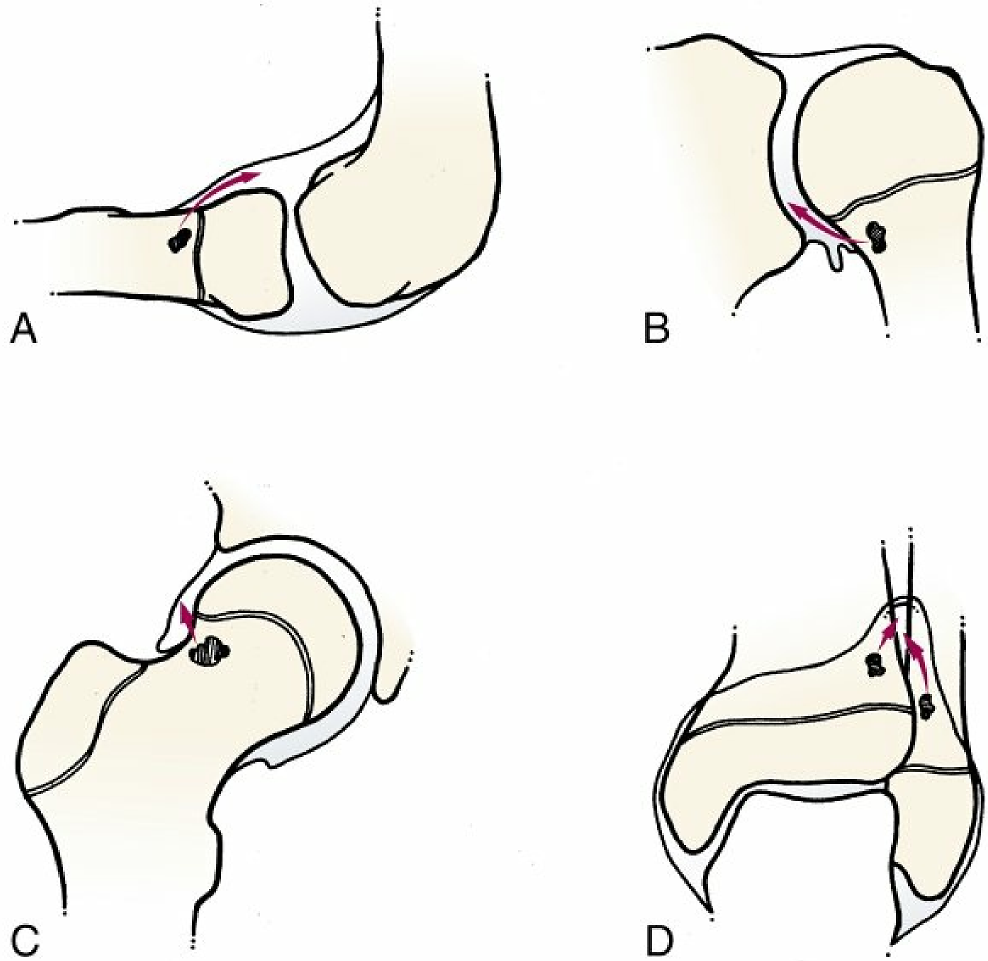


FIG. 3.13 Metaphyses of the proximal radius (A), proximal humerus (B), proximal femur (C), and distal tibia and fibula (D) are intraarticular. Osteomyelitis in these locations may decompress into the joint (*arrows*) and produce concomitant septic arthritis.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 27-23.

Table 3.6

Common Organisms in Septic Arthritis, by Age.

Age	Common Organisms	Empirical Antibiotics
<12 mo	*Staphylococcus* spp., group B streptococci	First-generation cephalosporin
6 mo–5 yr	*Staphylococcus* spp., *Haemophilus influenzae*	Second- or third-generation cephalosporin
5–12 yr	*Staphylococcus aureus*	First-generation cephalosporin
12–18 yr	*S. aureus, Neisseria gonorrhoeae*	Oxacillin/cephalosporin

- Infecting organisms vary with age (Table 3.6).
- Septic arthritis manifests as a much more acute process than

osteomyelitis.
  - Decreased ROM and severe pain with passive motion may be accompanied by systemic symptoms of infection.
- Diagnosis and radiographic findings
  - Radiographs may show a widened joint space or even dislocation.
  - Joint fluid aspirate shows a high WBC count (>50,000 cells/μL); glucose level may be 50 mg/dL lower than in serum; and in patients with gram-positive cocci or gram-negative rods, lactic acid level may be high.
  - Kocher criteria
    - WBC count higher than 12,000 cells/μL
    - ESR higher than 40 mm/hr
    - Inability to bear weight
    - Temperature greater than 101.5°F (38.6°C)
    - More than 90% of cases in which 3 of the 4 criteria are present are diagnosed with septic arthritis.
  - Ultrasonography can be helpful in identifying the presence of an effusion.
  - Lumbar puncture should be considered in a joint when sepsis is caused by *H. influenzae,* because of the increased incidence of meningitis.
  - Prognosis is usually good except in patients with delayed diagnosis.
  - *Neisseria gonorrhoeae* septic arthritis is usually preceded by migratory polyarthralgia, small red papules, and multiple joint involvement.
    - This organism typically elicits less WBC response (<50,000 cells/mm^3) and usually does not necessitate surgical drainage.
    - Large doses of penicillin are required to eliminate this organism.
- Treatment: aspiration should be followed by irrigation and débridement in major joints (especially in the hip; a culture of synovium is also recommended).

Knee and Leg

Leg

- **Genu varum (bowed legs) normally evolves naturally to genu valgum (knock-knees) by age 2.5 years, with a gradual transition to physiologic valgus angulation by age 4 years (** Fig. 3.14).
- **Physiologic genu varum (bowed legs)**
    - □ Normal in children younger than 2 years
    - □ Radiographs in physiologic bowing typically show flaring of the tibia and femur in a symmetric manner.
    - □ Pathologic conditions that can cause genu varum include osteogenesis imperfecta, osteochondromas, trauma, various dysplasias, and (most commonly) Blount disease.
- **Infantile Blount disease (age 0–4 years)**
    - □ Clinical features
        - Abnormal tibia vara
        - More common and usually affects both extremities
        - Classic presentation is in a child who is overweight and who begins walking before 1 year of age; disease is associated with internal tibial torsion.
    - □ Radiographic findings
        - Metaphyseal-diaphyseal angle abnormality and metaphyseal beaking
        - A Drennan metaphyseal-diaphyseal angle of more than 16 degrees is considered abnormal; the angle is formed between the metaphyseal beaks (demonstrated in Fig. 3.15).
        - Langenskiöld classification is based on degree of metaphyseal-epiphyseal changes (Fig. 3.16).
    - □ Treatment: based on age and correlated with stage of disease
        - Stage I or II: bracing in patients younger than 3 years
            - Better outcomes if unilateral or nonobese patients
            - Very difficult to ensure compliance
        - Stage II (if patient >3 years) and stage III: proximal osteotomy for tibia/fibula valgus angulation to overcorrect the deformity (because medial physeal growth abnormalities persist)
        - Stages IV to VI are complex, and multiple procedures may be required.
            - Epiphysiolysis is also needed for stages V and VI disease.
- **Adolescent Blount disease**

□ Clinical features

- Less severe than infantile forms and more often unilateral
- Epiphysis appears relatively normal and does not have the beaking seen in infantile forms
- Most characteristic radiographic finding is widening of the proximal medial physis
- Thought to be from mechanical overload in genetically susceptible patients (obese, African American)

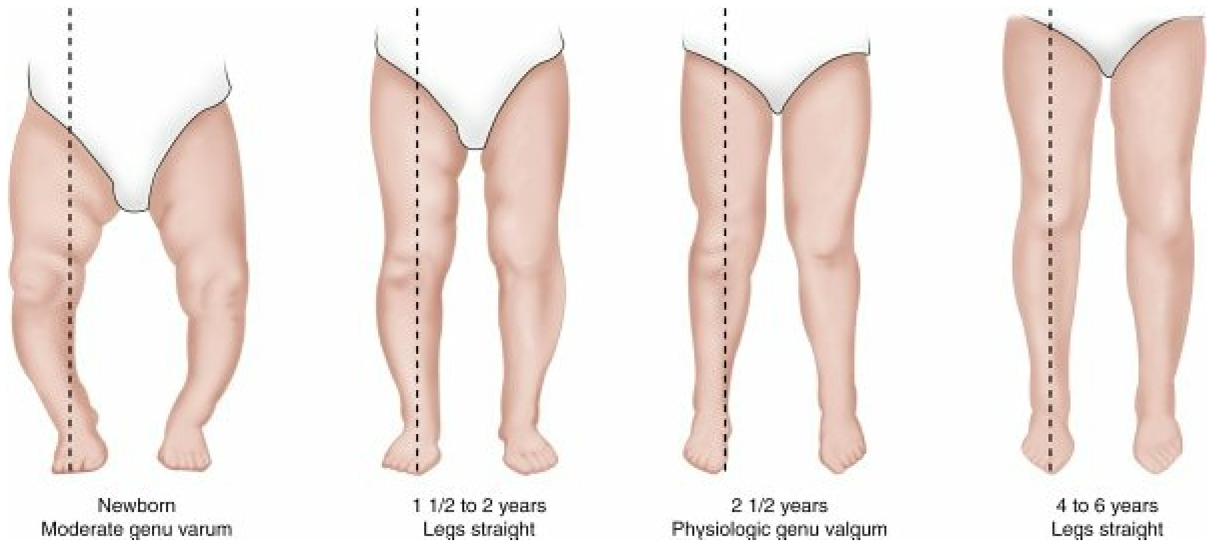


FIG. 3.14 In children with physiologic genu varum, the bowing begins to slowly improve at approximately 18 months of age and continues as the child grows. By age 3 to 4 years, the bowing has corrected and the legs typically have a normal appearance.

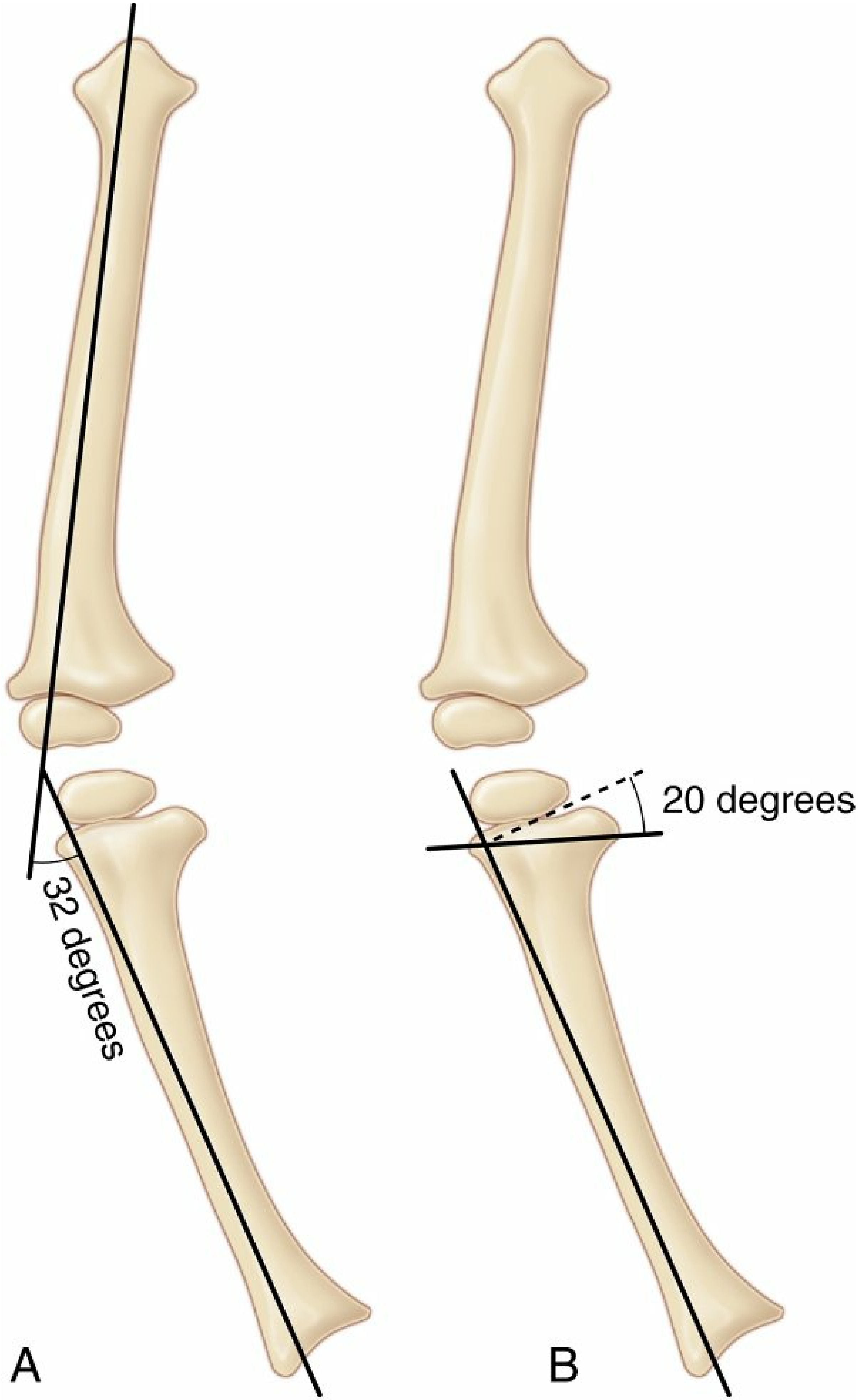


FIG. 3.15 Comparison of tibiofemoral angle with the Drennan metaphyseal-diaphyseal angle in tibia vara. (A) Lines are drawn along the longitudinal axes of the tibia and femur; the angle between the lines is the tibiofemoral angle (32 degrees).

(B) The metaphyseal-diaphyseal angle method is used to determine the metaphyseal-diaphyseal angle in the same extremity. A line is drawn perpendicular to the longitudinal axis of the tibia, and another is drawn through the two beaks of the metaphysis to determine the transverse axis of the tibial metaphysis. The metaphyseal-diaphyseal angle (20 degrees) is the angle bisected by the two lines.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders.

- □ Treatment
  - Initial treatment is proximal tibial and fibular lateral hemiepiphysiodesis when growth remains.
  - Larger plates are usually required because of incidence of plate failure.
  - If residual deformity exists or physes are closed proximally, tibial and fibular osteotomy is performed.
  - When significant LLD is present, the Ilizarov technique allows for deformity correction and lengthening.

▪ **Genu valgum (knock-knees)**
- □ Clinical features
  - Up to 15 degrees at the knee is common in children 2 to 6 years of age.
    - Maximum valgus between ages 3 and 4
    - Cases within this physiologic range do not require treatment.
  - Differential diagnosis includes renal osteodystrophy (most common cause if condition is bilateral), tumors (e.g., osteochondromas), infections (may stimulate proximal asymmetric tibial growth), and trauma.
- □ Treatment
  - Conservative treatment is ineffective in pathologic genu valgum.
  - Surgery at the site of the deformity should be considered in children older than 10 years with more than 10 cm between the medial malleoli or more than 15 degrees of valgus angulation.
  - Hemiepiphysiodesis (temporary or timed) of the medial side is effective for severe deformities if performed before the end of growth.

Tibial Bowing

Classified into three types (Table 3.7) on the basis of the apex of the curve.
- □ Posteromedial tibial bowing
  - Physiologic—thought to be due to intrauterine positioning. Posteromedial (PM) bowing is *p*robably *m*ild.

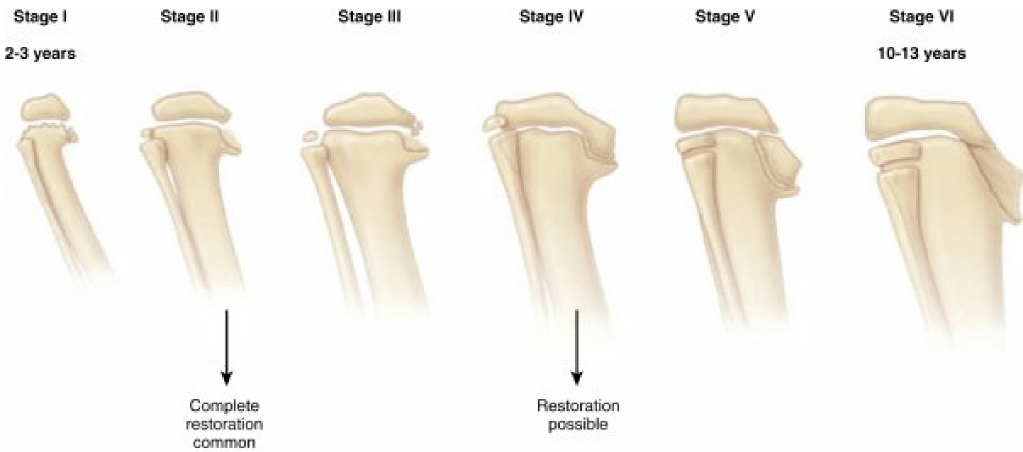


FIG. 3.16 Langenskiöld classification of infantile tibia vara in six progressive stages with increasing age.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders, Fig. 22-8.

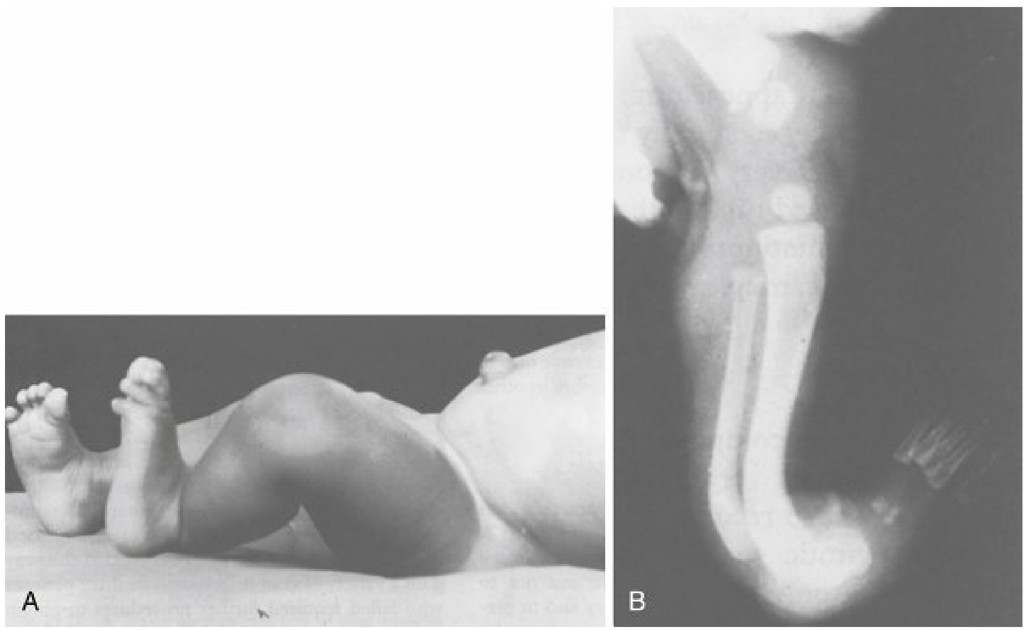


FIG. 3.17 Posterior medial angulation of the tibia. (A) Clinical photograph of an affected 5-month-old. (B) Lateral radiograph of the same patient. The appearance is dramatic, but these deformities are best treated with stretching and splinting into equinus position.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders, Figs. 22-46 and 22-47.

Table 3.7

Tibial Bowing.

Type	Cause	Treatment
Posteromedial	Physiologic/intrauterine positioning	Observation; monitoring for significant limb length discrepancy
Anteromedial	Fibular hemimelia	Bracing vs. amputation for severe deformities
Anterolateral	Congenital pseudarthrosis	Total-contact brace, intramedullary fixation, vascularized bone graft, or amputation of leg and foot

- Usually of the middle and distal thirds of the tibia (Fig. 3.17)
- Commonly associated with LLD, calcaneovalgus feet, and tight anterior structures
- Spontaneous correction is the rule, but patient should be monitored to evaluate LLD.
    - Most common sequela of posteromedial bowing is an average LLD of 3 to 4 cm, which may necessitate an age-appropriate epiphysiodesis of the long limb.
- Tibial osteotomies not indicated

□ Anteromedial tibial bowing
- Commonly caused by fibular hemimelia (a congenital longitudinal deficiency of the fibula, which is the most common long-bone deficiency)
- In addition to anteromedial bowing, fibular hemimelia is associated with:
    - Ankle instability due to ball-and-socket joint
    - Equinovalgus foot (with or without lateral rays)
    - Tarsal coalition
    - Femoral shortening (coxa vara, PFFD)
    - ACL insufficiency
- Significant LLD often results from this disorder.
- Classically, skin dimpling is seen over the tibia.
- The fibular deficiency can be intercalary, which involves the whole bone (fibula is absent), or terminal.
- Fibular hemimelia is linked to the sonic hedgehog gene.
- Radiographic findings
    - Complete or partial absence of fibula, a ball-and-socket ankle joint (secondary to tarsal coalitions),

and deficient lateral rays in the foot

- Treatment
  - Varies from a simple shoe lift or bracing to Syme amputation
  - Decisions are based on the degree of foot deformity, the number of rays, and the extent of shortening of the limb.
  - Amputation is usually performed in the patient with a severely shortened limb or a stiff, nonfunctional foot, at about 10 months of age.
  - For less severe cases, reconstructive procedures, including lengthening, may be an alternative.
    - Such a procedure should include resection of the fibular remnant to avoid future foot problems.

□ Anterolateral tibial bowing

- Clinical features
  - Congenital pseudarthrosis of the tibia is the most common cause of anterolateral bowing. Rarely is anterolateral (AL) bowing physiologic, so one should *a*lways *l*ook.
  - Often accompanied by neurofibromatosis
    - About 50% of patients with anterolateral tibial bowing have neurofibromatosis.
    - Only 10% of patients with neurofibromatosis have tibial bowing.
- Treatment
  - Initial management/workup should include genetic consultation to check for possibility of neurofibromatosis.
  - Initial treatment includes a total-contact brace to protect the patient from fractures.
  - Intramedullary fixation with excision of hamartomatous tissue and autogenous bone grafting are options for nonhealing fractures.
  - A vascularized fibular graft or the Ilizarov method should also be considered if bracing fails.
  - Osteotomies to correct the anterolateral bowing are contraindicated.
  - Amputation (Syme) and prosthetic fitting are indicated after failure of two or three surgical

attempts or as primary treatment.

- Syme amputation is preferred to below-knee amputation in these patients because the soft tissue available at the heel pad is superior to that in the calf as a weight-bearing stump.
- The soft tissue in the calf in these patients is often scarred and atrophic.

- **Other lower limb deficiencies**
  - Tibial hemimelia
    - Congenital longitudinal deficiency of the tibia
    - The only long-bone deficiency with a known inheritance pattern (autosomal dominant)
    - Much less common than fibular hemimelia and often associated with other bone abnormalities (especially a lobster-claw hand)
    - Also associated with insufficient extensor mechanism, clubfoot deformity
    - Clinically, the extremity is shortened and bowed anterolaterally with a prominent fibular head and an equinovarus foot, with the sole of the foot facing the perineum.
    - Treatment for severe deformity with total absence of the tibia is a knee disarticulation.
      - Fibular transposition (Brown) has been unsuccessful, especially when quadriceps function and the proximal tibia are absent.
      - When the proximal tibia and quadriceps functions are present, the fibula can be transposed to the residual tibia to create a functional below-knee amputation.

Osteochondritis Dissecans (See Chapter 4, Sports Medicine)

- **Clinical features**
  - An intraarticular condition common in children 10 to 15 years of age that can affect many joints, especially the knee and elbow (capitellum)
  - Lesion thought to be secondary to trauma, ischemia, or abnormal epiphyseal ossification

- Posterolateral portion of medial femoral condyle is most frequently involved
- Symptoms include activity-related pain, localized tenderness, stiffness, and swelling, with or without mechanical symptoms.
- Differential diagnosis includes anomalous ossification centers.

- **Radiographic studies**
  - Tunnel (notch) view to evaluate condyles
  - MRI can determine whether there is synovial fluid behind the lesion (the worst prognosis for nonoperative healing).
- **Treatment**
  - Nonoperative
    - Bracing and restricted weight bearing if the potential for growth remains significant (highest healing rates with open physes)
  - Operative
    - Surgical therapy is reserved for the adolescent with minimal growth left or a loose lesion.
      - Operative treatment includes drilling with multiple holes, fixation of large fragments, and bone grafting of large lesions.
    - Osteochondritis dissecans is commonly treated arthroscopically.
    - Poor prognosis is associated with lesions in the lateral femoral condyle and patella.

Osgood-Schlatter Disease (See Chapter 4, Sports Medicine)

- **Clinical features**
  - An osteochondrosis, or fatigue failure, of the tibial tubercle apophysis caused by stress from the extensor mechanism in a growing child (tibial tubercle apophysitis)
  - Pain over tibial tubercle, especially with direct pressure
  - Seen in active children
- **Radiographic findings**
  - Irregularity and fragmentation of the tibial tubercle
- **Treatment**
  - Usually self-limiting; activity modification may be required.
  - Ice and quadriceps stretching also alleviate symptoms.
  - Condition usually does not resolve until growth has halted.
  - Late excision of separate ossicles is rarely needed.

Discoid Meniscus (See Chapter 4, Sports Medicine)

- **Clinical features**
  - Abnormal development of the lateral meniscus leads to formation of a disc-shaped (or hypertrophic) meniscus rather than the normal crescent-shaped meniscus.
  - Symptoms include mechanical block and pain with catching and palpable click at knee.
- **Radiographic findings**
  - Widening of the cartilage space on the affected side (up to 11 mm)
  - Squaring of condyles may be visible.
  - MRI yields three successive sagittal images with the meniscal body present.
- **Classification**
  - Complete covering of tibial plateau
  - Incomplete covering of tibial plateau
  - Wrisberg variant—lacks posterior meniscotibial attachment; unstable
- **Treatment**
  - If symptomatic and torn, the discoid meniscus can be arthroscopically débrided and then saucerized so it resembles a normal-appearing meniscus.
  - If not torn, it should be observed.
  - If detached (Wrisberg variant), meniscus should be repaired.

Congenital Dislocation of the Knee

- **Clinical features**
  - Spectrum of disease from rigid dislocation to mild contractures
  - Classic position is knee hyperextension
  - Often occurs in patients with myelodysplasia, arthrogryposis, Larsen syndrome
  - Structural components
    - Quadriceps contracture
    - Tight collateral ligaments and anterior subluxation of hamstring tendons
- **Associations**
  - Developmental hip dysplasia (50% of patients have concomitant DDH)
  - Clubfoot
  - Metatarsus adductus
- **Treatment**
  - Nonoperative
    - Reduction with manipulation and serial casting
    - Weekly casting
    - Knees should be reduced and cast before being treated with

a Pavlik harness for DDH.

- □ Operative
  - Performed if failure to achieve 30 degrees of knee flexion after 3 months of casting
  - Goal is to achieve 90 degrees of knee flexion.
  - Quadriceps lengthening (V-Y-plasty or Z-plasty)
  - Hamstring tendon transposition posteriorly
  - Collateral ligament mobilization

Foot

Fig 3.18 depicts common childhood foot disorders.

Clubfoot (Congenital Talipes Equinovarus)

- **Clinical features**
  - **CAVE—*c*avus, *a*dduction of forefoot, *v*arus of hindfoot, *e*quinus**
  - **Talar neck deformity (medial and plantar deviation) with medial rotation of calcaneus and medial displacement of navicular and cuboid**
  - Shortening or contraction of muscles (intrinsic muscles, Achilles tendon, tibialis posterior, flexor hallucis longus, flexor digitorum longus), joint capsules, ligaments, and fascia, which leads to the associated deformities
  - **Associated with absence of or diminutive anterior tibial artery**
- **Epidemiology**
  - Boys affected twice as often as girls
  - 50% of cases are bilateral
- **Causes**
  - Majority of cases idiopathic though genetic cause strongly suggested
    - **PITX1-TBX4 transcriptional pathway**
  - Can be associated with arthrogryposis, myelomeningocele, hand anomalies (Streeter dysplasia), diastrophic dwarfism, prune-belly syndrome, tibial hemimelia, and other neuromuscular and syndromic conditions
- **Radiographic studies and findings**
  - Minimal ossification of foot in the infant; thus radiographs rarely used
  - Parallelism of calcaneus and talus seen on radiographs
  - On the dorsiflexion lateral view (Turco) the talocalcaneal angle is less than normal (35 degrees).
  - On the AP view the talocalcaneal (Kite) angle is also less than normal (20–40 degrees). The talus–first metatarsal angle is negative (normally 0–20 degrees) (Fig 3.19).
- **Treatment**
  - Ponseti casting
    - First-line treatment
    - Serial weekly manipulation and casting using long-leg plaster casts
    - **Sequence of correction (CAVE): *c*avus, *a*dductus, *v*arus, *e*quinus**
    - First cast corrects cavus by supinating the forefoot and

dorsiflexing the first ray.
        - Subsequent casts correct adduction and varus using lateral pressure on the distal talar head as a fulcrum.
        - Most patients (90%) undergo percutaneous Achilles lengthening at the end of casting to address hindfoot equinus.
        - Last cast placed in 70 degrees of abduction.
        - Post-casting bracing with foot-abduction brace is imperative.
            - Typically used full time for 3 months, followed by use during naps and at night for 3 years.
            - **No impairment in athletic ability after successful treatment**
        - Complications
            - **Recurrence or undercorrection**
                - **Associated with brace noncompliance**
                - **Treated with recasting initially**
            - Rocker-bottom deformity: from an attempt to dorsiflex hindfoot before varus corrected
            - Flat-top talus: aggressive dorsiflexion causes flattening of talar dome
- **Operative treatment**
    - Posteromedial release
        - Reserved for resistant or refractory clubfeet (only 5% of presenting idiopathic clubfeet)
        - Tendon lengthening; subtalar, tibiotalar, and talonavicular release; and realignment
        - Posterior tibial artery must be carefully protected; dorsalis pedis artery often insufficient
        - In older patients (3–10 years), a medial opening-wedge or lateral column–shortening osteotomy or a cuboidal decancellation is used to treat adductus.
    - Triple arthrodesis for children presenting late
        - Contraindicated in patients with insensate feet; causes rigidity of the foot, which may lead to ulceration
    - Dorsal bunion can occur after clubfoot surgery.
        - Strong tibialis anterior and flexor hallucis brevis/abductor hallucis contribute
        - May be iatrogenic if peroneus longus divided
        - Treated with capsulotomy, flexor hallucis longus lengthening, and transfer of the flexor hallucis brevis to become a metatarsophalangeal extensor.
    - Dynamic supination
        - Common deformity after clubfoot treatment; occurs in up to

15% to 20% of patients

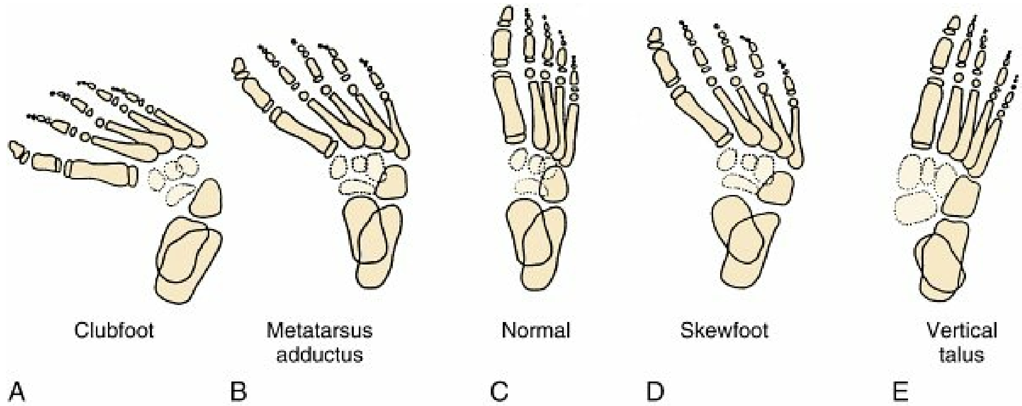


FIG. 3.18 Skeletal illustrations of common childhood foot disorders: anteroposterior view. (A) Varus position of hindfoot and adducted forefoot in clubfoot. (B) Normal hindfoot and adducted forefoot in metatarsus adductus. (C) Normal foot. (D) Valgus hindfoot (with increased talocalcaneal angle) and adducted forefoot in skewfoot. (E) Increased talocalcaneal angle and lateral deviation of the calcaneus in congenital vertical talus.

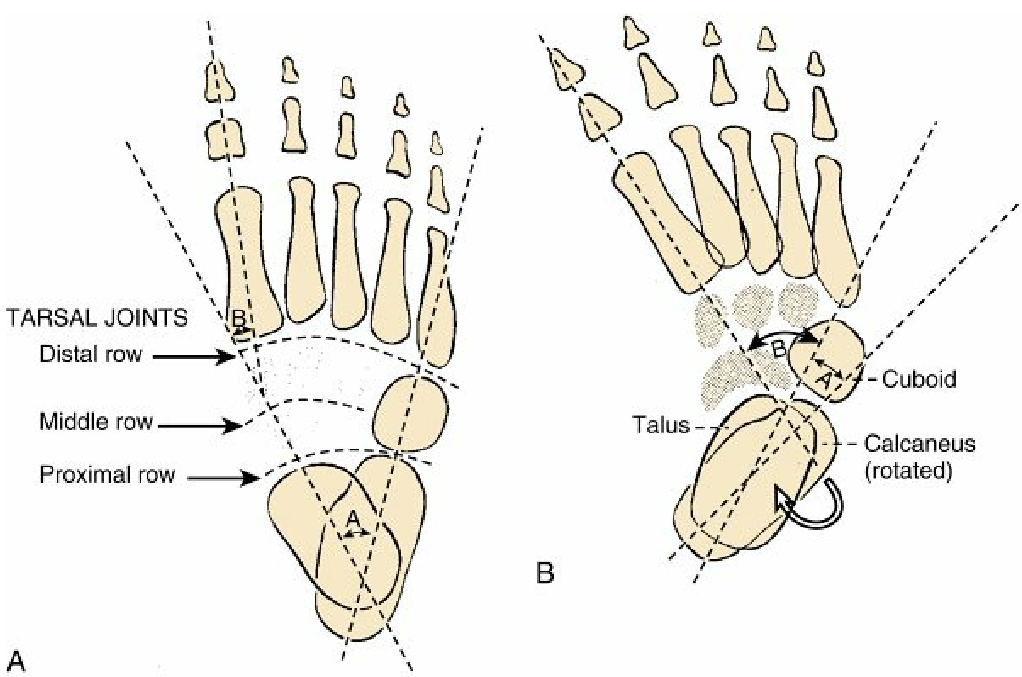


FIG. 3.19 Skeletal illustrations of the radiographic evaluation of the foot. (A) Normal foot. (B) Clubfoot. Note the "parallelism" of the talus and calcaneus, with a talocalcaneal angle (angle *A*) of less than 20 degrees and a negative talus–first metatarsal angle (angle *B*) on the clubfoot side.
From Simons GW: Analytical radiology of club feet, *J Bone Joint Surg Br* 59:485–489, 1977.

- Overpull of the anterior tibialis, with a weak peroneus longus or undercorrection of forefoot supination
- Treated with transfer of the tibialis anterior laterally

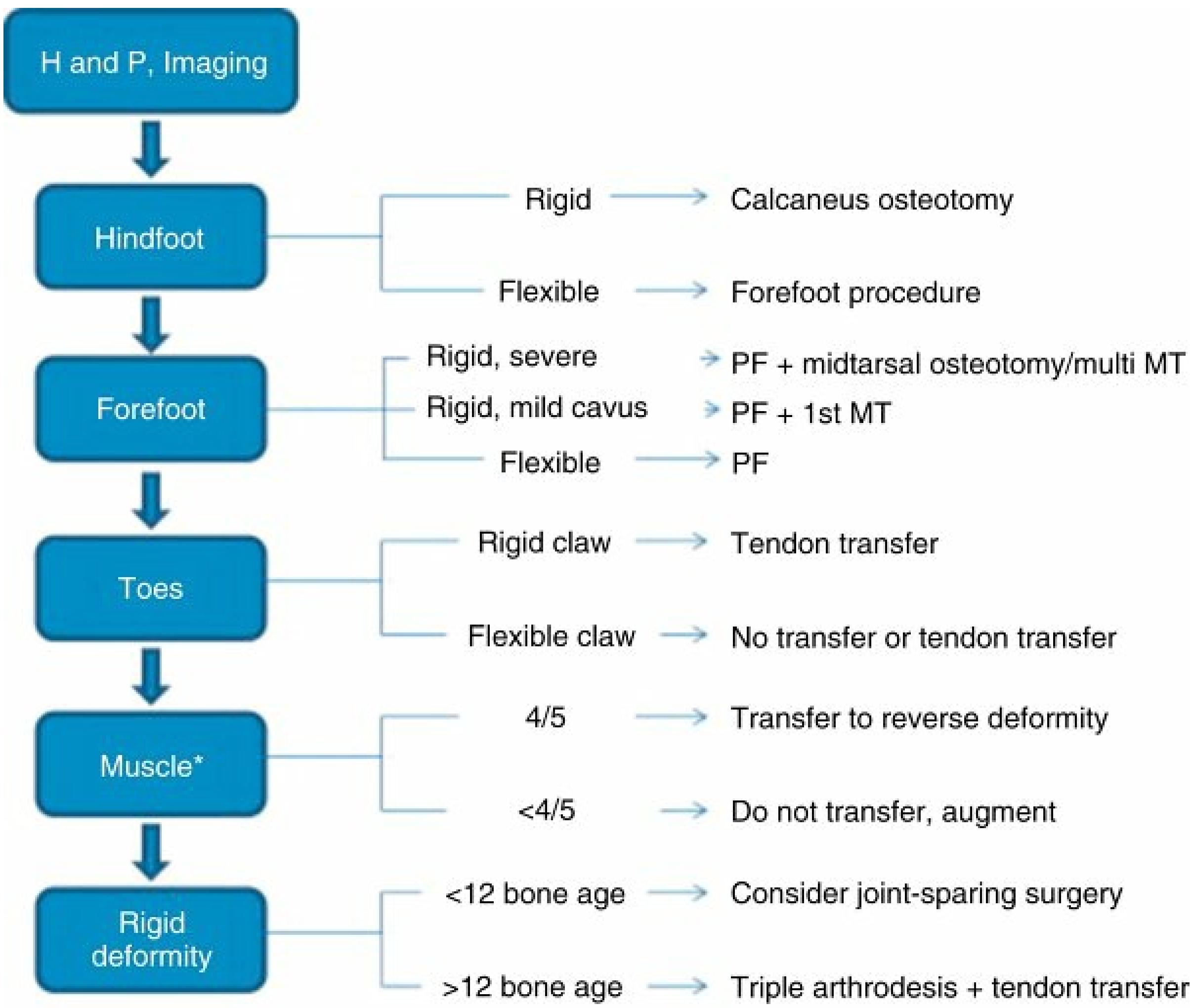
Metatarsus Adductus and Skewfoot

- **Clinical features (see** Fig. 3.18)
  - Forefoot adduction with the hindfoot in normal alignment
  - Skewfoot (Also called *Z-foot* or *serpentine foot*):
    - Adductus with hindfoot valgus and lateral subluxation of the navicular on the talus
    - More significant and rigid deformities than simple metatarsus adductus
  - Grading
    - Based on the heel bisector line (Bleck method)
    - Normally, the heel bisector should align with the web space between the second and third toes.
- **Treatment**
  - If peroneal muscle stimulation corrects metatarsus adductus, the condition usually responds to stretching.
  - Otherwise, manipulation and off-the-shelf orthoses or serial casting may be required.
  - Surgical for refractory cases in older children
    - Abductor hallucis longus recession (for an atavistic first toe)
    - Osteotomies include lateral column shortening osteotomies of the calcaneus and cuboid and open-wedge osteotomies of the medial cuneiform.
    - Calcaneal osteotomy for hindfoot valgus in skewfoot

Pes Cavus (Cavus Foot)

- **Cavus deformity of the foot (elevated longitudinal arch) with calcaneus or varus hindfoot**
- **Up to 67% of cases due to neurologic disorder**
  - **Charcot-Marie-Tooth (CMT) disease (most common): defect in gene responsible for peripheral myelin protein 22 *(PMP22)***
  - Also polio, cerebral palsy, Friedreich ataxia, myelomeningocele, and spinal cord injury, tumor, or abnormality

FIG. 3.20 (A) Varus foot in adolescent boy with cerebral palsy. (B) Hindfoot varus is present, and there is a callus beneath his fifth metatarsal base. (C) The hindfoot varus is passively correctable to neutral. (D) The Coleman block test shows partial correction of the varus. From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 23-97.



*Muscle strength evaluation is needed to determine which transfer is indicated.

FIG. 3.21 Algorithm for surgical decision making in the treatment of cavovarus feet. Each section of the foot is considered separately, and appropriate treatments are planned depending on clinical and radiographic findings. *MT,* Metatarsal osteotomy; *PF,* plantar fascia release. From Lee MC: Pediatric issues with cavovarus foot deformities, *Foot Ankle Clin* 13:199–219, 2008.

- **Muscle imbalance**
  - **CMT disease: strong peroneus longus and posterior tibialis overpower tibialis anterior and peroneus brevis, resulting in hindfoot varus and a depressed first metatarsal head.**
  - **In addition, recruitment of the extensor hallucis longus for dorsiflexion of the foot over time causes shortening of plantar fascia and resultant cavus.**
- **Evaluation**
  - **Full neurologic examination**
  - **MRI of the neuraxis (especially for unilateral cavus foot)**
  - **Consider genetics/neurology referral (DNA testing for CMT disease)**
  - **The lateral block (Coleman) test is used to assess hindfoot flexibility of the cavovarus foot (a flexible hindfoot corrects to neutral with a lift placed under the lateral aspect of the foot) (Fig. 3.20).**
- **Treatment (** Fig. 3.21)
  - Nonoperative management rarely successful once deformity has developed
  - Operative management
    - Options include soft tissue procedures (plantar fascia release, tendon transfer), osteotomies, and triple arthrodesis.
    - Generally, if hindfoot is fixed in varus (Coleman block test) calcaneal osteotomy should also be performed.

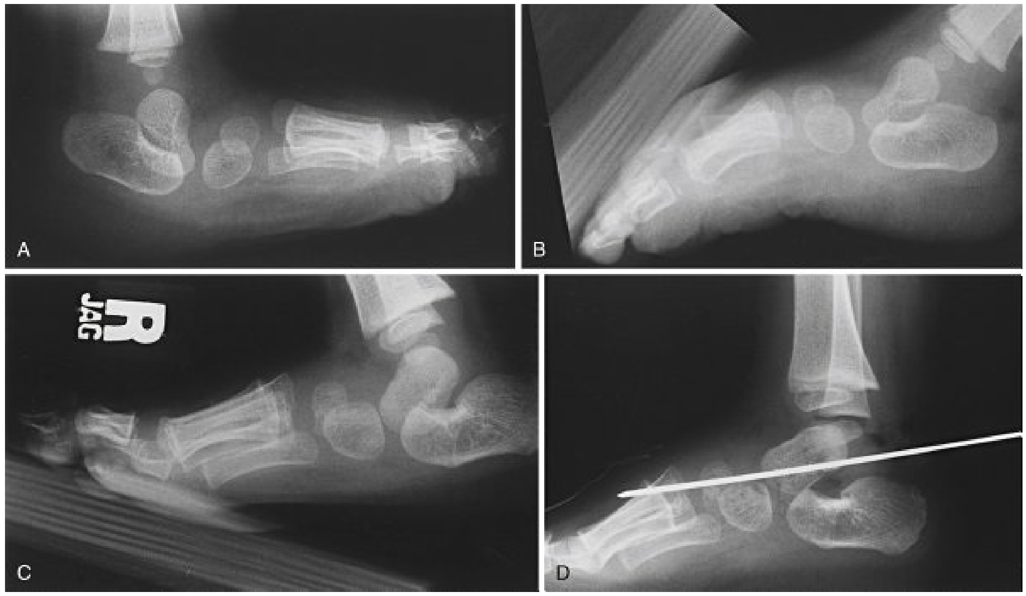


FIG. 3.22 Congenital vertical talus. (A) Lateral radiograph showing the increased talocalcaneal angle, equinus of the calcaneus, and dorsal dislocation of the navicular. The bone ossified over the talus is the medial cuneiform; it indicates the position of the navicular, which is not yet ossified in this child. (B) Plantar-flexion lateral radiograph. The navicular is still dorsally displaced over the talar neck. (C) Dorsiflexion lateral radiograph. The hindfoot remains in neutral position and lacks true dorsiflexion. (D) Lateral radiograph after open reduction of the dislocated navicular and soft tissue release.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 23-74.

- Triple arthrodesis has been used for rigid deformity in skeletally mature patients.

Congenital Vertical Talus (Congenital Convex Pes Valgus)

- **Clinical features**
  - □ **Irreducible dorsal dislocation of the navicular on the talus**
  - □ Rocker-bottom or Persian slipper foot:
    - Fixed equinovalgus hindfoot deformity and convex sole
    - Talar head is prominent medially.
    - Abducted and dorsiflexed forefoot
  - □ Patients may demonstrate a peg-leg gait (awkward gait with limited forefoot push-off).
  - □ Often associated with neuromuscular and syndromic conditions: myelomeningocele, arthrogryposis, prune-belly syndrome, spinal muscular atrophy, neurofibromatosis, trisomies
  - □ Less severe form is termed *oblique talus.*
    - Navicular reduced with plantar flexion
    - Treated with observation and occasionally talonavicular pinning and Achilles lengthening
- **Radiographic findings (** Fig. 3.22)

- Lateral radiograph
  - Talus appears nearly vertical, calcaneus is in equinus, navicular is dorsally dislocated, and talocalcaneal angle is increased.
  - Position of navicular (not ossified in children <3) can be inferred from examination of first metatarsal and medial cuneiform
  - **Navicular does not reduce on forced plantar-flexion lateral view.**
- AP radiograph
  - Increased talocalcaneal angle (normal, 20–40 degrees)

- **Treatment**
  - **Serial manipulation and casting followed by limited surgery consisting of percutaneous Achilles tenotomy and minimal talonavicular capsulotomies and pin fixation**
  - If casting fails, surgery at 6 to 12 months of age
    - Soft tissue release with lengthening of the extensor tendons, peroneal muscles, and Achilles tendon and reduction of the talonavicular joint with reconstruction of the spring ligament

Tarsal Coalitions (Fig. 3.23)

- **A disorder of mesenchymal segmentation that leads to fusion of tarsal bones and rigid flatfoot**
- **Talocalcaneal and calcaneonavicular most common**
- **Can be fibrous, cartilaginous, or osseous**
- **Can be associated with autosomal dominant craniosynostosis syndromes (*FGFR-1*, *FGFR-2*, and *FGFR-3* mutations)**
- **Symptoms include calf and sinus tarsi pain caused by peroneal spasticity, flatfoot, multiple ankle sprains**
- **Limited subtalar motion on examination**
- **Calcaneonavicular coalition is most common in children 9–12 years of age, and talocalcaneal coalition more common in children 12–14 years of age.**
- **Radiographic findings**

FIG. 3.23 Tarsal coalition. (A) Oblique radiograph demonstrating a calcaneonavicular coalition. (B) Harris view showing irregular surfaces and narrowing of the medial facet, suggestive of a talocalcaneal coalition. (C) CT scan showing a large bar across the medial facet of the subtalar joint, which confirms the subtalar coalition.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders, Fig. 23-83.

  - □ Lateral radiographs may demonstrate an elongated anterior process of the calcaneus (anteater sign).
  - □ Talocalcaneal coalitions may demonstrate talar beaking on the lateral view (does not denote degenerative joint disease) or an irregular middle facet on the Harris axial view.
  - □ **The best study for identifying and measuring the cross-sectional area of a talocalcaneal coalition is a CT scan, which can also reveal multiple coalitions (20% of cases).**
- **Treatment**
  - □ Initial treatment involves immobilization (casting) or orthoses.
  - □ Surgery

- Calcaneonavicular coalitions
    - Resection with interposition of muscle (extensor digitorum brevis) or fat
- **Talocalcaneal coalitions**
    - **For those involving less than 50% of the middle facet: resection and interposition**
    - **For those involving more than 50% of the middle facet: subtalar arthrodesis preferred**
- In advanced cases, after failed resections, and in patients with multiple coalitions, triple arthrodesis is often required.

Calcaneovalgus Foot

- **Clinical features**
    - Neonatal condition associated with intrauterine positioning
    - More common in females and firstborn children
    - **Dorsiflexed (calcaneus) hindfoot**
        - **In contrast to congenital vertical talus, in which hindfoot is plantar flexed (equinus)**
    - **Associated with posteromedial bowing of tibia and LLD**
    - Also seen with myelomeningocele at the L5 level as a result of muscular imbalance between foot dorsiflexors/evertors (L4 and L5 roots) and plantar flexors/inverters (S1 and S2 roots)
- **Treatment**
    - Passive stretching and observation

Juvenile Bunions

- **Clinical features**
    - Often bilateral and familial
    - Less common and usually less severe than adult form
    - May be associated with ligamentous laxity, pes planus, hypermobile first ray, and metatarsus primus varus
    - Usually occurs in adolescent girls
- **Treatment**
    - Nonoperative: modification of shoes with a wide toe box and arch supports
    - Surgical
        - **Should be avoided because recurrence is common in growing patients (>50%)**

Kohler Disease

- **Clinical features**
  - Osteonecrosis of the tarsal navicular bone
  - Manifests at the age of about 5 years
  - **Pain is the typical presenting complaint.**
  - **Radiographs show sclerosis and flattening of the navicular bone.**
- **Treatment**
  - **Resolves spontaneously with decreased activity, with or without immobilization**

Flexible Pes Planus

- **Clinical features**
  - Foot is flat only with standing and not with toe walking or foot hanging.
  - If arch does not reconstitute upon standing, tarsal coalition should be considered.
  - This condition is frequently familial and almost always bilateral.
  - Commonly associated with mild lower extremity rotational problems and ligamentous laxity
  - Symptoms can include an aching midfoot and pretibial pain.
- **Radiographic findings**
  - Lateral radiograph: broken Meary angle with plantar-directed sag, hindfoot equinus
  - AP radiograph: talar head uncoverage
- **Treatment**
  - **Asymptomatic patients should be monitored with observation.**
  - **Symptomatic patients: arch supports and shoes with stiffer soles may offer pain relief but do not result in deformity correction.**
  - Surgical treatment
    - May be indicated in severe cases with failure of extensive nonoperative treatment
    - Calcaneal lengthening osteotomy with or without medial imbrication (Evans procedure)
      - **Calcaneocuboid subluxation must be avoided during lengthening**
    - 3C osteotomy: sliding calcaneal osteotomy, open-wedge cuboid osteotomy, and a plantar flexion closed-wedge osteotomy of the medial cuneiform

Idiopathic Toe Walking

- **Clinical features**
  - Persistent toe walking without identifiable etiology in patients older than 2 years
  - **Imperative that other etiologies (tethered cord, CMT disease, CP, muscular dystrophy, autism, LLD) be excluded**
  - Contracture of the Achilles tendon may be present.
- **Treatment**
  - Stretching and night splints versus serial casting
  - Surgical lengthening if nonoperative treatment fails
    - **Appropriate level determined using Silfverskiöld test**
      - Dorsiflexion <20 degrees short of neutral with knee extension but dorsiflexion past neutral with knee flexion = gastrocnemius contracture
        - Treatment with gastrocnemius lengthening or recession (Strayer or Vulpius)
      - Dorsiflexion <20 degrees short of neutral with knee extension and flexion = gastrocnemius and soleus contracture
        - Treatment with Achilles lengthening

Accessory Navicular

- **Clinical features**
  - Normal variant that is present in up to 12% of the general population
  - Posterior tibial tendon typically inserts into accessory navicular
  - Commonly associated with flatfoot
  - Symptoms usually include medial arch pain with overuse and tenderness over prominent os.
  - External oblique (supination oblique) radiograph helpful
- **Treatment**
  - Most cases resolve spontaneously and can be treated with activity restriction and shoe modification, a UCBL (University of California at Berkeley Laboratory) orthosis to control hindfoot valgus, or a course of casting.
  - If nonoperative treatment fails, the accessory bone can be excised with repair and advancement of the posterior tibial tendon (Kidner procedure).

Ball-and-Socket Ankle

- **Abnormal formation with a spherical talus (ball) and a cup-shaped tibiofibular**

articulation (socket)

- **Usually necessitates no treatment but should be recognized because of high association with tarsal coalition (50% of cases), absence of lateral rays (50% of cases), fibular deficiency, and LLD**

Congenital Toe Disorders

- **Syndactyly**
  - Fusion of the soft tissues (simple) and sometimes bones (complex) of the toes
  - Simple syndactyly usually does not require treatment; complex syndactyly in the foot is treated in the same way as in the hand.
- **Polydactyly (extra digits)**
  - May be autosomal dominant and usually involves the lateral ray in patients with a positive family history
  - The AP axis is controlled by a zone of polarizing activity (ZPA) in the posterior aspect of the apical ectodermal ridge
  - Treatment includes ablation of the extra digit and any bony protrusion of the common metatarsal (the border digit is typically excised).
    - Procedure usually done at ages 9 to 12 months, but some rudimentary digits can be ligated in the newborn nursery
- **Oligodactyly**
  - Congenital absence of the toes
  - May be associated with more proximal agenesis (i.e., fibular hemimelia) and tarsal coalition
  - Usually necessitates no treatment
- **Atavistic great toe (congenital hallux varus)**
  - Deformity involving great-toe adduction that is often associated with polydactyly
  - Must be differentiated from metatarsus adductus
  - Deformity usually occurs at metatarsophalangeal joint and includes a short, thick first metatarsal and a firm band (abductor hallucis longus muscle) that may be responsible for the disorder.
  - Surgery sometimes required and includes release of abductor hallucis longus muscle
- **Overlapping toe**
  - Fifth toe overlaps fourth (usually bilaterally) and may cause problems with footwear.
  - Initial treatment includes passive stretching and buddy taping, but usually the overlapping resolves with time.
  - Surgical options include tenotomy, dorsal capsulotomy, and syndactylization to the fourth toe (McFarland procedure).

- **Underlapping toe (congenital curly toe)**
  - Usually involves the lateral three toes and is rarely symptomatic
  - Surgery (flexor tenotomies) occasionally indicated

Adolescent Idiopathic Scoliosis

- **Onset after 10 years of age**
- **Likely multifactorial cause**
  - May be related to a hormonal, brainstem, or proprioception disorder
  - Most patients have a positive family history but variable expression.
- **Diagnosis**
  - School screening mandated by several states
  - Rotational deformities noted on the Adams forward bend test (assessed with scoliometer)
    - Threshold level of 7 degrees is thought to be an acceptable compromise between overreferral and a false-negative diagnosis and correlates with a 20-degree coronal curve.
  - Shoulder elevation, waistline asymmetry, trunk shift, LLD, rib rotational deformity (rib hump), and prominent scapula
  - Neurologic findings should be normal.
    - **Abnormal findings, especially asymmetric abdominal reflexes, should prompt an MRI study.**
    - Cavus feet should also prompt MRI to assess for intraspinal abnormalities.
- **Imaging studies**
  - Standing full-length posteroanterior radiograph
    - Cobb method used to measure magnitude of curves (Fig. 3.24)
    - Assessment for Risser sign (ossification of the iliac crest apophysis)
    - Stable vertebra: most proximal vertebra that is the most closely bisected by the center sacral vertical line (CSVL)
    - End vertebrae: the most tilted vertebrae
    - Neutral vertebra: the vertebra that has no rotation in the axial plane
  - Lateral radiograph
    - Hypokyphosis of thoracic spine and hypolordosis of lumbar spine typically seen
    - If hyperkyphosis of the thoracic spine is observed, MRI should be considered.
    - Spondylolisthesis at the level of L5–S1 should be sought.
  - **MRI indications:**
    - **Left thoracic curves**
    - **Painful or rapidly progressing scoliosis**

- **Apical kyphosis of the thoracic curve**
- **Juvenile-onset scoliosis (onset before age 10 years)**
- **Neurologic signs or symptoms**
- **Congenital abnormalities**

- **Classification**
  - Lenke classification: six curve types, three lumbar modifiers, three thoracic sagittal modifiers (Fig. 3.25)
  - Helps determine fusion levels during surgery
  - Structural curves: (1) the largest curve, (2) additional curves that fail to bend to less than 25 degrees
  - Lumbar modifier: based on position of the CSVL in relation to the apical vertebra of the thoracolumbar/lumbar curve

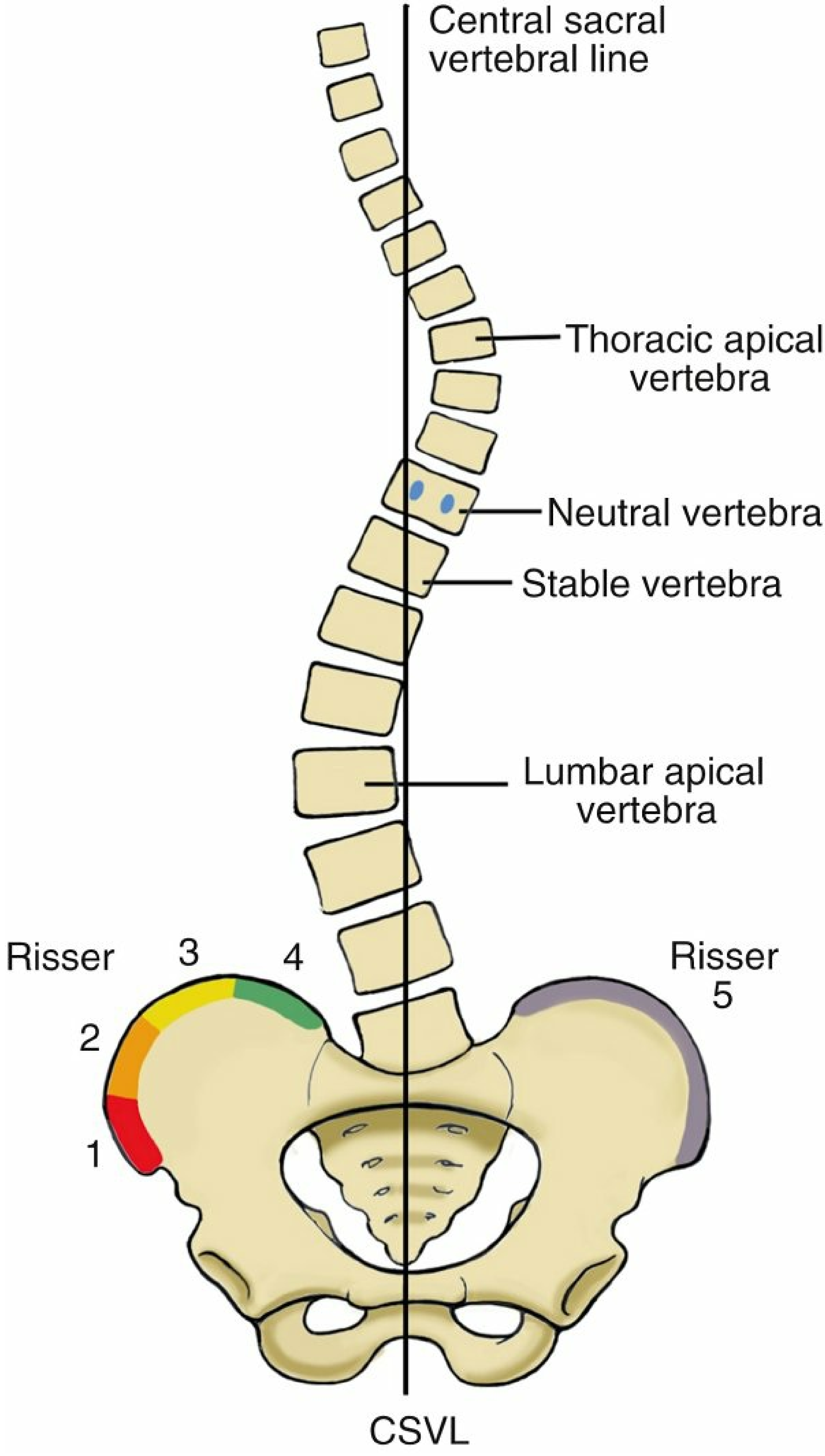
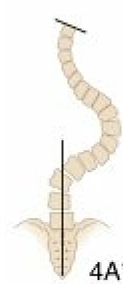
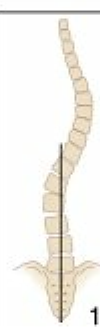
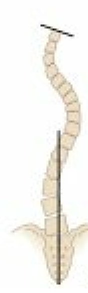
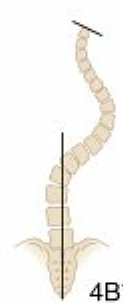

Central sacral
vertebral line
Thoracic apical
vertebra
Neutral vertebra
Stable vertebra
Lumbar apical
vertebra
Risser
3
4
2
1
Risser
5
CSVL

FIG. 3.24 Measurements for idiopathic scoliosis: Center sacral vertical line, apical vertebrae, stable vertebrae, neutral vertebrae, and grading of Risser sign (1 to 5).

Lumbar spine modifier	Curve type (1–6)					
	Type 1 (main thoracic)	Type 2 (double thoracic)	Type 3 (double major)	Type 4 (triple major)	Type 5 (TL/L)	Type 6 (TL/L-MT)
A (No to minimal curve)	 1A*	 2A*	 3A*	 4A*		
B (Moderate curve)	 1B*	 2B*	 3B*	 4B*		

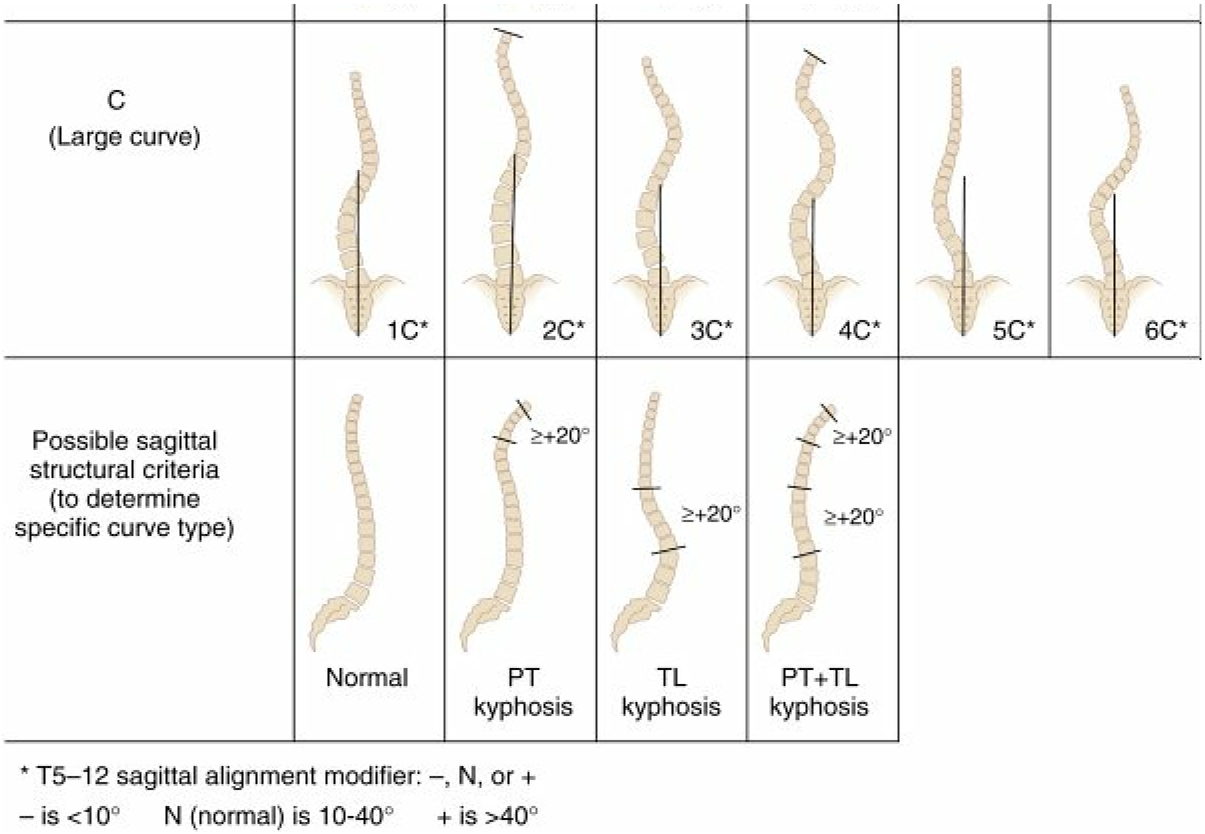


FIG. 3.25 Lenke classification. Schematic drawings of the curve types, lumbar modifiers, and sagittal structural criteria that determine specific curve patterns. *MT,* Main thoracic; *PT,* proximal thoracic; *TL,* thoracolumbar; *TL/L,* thoracolumbar/lumbar.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Figs. 12-26 and 12-27.

- Type A: CSVL is between the pedicles of the apical vertebra
- Type B: CSVL touches between the concave pedicle and the lateral body
- Type C: CSVL falls outside of apical vertebral body

▪ **Risk factors for curve progression**

□ Risk of progression is related to curve size and remaining skeletal growth, which can be difficult to assess.

□ Curves greater than 20 degrees in very young patients

□ Thoracic curves greater than 45–50 degrees at skeletal maturity are likely to progress during adulthood.

□ Lumbar curves may progress at a lower threshold.

□ Peak height velocity (PHV) (Fig. 3.26)

- Best predictor for progression
- Occurs during Risser stage 0, which makes the Risser sign less useful
- Occurs before menarche
- Closure of the olecranon apophysis correlates with PHV
- Modified Tanner-Whitehouse RUS (radius-ulna–short bones) score of 3 (the majority of digits are capped and the metacarpal epiphyses are wider than their metaphyses) correlates with PHV. Patients with a curve of 30 degrees at

this stage have a nearly 100% chance of progressing to a range requiring surgery.

- **Treatment**
  - **Depends on the likelihood of curve progression**

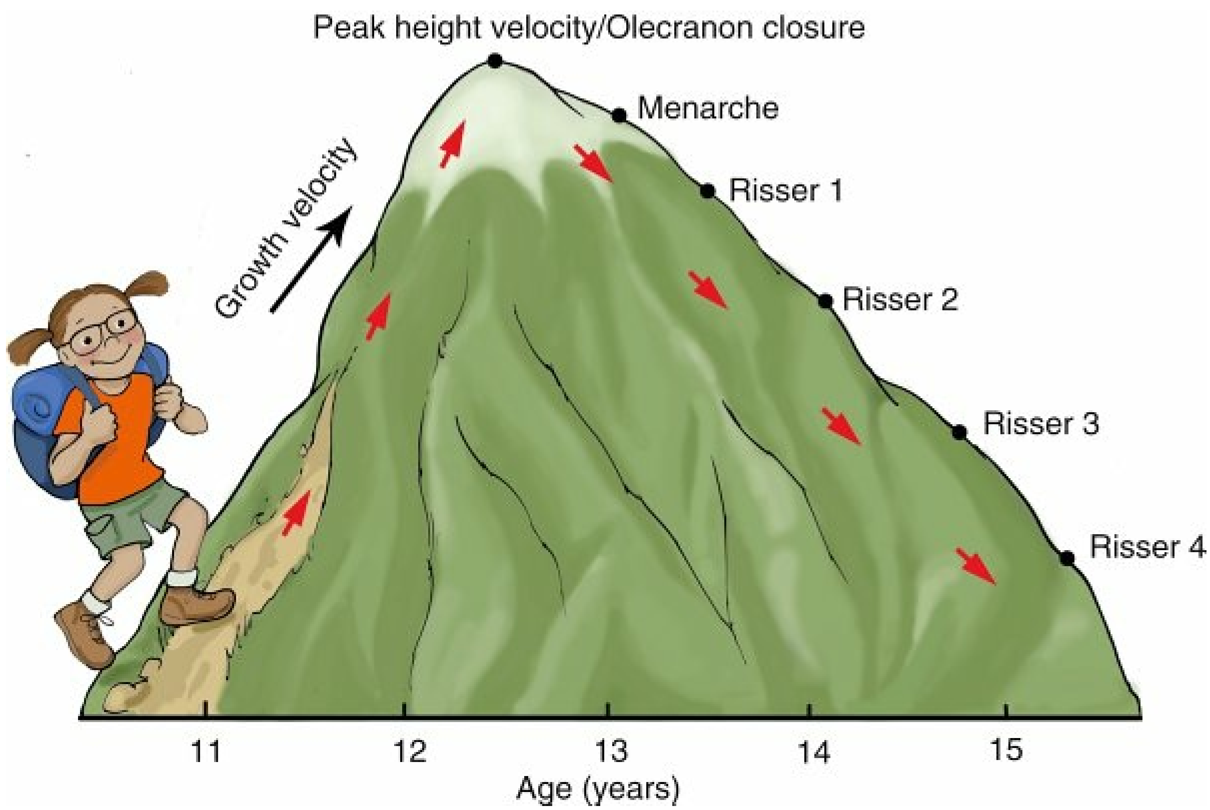


FIG. 3.26 Peak height velocity (PHV). PHV occurs around the time of the olecranon apophysis closure but prior to menarche and Risser stage 1.

  - **Observation**
    - **Skeletally immature patients with curves less than 20–25 degrees**
    - **Skeletally mature patients with curves less than 45 degrees**
  - Bracing
    - **Goal: to halt or slow curve progression in skeletally immature patients (Risser stages 0 to 2); however, bracing does not reverse the curve.**
    - **Indications: curves of more than 25 degrees or of 20 degrees with documented progression**
    - Types of braces:
      - Milwaukee brace (cervicothoracolumbosacral orthosis [CTLSO]); *rarely* used
      - Boston underarm thoracolumbosacral (TLSO) orthosis
        - For curves with the apex at T8 or below
        - Thoracic lordosis or hypokyphosis is a

relative contraindication.
            - Bracing has been shown to be less effective in boys and overweight patients.
            - **Some writers recommend 18 hours/day in patients at Risser stage 0.**
            - **Effectiveness of bracing in patients with idiopathic scoliosis is "dose dependent"; 90% effective when worn more than 12–13 hours/day**

- □ Surgery
    - Goals
        - Prevent curve progression and obtain solid fusion
        - Obtain and maintain correction in the coronal, axial, and sagittal planes while avoiding complications
    - Posterior instrumentation and fusion
        - Segmental instrumentation with pedicle screws (most common), hooks, or wires connected to rods
        - **Pullout strength increased by using larger screws and longer screws, tapping 1 mm less than screw diameter, and using "straightforward" insertion technique**
        - Correction of deformity and arthrodesis (fusion)
    - Anterior instrumentation and fusion
        - Uncommon as single approach but useful in two cases:
            - Single thoracic fusion, especially if hypokyphosis is present and if fusion levels can be saved
            - Single thoracolumbar/lumbar fusion
        - Indications for use in combination with posterior approach:
            - Very young patients: triradiate cartilage open; used to prevent crankshaft phenomenon
            - Large or stiff curves: to improve flexibility, usually for curves of more than 75 degrees. However, the use of pedicle screws and posterior osteotomies may obviate this.

- Fusion levels
    - Determining levels is complex and based on many factors.
    - Main goal: to minimize the number of fusion levels while achieving good coronal and sagittal balance
    - Generally the fusion should:
        - Include structural curves
        - Include nonstructural lumbar curves that are:
            - Greater than 45 degrees
            - Associated with significant rotation or translation
    - Fusion to T2 proximally when:
        - Left shoulder is elevated
        - T1 tilt is greater than 5 degrees
        - Proximal thoracic curve has significant rotation
    - For Lenke 1 and 2 curves:
        - A modifier: fusion distally to vertebra touched by CSVL unless L4 is tilted to the right (fuse one or two levels distally)
        - B modifier: fusion distally to stable vertebra
    - Lenke 3 through 6 curves:
        - Fusion to distal end vertebra
- Complications
    - Infection (1.2%–1.3%)
        - Acute
            - *S. aureus* most common
            - Irrigation and débridement and antibiotic suppression usually required until

            - fusion if infection is deep
        - Delayed
            - Slow-growing organisms: *Propionibacterium acnes, Staphylococcus epidermidis*
            - Treatment: removal of implants, check for pseudarthrosis, antibiotics
- Pseudarthrosis: (1%–3%)
    - Manifests with pain, fractured rod
    - Difficult to visualize with imaging studies
    - Treatment: compression instrumentation bone grafting
- Neurologic deficits (0.5%–0.7%)
    - Usually nerve root or incomplete spinal cord injury
    - Implant related: instrumentation placed in canal or foramen
    - Blood vessel–related: during correction
    - **Intraoperative spinal cord monitoring is crucial.**
        - **If changes occur intraoperatively, the surgical team should check leads, raise blood pressure, transfuse, reverse steps of surgery, and reassess.**
        - If neurologic responses are still diminished, implants should be completely removed.
- Crankshaft phenomenon
    - Continued anterior spinal growth after posterior fusion in skeletally immature patients
    - Increased rotation and deformity of

the spine
- Can be avoided by anterior discectomy and fusion coupled with posterior spinal fusion

Early-Onset Scoliosis

- **The Scoliosis Research Society defines early-onset scoliosis (EOS) as scoliosis diagnosed before age 10 years.**
- **Comprises a heterogeneous group, including congenital scoliosis and infantile and juvenile idiopathic scoliosis; see individual sections for treatment options.**
- **Thoracic insufficiency syndrome**
  - Inability of the thorax to support normal respiration or lung growth
  - Causes
    - Severe congenital scoliosis with rib fusions
    - Jarcho-Levin syndrome: extensive vertebral and rib fusions
    - Jeune syndrome or asphyxiating thoracic dystrophy: rib dysplasia causing a shortened and narrow thorax
  - Diagnosis
    - Clinical signs of respiratory insufficiency
    - Loss of chest wall mobility as demonstrated by the thumb excursion test
    - Worsening indices of three-dimensional thoracic deformity
      - Radiographic studies: measurement of T1–12 height
      - CT scans: lung volumes
      - Pulmonary function tests: Relative decline in percentage of predicted vital capacity

Juvenile Idiopathic Scoliosis

- **Definition: idiopathic scoliosis that manifests between 4 and 10 years of age**
- **Presentation: similar to that of adolescent scoliosis in terms of manifestations and treatment**
  - Right thoracic curve most common
- **Differences from adolescent idiopathic scoliosis**
  - Higher risk of progression, up to 95% in one study
  - Less likely to respond to bracing
  - More likely to require surgical treatment
- **Rate of spinal cord abnormality: 25%**
  - MRI should routinely be obtained.
- **Treatment**

- Observation: curves less than 25 degrees
- Nonoperative treatment: curves between 25 and 45 degrees
    - Bracing
    - Stiff, inflexible curves may require initial casting.
    - Growing rods for patients younger than 8–10 years with large progressive curves
    - Definitive fusion for patients older than 10 years
        - Anterior and posterior fusion often required

Infantile Idiopathic Scoliosis

- **Definition: idiopathic scoliosis that manifests before age 4 years**
- **Differences from adolescent idiopathic scoliosis**
    - Left thoracic curve most common
    - More common in boys
    - Plagiocephaly (skull flattening) often present
        - Other congenital defects frequent
- **Natural history**
    - Significant number of curves resolves spontaneously, up to 90% in one study.
    - **Risk for curve progression**
        - **Phase of the ribs: position of the medial rib relative to the apical vertebra**
            - **Phase I:** ***no*** **rib overlap**
                - **Measure the rib-vertebra angle difference (RVAD) with Mehta classification**
                - **Less than 20 degrees: low risk for progression (80% chance of no progression)**
                - **More than 20 degrees: high risk for progression (80% chance of progression)**
            - **Phase II: rib overlaps the apical vertebra**
                - **Very high risk for curve progression**
- **Evaluation**
    - Clinical: examiner should look for plagiocephaly, perform complete neurologic examination, ask about developmental milestones.
    - MRI: progressive infantile idiopathic scoliosis should be evaluated with MRI of the spinal cord. High incidence of neural axis abnormalities.
- **Treatment**
    - Observation: curves less than 25 degrees with RVAD less than 20

degrees

□ Bracing

- Used for modest and/or flexible deformity
- Milwaukee brace frequently used

□ **Mehta or derotational casting**

- **Indications: progressive deformity (progression of 10 degrees or past 25 degrees)**
- **Changed every 2–4 months**
- **Goals**
  - **May be definitive treatment when initiated in very young patients**
  - **May delay surgical treatment in other patients**

□ Surgery

- Distraction-based techniques

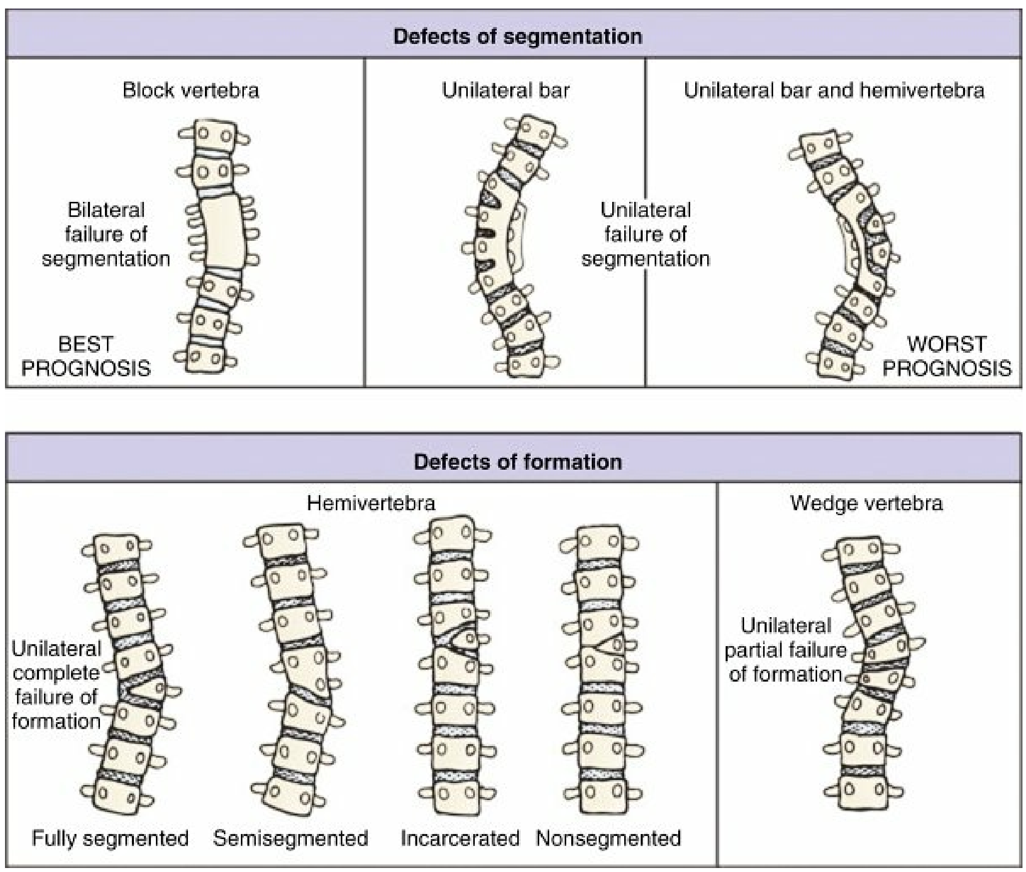


FIG. 3.27 Vertebral anomalies that lead to congenital scoliosis.
Adapted from Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders, Fig. 12-57.

Table 3.8

Progression of Congenital Scoliosis Patterns and Treatment Options.

Conditions Posing Risk for Progression (highest to lowest)	Character of Curve Progression	Treatment Options
Unilateral unsegmented bar with contralateral hemivertebra	Rapid and relentless	Posterior spinal fusion (add anterior fusion for girls <10 yr, boys <12 yr)
Unilateral unsegmented bar	Rapid	Posterior spinal fusion (add anterior fusion for girls <10 yr, boys <12 yr)
Fully segmented hemivertebra	Steady	Anterior spinal fusion Hemivertebra excision
Partially segmented hemivertebra	Less rapid; curve usually <40 degrees at maturity	Observation, hemivertebra excision
Incarcerated hemivertebra	May slowly progress	Observation
Nonsegmented hemivertebra	Little progression	Observation

- Traditional growing rods, VEPTR (Vertical Expandable Prosthetic Titanium Rib), or magnetically controlled growing rods
- Serial lengthening every 4 to 6 months
- High rate of complications, both implant related and wound related

- Definitive fusion when patient is older than 10 years, if possible

Congenital Spinal Deformities

- **Congenital scoliosis**
  - Caused by a developmental defect in formation of the spine during fifth to eighth weeks of gestation
  - **High incidence of associated abnormalities**
    - **Intraspinal: 20%–40%; obtain MRI**

- **Cardiac: 12%–26%**
- **Genitourinary: 20%**

□ Three basic types of defects (Fig. 3.27)

- Failure of segmentation (i.e., vertebral bar)
- Failure of formation (i.e., hemivertebrae)
- Mixed

□ Risk for progression (Table 3.8)

- Depends on:
    - Type of anomaly
    - Remaining growth: worsens most rapidly during first 2 years of life and during adolescent growth spurt
- From most likely to progress to least likely:
    - Unilateral bar with contralateral fully segmented hemivertebra(e): rapid and severe progression
    - Unilateral bar: most common congenital deformity
    - Multiple unilateral fully segmented hemivertebrae

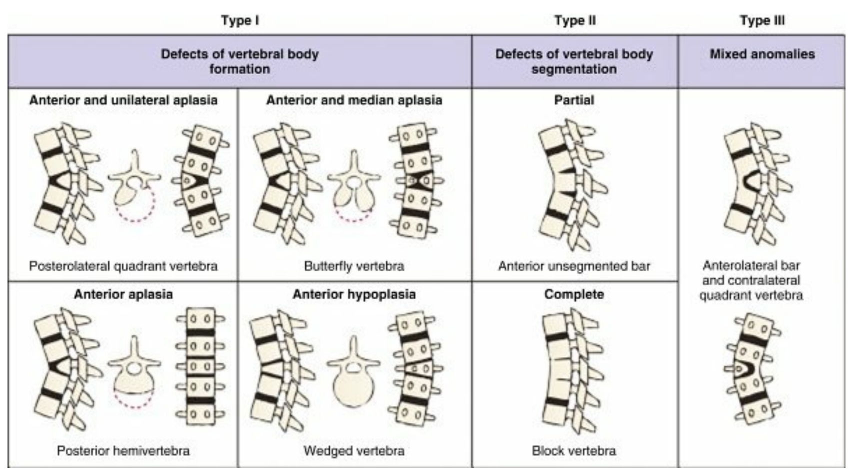


FIG. 3.28 Vertebral anomalies leading to congenital kyphosis.
Adapted from Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders, Fig.12-69.

-
    - Single fully segmented hemivertebra
    - Unsegmented or incarcerated hemivertebra (fused above and below)
    - Block vertebrae: best prognosis

□ Treatment

- Nonoperative
    - Bracing generally ineffective
    - May be useful for controlling compensatory curves and delaying surgery

- Operative
  - Surgical options are varied and somewhat controversial.
  - In situ spinal fusion
    - Posterior in older patients or anterior/posterior spinal fusion in younger patients to avoid crankshaft phenomenon
    - For smaller deformities with high likelihood of progression
  - Convex hemiepiphysiodesis
    - For smaller deformities with high likelihood of progression
  - "Growth friendly" techniques
    - Growing rods
    - VEPTR
    - Shilla technique
      - Apical fusion with pedicle screws placed at proximal and distal extents of curve
      - Rods slide along pedicle screws, promoting guided growth.
    - Designed to allow thorax to continue to grow and delay definitive treatment
  - Hemivertebra resection
    - May be indicated for lumbosacral hemivertebrae associated with progressive curves and an oblique takeoff (severe truncal imbalance)
    - Isolated hemivertebra excision should be accompanied by anterior/posterior arthrodesis with instrumentation to stabilize the adjacent vertebrae.

▪ **Congenital kyphosis (** Fig. 3.28)

- □ Types
  - Failure of formation (type I)
    - Most common
    - Worse prognosis
    - Highest risk for neurologic complications
    - When severe: immediate indication for surgery

- Failure of segmentation (type II)
- Mixed abnormalities (type III)

□ Treatment

- Posterior fusion
  - Favored in young children (<5 years) with curves of less than 50 degrees and normal findings on neurologic examination
  - Functions as a posterior (convex) hemiepiphysiodesis
- Anterior/posterior fusion
  - Reserved for older children or more severe curves
- Anterior vertebrectomy, spinal cord decompression, and anterior fusion followed by posterior fusion are indicated for curves associated with neurologic deficits.
- Vertebral column resection: hemivertebra causing coronal or sagittal plane deformity and/or large fixed spinal deformity
- A type II congenital kyphosis can be monitored to document progression, but progressive curves should be fused posteriorly.

Neuromuscular Scoliosis (Table 3.9)

- **Spine deformity is common with neuromuscular conditions.**
- **Typical underlying neuromuscular conditions associated with scoliosis**

Table 3.9

Treatment in Neuromuscular Scoliosis.

Condition	Bracing	Operative
Duchenne muscular dystrophy	Ineffective	Early; 25–30 degrees to delay pulmonary function deterioration
Friedrich ataxia	Ineffective	Fusion if >50 degrees or progressive
Spinal muscular atrophy	Useful to delay fusion in young patients with curves between 25 and 45 degrees	Fusion if >50 degrees or progressive
Spina bifida (myelomeningocele)	Useful to delay fusion in young patients with curves between 25 and 45 degrees	Fusion if >50 degrees or progressive
Cerebral palsy	Ineffective	>50 degrees in ambulatory patients Progressive curves >50 degrees in communicative and aware patients Curve interfering with seating and nursing, with family desire for surgery
Neurofibromatosis	Nondystrophic curves between 25 and 40 degrees	Fusion if >40 degrees or progressive
Arthrogryposis	Ineffective	Fusion if >50 degrees or progressive

  - □ Traumatic paralysis, Duchenne muscular dystrophy, Friedrich ataxia, spinal muscular atrophy, myelomeningocele, cerebral palsy, neurofibromatosis, arthrogryposis
- **Curve characteristics**
  - □ Long, sweeping C-shaped curves
  - □ Associated pelvic obliquity
  - □ Can be rapidly progressive, especially for the patient in a wheelchair
- **Associated characteristics**
  - □ Most affected patients have some pulmonary involvement secondary to

the underlying condition (Duchenne muscular dystrophy) and detrimental contribution from the scoliosis.
    - Cardiac issues common in Duchenne muscular dystrophy and other conditions
- **Evaluation**
    - Pulmonary: bilevel positive airway pressure (BiPAP) may be required before and after surgery.
    - Cardiac: for patients with Duchenne muscular dystrophy
    - Nutritional laboratory markers
        - Patients with WBC counts less than 1500 cells/μL and albumin levels lower than 3.5 g/dL have higher infection rates and longer hospital stays.
        - Supplemental nutrition or gastrostomy tube feeding should be considered.
- **Nonoperative treatment**
    - For the patient in a wheelchair, trunk support can be modified to provide better truncal balance.
    - Use of corticosteroids in patients with Duchenne muscular dystrophy has been shown to reduce incidence and delay development of scoliosis.
    - Brace
        - Controversial and not typically used
        - May be used to delay surgical treatment
- **Surgical treatment**
    - Indications: vary with diagnosis and somewhat controversial
        - **Duchenne muscular dystrophy**
            - **Surgery indicated when curve is progressive and more than 25–30 degrees in patients whose forced vital capacity (FVC) is greater than 40% of normal.**
            - **Surgery is best tolerated before the patient's FVC is less than 35% of age-matched normal values.**
            - **Curve progression is rapid, and pulmonary and cardiac conditions worsen with time, precluding surgery.**
        - Cerebral palsy
            - Ambulatory patients: surgery should be considered for a curve exceeding 50 degrees
            - Nonambulatory patients: need for surgery depends on sitting balance and whether there are challenges with caring for the child. Curve magnitudes may be very large before surgical treatment.

- Fusion levels
  - **Nonambulatory patients**
    - **Usually from T2 to pelvis**
    - **Pelvic fixation with unit rods, Dunn-McCarthy rods, iliac bolts, or S2AI screws**
    - **Segmental spinal fixation with wires or pedicle screws**
- High complication rate
  - Infection: up to 15% in one study; pelvic instrumentation a risk factor

Neurofibromatosis

- **Autosomal dominant disorder affecting** *NF1* (neurofibromin 1) gene on chromosome 17
- **Diagnosis—two of the following criteria:**
  - More than six café-au-lait spots
  - Two or more neurofibromas of any type or one plexiform neurofibroma
  - Freckling in the axillae or inguinal regions
  - Optic glioma
  - Two or more Lisch nodules (iris hamartomas)
  - A distinctive bone lesion, such as thinning of the cortex of a long bone
  - A first-degree relative (parent, sibling, or offspring) with neurofibromatosis
- **The spine is the most common site of skeletal involvement, affecting up to 10% of patients.**
- **Curve classification**
  - Nondystrophic (similar to that in idiopathic scoliosis): can modulate into dystrophic pattern
  - Dystrophic
- **Characteristic radiographic abnormalities**
  - Short-segment curves with tight apex, vertebral scalloping, enlarged foramina, penciling of transverse processes and ribs

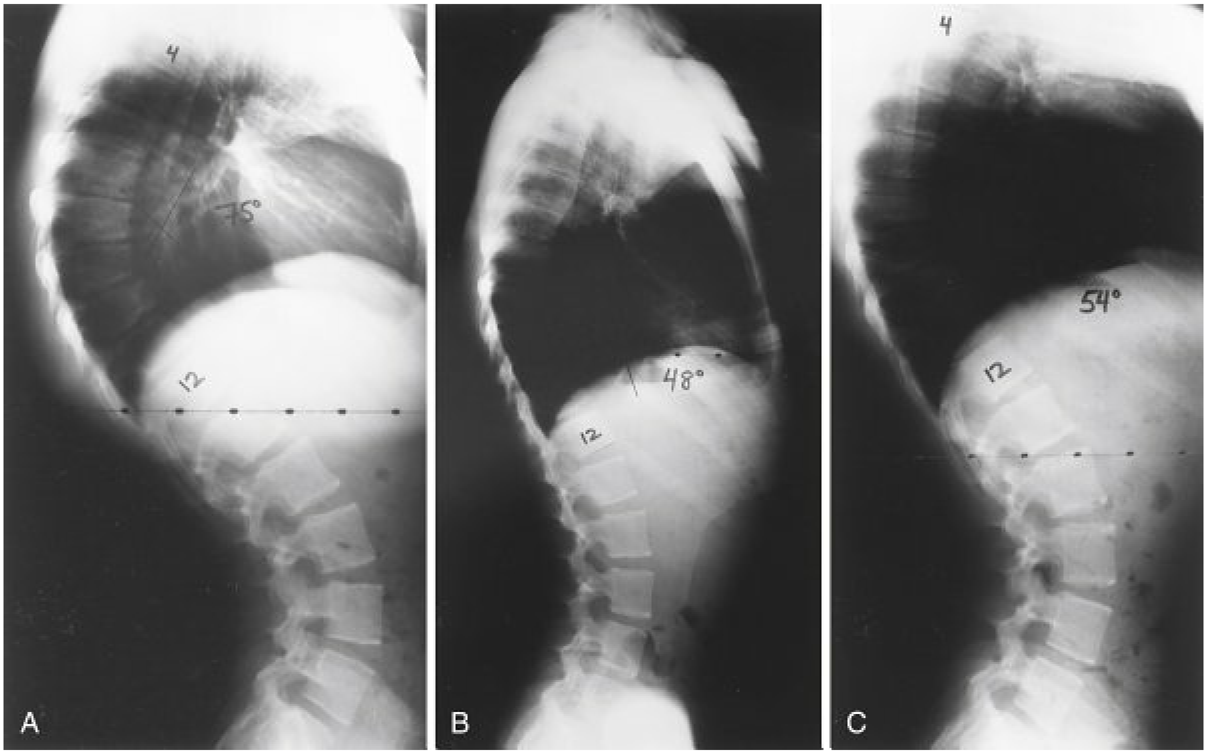


FIG. 3.29 (A) A 16-year-old boy with Scheuermann kyphosis measuring 75 degrees. (B) After 6 months of serial Risser casting, the deformity was reduced to 48 degrees. (C) At 18 years of age, the kyphosis measured 54 degrees.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 13-7.

- Penciling of three or more ribs is a prognostic factor for impending rapid progression of spinal deformity
- □ Severe apical rotation
- □ Sometimes severe kyphoscoliosis

▪ **Treatment**

- □ Nondystrophic scoliosis: treatment is similar to that of idiopathic scoliosis.
- □ Dystrophic deformities
  - More aggressively treated, especially when kyphosis is present; surgical treatment is indicated for any progression and when curves reach 40 degrees.
  - Anterior/posterior surgery:
    - In young patients, especially when deformities are associated with kyphosis
    - To prevent crankshaft phenomenon
    - To improve fusion rates
    - Isolated kyphosis of the thoracic spine is treated with anterior decompression of the kyphotic angular cord compression, followed by anterior and posterior fusion or vertebral column resection from the posterior approach.
    - Cervical spine involvement includes kyphosis or atlantoaxial instability.

- Treatment: posterior fusion with autologous grafting and halo immobilization is recommended for severe cervical spine deformity with instability.

Kyphosis

- **Scheuermann disease**
  - Definition: increased thoracic kyphosis (>45 degrees) with 5 degrees or more anterior wedging at three sequential vertebrae (Fig. 3.29)
  - Other radiographic findings
    - Disc space narrowing and end plate irregularities
    - Spondylolysis (30%–50% of cases)
    - Scoliosis (33% of cases)
    - Schmorl nodes
  - Clinical characteristics
    - More common in boys
    - Affected patients usually overweight
    - Kyphosis is not postural—does not completely correct with hyperextension.
    - Neurologic changes are rare; MRI indicated if they are present.
  - Treatment
    - Bracing
      - Progressive curve in a patient with 1 year or more of skeletal growth remaining (Risser stage 2 or below)
      - Indicated for kyphotic curvature of 50–75 degrees
      - A modified Milwaukee brace is used but often not well tolerated.
    - Surgery
      - Posterior fusion with multilevel osteotomies
      - Fusion to first lordotic disc and the vertebra touched by the posterior sacral vertical line (vertical line extending from the posterior edge of S1).
      - Indicated for progressive or severe (>75 degrees) curve, continued pain despite physical therapy (PT)
- **Postural kyphosis or round back**
  - Does not demonstrate vertebral body changes

- No sharp angulation as in Scheuermann disease
- Correction with backward bending and prone hyperextension is typical.
- Treatment includes a hyperextension exercise program.

- **Other causes of kyphosis**
  - Trauma or infection
  - Bone dysplasias (mucopolysaccharidoses, Kniest syndrome, diastrophic dysplasia), and neoplasms
  - Laminectomy (most often for spinal cord abnormalities)
    - Postlaminectomy kyphosis can be severe and necessitates anterior and posterior fusion.

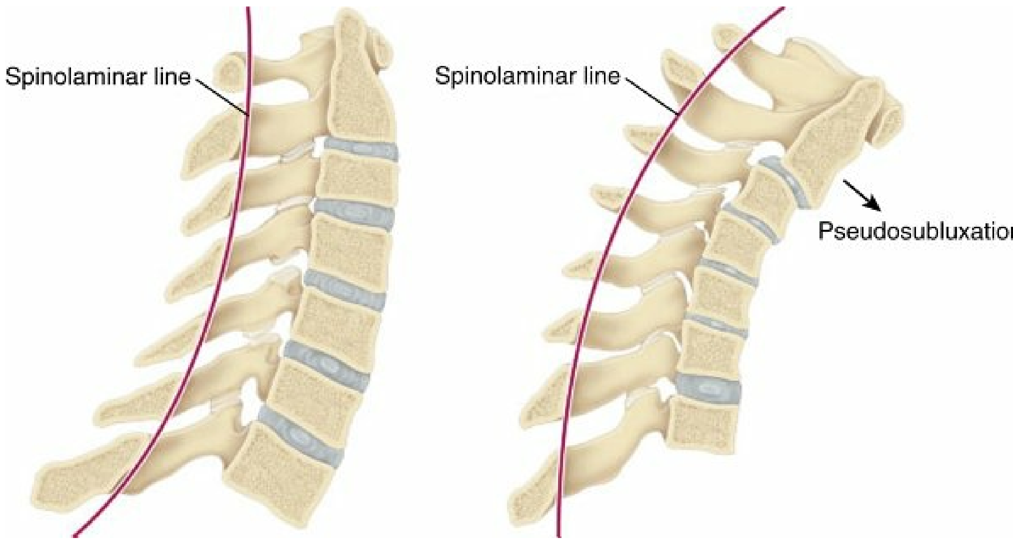


FIG. 3.30 Pseudosubluxation of C2–3 (most common). Actual subluxation is not possible because of the intact spinolaminar line at C2–3.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2008, Saunders, Fig. 11-4.

- Total laminectomy in immature patients without stabilization is contraindicated for this reason.

Cervical Spine Disorders

- **Klippel-Feil syndrome**
  - **Abnormalities in multiple cervical segments as a result of failure of normal segmentation or formation of cervical somites at 3 to 8 weeks' gestation**
  - Associations
    - Congenital scoliosis
    - **Renal disease (aplasia: 33% of cases)**
    - **Auditory issues (deafness: 30% of cases)**
    - **Sprengel deformity (30% of cases)**

- **Congenital heart disease (14%–29% of cases)**
- Brainstem abnormalities
- Congenital cervical stenosis
  - MRI required to rule out intraspinal cord abnormalities

- The classic triad (seen in <50% of cases)
  - Low posterior hairline
  - Short "webbed" neck
  - Limited cervical ROM
- Treatment
  - **With multilevel fusion of the cervical spine, any involvement of C2, or limited cervical motion, collision sports should be avoided.**
  - Surgery for chronic pain with myelopathy

- **Atlantoaxial instability**
  - Associated with:
    - Down syndrome (trisomy 21)
      - If normal neurologic findings: patient should avoid contact sports
      - If neurologic symptoms or atlantodens interval (ADI) greater than 10 mm: posterior fusion (associated with high rate of complications)
    - Juvenile rheumatoid arthritis
    - Skeletal dysplasias such as spondyloepiphyseal dysplasia, diastrophic dysplasia, and Kniest dysplasia
    - Os odontoideum and other abnormalities
  - Atlantoaxial rotatory displacement or subluxation
    - May manifest as torticollis
    - Causes
      - Ligamentous laxity (Down syndrome)
      - **Retropharyngeal inflammation following upper respiratory infection (Grisel disease)**
      - Trauma
    - Diagnosis
      - CT scans at the C1–2 level with the head straightforward, then in maximum rotation to the right, and then in maximum rotation to the left
  - Treatment
    - **Symptoms for less than 1 week: cervical collar, analgesics, heat**
    - **Symptoms for between 1 and 4 weeks: traction and collar immobilization**
    - **Symptoms for longer than 1 month: traction, reduction, and**

halo immobilization
    - **Irreducible or recurrent instability: surgical reduction and fusion (C1–2)**

- **Os odontoideum**
  - Previously thought to result from failure of fusion of the base of the odontoid (usually fuses between ages 4 and 6 years)
  - May represent the residue of an old traumatic process
  - Two types:
    - Orthotopic type: in place of the normal odontoid process
    - Dystopic type: may fuse to the clivus (more often seen with neurologic compromise)
  - Treatment
    - Conservative except in the following cases
      - Instability (>10 mm of the atlantodens interval or <13 mm space available for the cord)
      - Presence of neurologic symptoms, which necessitate a posterior C1–2 fusion
- **Pseudosubluxation of the cervical spine**
  - Subluxation of C2 on C3 (and occasionally of C3 on C4) of up to 40%, or 4 mm
  - Can be a normal finding in children younger than 8 years because of the orientation of the facets
  - Rapid resolution of pain, relatively minor trauma, lack of anterior swelling
  - Continued alignment of the posterior interspinous distances and the posterior spinolaminar line (Swischuk line) on radiographs (Fig. 3.30)
  - The fact that the subluxation can be reduced with neck extension helps differentiate this entity from more serious disorders.

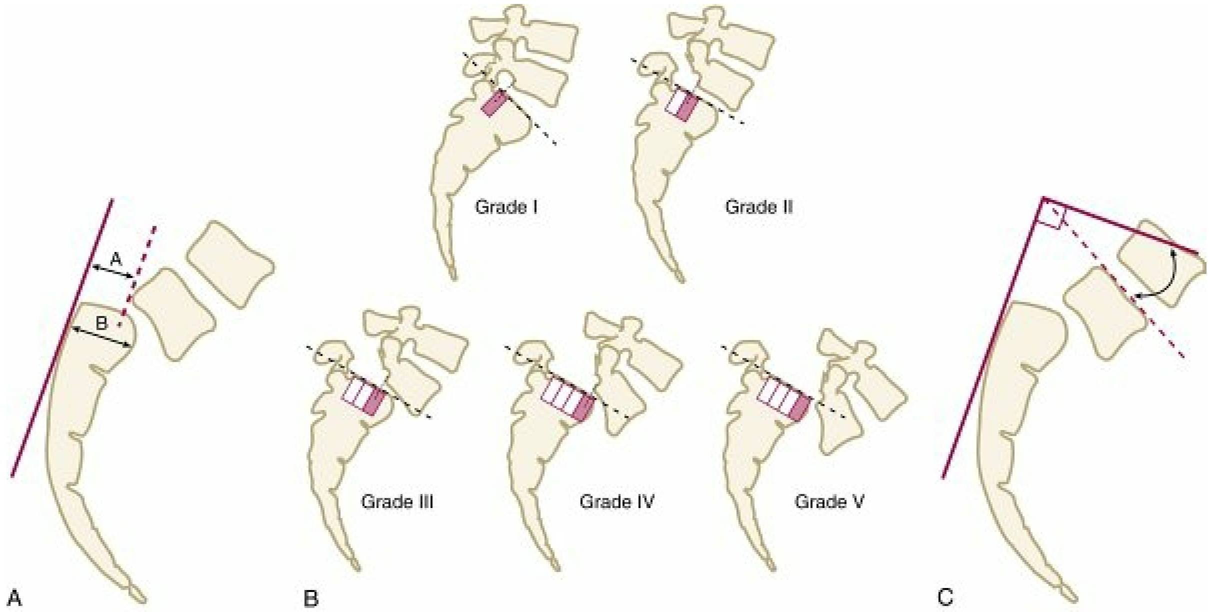


FIG. 3.31 Spondylolisthesis. (A) Percentage of forward slippage (*A/B*) described by Taillard. (B) Meyerding grades I to V. The degree of spondylolisthesis is determined by dividing the sacral body into four segments. Grade V is complete spondyloptosis. (C) The slip angle is measured as follows: A line *(solid)* is drawn perpendicular to a line along the posterior edge of the sacrum, and another (*dotted)* from the superior end plate of L5; the angle between these lines *(arrows)* is the slip angle. From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 14-7.

Spondylolysis and Spondylolisthesis

- **Spondylolysis: fracture at the pars interarticularis**
  - Common in athletes who use hyperextension (gymnasts, football linemen, wrestlers, divers)
  - **Pain with hyperextension**
  - Imaging
    - AP and lateral radiographs
      - Oblique views offer no additional benefit and involve more radiation
    - MRI: high sensitivity, shows early stress fractures
    - CT: best bony detail
  - Treatment
    - Skeletally mature patients with incidental finding of spondylolysis require no follow-up.
    - Nonoperative treatment for symptomatic spondylolysis
      - Rest and PT for core strengthening and hamstring flexibility
      - **Bracing in the acute period or with acute injuries with an antilordotic brace (TLSO with thigh extension)**
    - Operative

- Indications: continued pain or neurologic symptoms despite conservative treatment
- Direct pars repair
  - Useful in young patients with "hot" bone scan indicating healing potential
- In-situ L5–S1 posterolateral arthrodesis

▪ **Spondylolisthesis: forward slippage of the proximal vertebra on the distal vertebra**
  - Most commonly seen at L5–S1
  - **High-grade slippage (>50%) may be accompanied by a flexed hip and knee posture with equinus, sacral prominence, and proximal hyperlordosis.**
  - Types (Wiltse classification)
    - Isthmic (from spondylolysis)
    - Dysplastic (congenital absence or dysplasia of the facets)
      - Greater risk for progression
  - Radiographs (Fig. 3.31)
    - Translation: Meyerding grading system (low: grades 1 and 2; high: grades 3 and 4)
    - **Slip angle**
      - **Most important determinant for nonunion and pain**
      - **Measured from a line drawn from the superior end plate of L5 and a line drawn perpendicular to the posterior edge of the sacrum**
      - **Angle greater than 45–50 degrees is associated with greater risk of slip progression, instability, and development of postoperative pseudoarthrosis.**
    - **Pelvic incidence (PI) (Fig. 3.32)**
      - **Angle created by a line from the midpoint of the sacral end plate to the center of the femoral heads and a line perpendicular to the sacral end plate (normal, ≈50 degrees)**
      - **Unaffected by posture**
      - **Measure of pelvic version**
      - **Sum of pelvic tilt (PT) and sacral slope (SS): PI = PT + SS**
      - **Increased PI may predispose to spondylolisthesis.**
  - Treatment
    - **Asymptomatic low-grade spondylolisthesis**
      - **No treatment; younger patients should be**

monitored for progression, although risk of progression necessitating surgery < 5%.

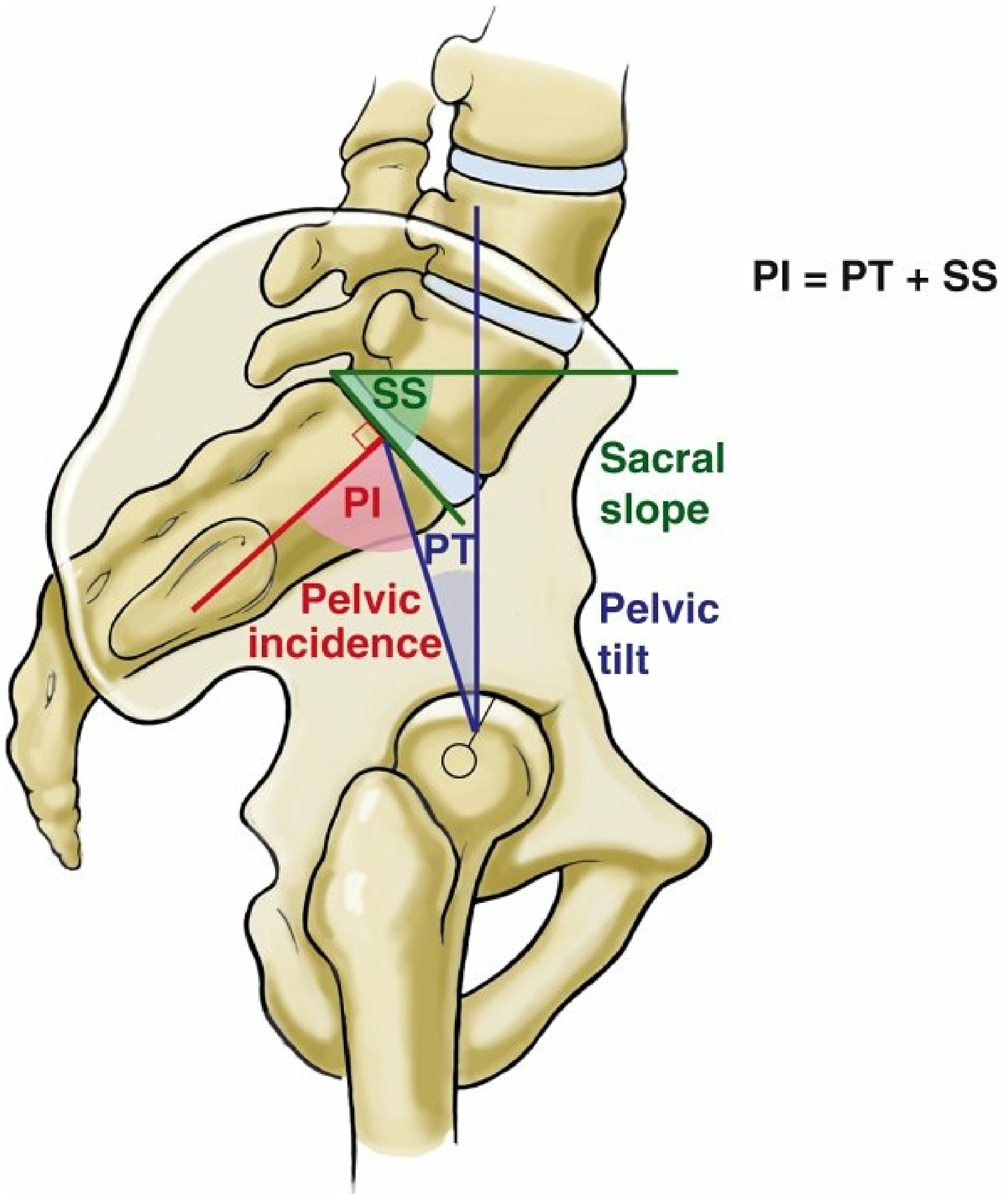


FIG. 3.32 Pelvic incidence. A line is drawn perpendicular to the midpoint of the sacral end plate. A second line is drawn connecting the same sacral midpoint and the center of the femoral heads. The angle subtended by these lines is the PI. Pelvic incidence is equal to the sum of pelvic tilt and sacral slope.

- **Symptomatic low-grade spondylolisthesis**
  - **Similar to that for spondylolysis (rest, PT, activity modification, brace)**
  - **If continued pain: arthrodesis with or without instrumentation**
- High-grade spondylolisthesis
  - In general, surgery indicated because of high risk for progression
  - Multiple techniques, somewhat controversial

- In general, L4–S1 fusion required
- Decompression with high-grade slips or neurologic symptoms
- Correction of slip angle and reduction (controversial because it may increase risk of neurologic deficits); L5 root injury is the most common neurologic complication.

Other Spinal Conditions

- **Infectious spondylitis (discitis and vertebral osteomyelitis)**
  - Epidemiology
    - Patients with discitis often younger (mean age, 2.8 vs. 7.5 years)
    - Most commonly seen at L3–4 and L4–5 disc spaces
    - *S. aureus* most commonly seen, though *K. kingae*, *Mycobacterium tuberculosis*, *Bartonella henselae*, and *Salmonella* also seen
  - Presentation and evaluation
    - Acute back pain, refusal to sit or bear weight
    - Radiographic changes usually lag behind clinical findings.
      - Loss of lumbar lordosis, disc space narrowing, loss of vertebral height, and end plate changes, in that order
    - MRI also highly sensitive and specific
  - Treatment
    - Culture results positive in only 60% of cases; routine disc biopsy for culture not necessary

Table 3.10

Differential Diagnosis for Low Back Pain in Children.

Category	Disease
Musculoskeletal	Nonspecific back pain or sprain/strain
	Spondylolysis/spondylolisthesis
	Fracture
	Intervertebral disc degeneration or herniation
	Scoliosis
	Scheuermann kyphosis
Infectious	Discitis
	Vertebral osteomyelitis
	Epidural abscess
	Sacroiliac septic arthritis
	Paraspinal abscess
	Nonspinal infection (pneumonia, pyelonephritis, appendicitis)
Inflammatory	Ankylosing spondylitis
	Psoriatic arthritis
	Reactive arthritis
Neoplastic	Osteoid osteoma or osteoblastoma
	Aneurysmal bone cyst
	Neurofibroma
	Eosinophilic granuloma
	Leukemia/lymphoma
	Solid malignancy (Ewing sarcoma, osteosarcoma)
	Primary spinal cord tumor (astrocytoma, ependymoma)
	Metastatic disease
Miscellaneous	Sickle cell crisis
	Syringomyelia or tethered cord
	Idiopathic juvenile osteoporosis
	Chronic multifocal recurrent osteomyelitis (CMRO)
	Conversion disorder

- Intravenous antibiotic treatment with coverage for *S. aureus*
- Surgery indications include abscess and failure of nonoperative management.

▪ **Low back pain (** Table 3.10)

- Low back pain and especially painful scoliosis should be taken seriously in children.
- However, up to 75%–80% of children with low back pain do not have a diagnosis.
- Additional etiologies not discussed
    - **Osteoid osteoma**
        - **Night pain relieved by NSAIDs**
        - **Central nidus < 2 cm with ring of lucency on imaging**
        - **Can be associated with scoliosis**
    - Herniated nucleus pulposus (can also be a herniated end plate in adolescence)
        - Uncommon in children
        - Manifestations and initial treatment similar to those in adults (see Chapter 8, Spine)
    - Diastematomyelia
        - Fibrous, cartilaginous, or osseous bar creating a longitudinal cleft in the spinal cord
        - More commonly occurs in the lumbar spine: can lead to tethering of the cord, with associated neurologic deficits
        - Intrapedicular widening on plain radiographs is suggestive.
        - CT or MRI is necessary to fully define the disorder.
        - Must be resected before correction of a spinal deformity; otherwise, if asymptomatic it may be monitored without surgery.
    - Sacral agenesis (caudal regression)
        - Partial or complete absence of the sacrum and lower lumbar spine
        - **Strongly associated with maternal diabetes**
        - Often accompanied by gastrointestinal, genitourinary, and cardiovascular abnormalities
        - Presentation:
            - Prominent lower lumbar spine and atrophic lower extremities
            - Child may sit in a Buddha position
            - **Motor impairment is at the level of the agenesis, but sensory innervation is largely spared.**
        - Management may include amputation of the legs or spinal-pelvic fusion.

Cerebral Palsy

Introduction

- **Nonprogressive neuromuscular disorder**
  - Onset before age 2 years
  - Results from injury to the immature brain
- **Cause is usually not identifiable but can include:**
  - Prematurity (most common)
  - Prenatal intrauterine factors
  - Perinatal infections (TORCH—*t*oxoplasmosis, *o*ther infections, *r*ubella, *c*ytomegalovirus infection, and *h*erpes simplex)
  - Anoxic injuries
  - Meningitis
- **This upper motor neuron disease results in a mixture of muscle weakness and spasticity.**
- **Initially the abnormal muscle forces cause dynamic deformity at joints.**
  - Persistent spasticity can lead to contractures, bony deformity, and ultimately joint subluxation/dislocation.
- **MRI of the brain commonly reveals periventricular leukomalacia.**

Classification

- **Cerebral palsy can be classified on the basis of physiology (according to the movement disorder), anatomy (according to geographic distribution), or function.**
- **Physiologic classification (** Fig. 3.33)
  - Spastic
    - Increased muscle tone and hyperreflexia with slow, restricted movements because of simultaneous contraction of agonist and antagonist
    - Most common and is most amenable to improvement of musculoskeletal function by operative intervention
  - Athetosis
    - Constant succession of slow, writhing, involuntary movements
    - Less common and more difficult to treat
  - Ataxia
    - Inability to coordinate muscles for voluntary movement, resulting in unbalanced wide-based gait
    - Less amenable to orthopaedic treatment

□ Mixed

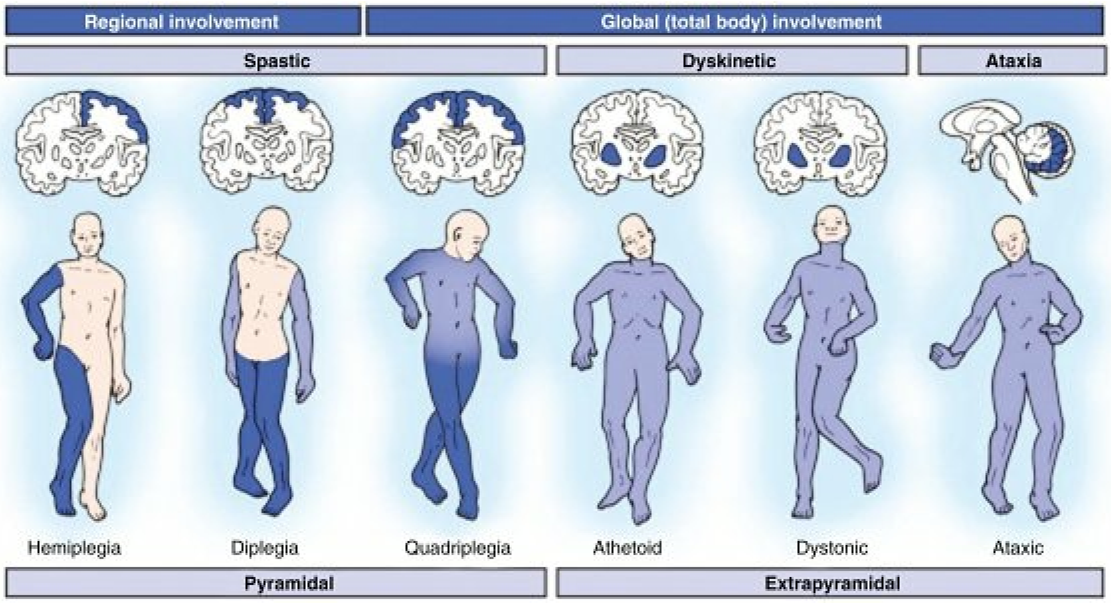


FIG. 3.33 Classification of cerebral palsy. Although overlaps in terminology exist, cerebral palsy can be classified according to distribution (regional versus global involvement; hemiplegic, diplegic, quadriplegic), physiologic type (spastic, dyskinetic/dystonic, dyskinetic/athetoid, ataxic), or presumed neurologic substrate (pyramidal, extrapyramidal).
Redrawn from Pellegrino L: Cerebral palsy. In Batshaw ML, editor: *Children with disabilities,* ed 4, Baltimore, 1997, Paul H. Brookes.

- Typically involves a combination of spasticity and athetosis with total body involvement

- **Anatomic classification (see Fig. 3.33):**
  - □ Hemiplegia
    - Involves upper and lower extremities on the same side, usually with spasticity
    - “Handedness” often develops early
    - All children with hemiplegia are eventually able to walk, regardless of treatment
  - □ Diplegia
    - Lower extremity involved more extensively than upper extremity
    - Most diplegic patients eventually walk.
    - IQ may be normal; strabismus is common.
  - □ Total involvement (quadriplegia)
    - Extensive involvement, low IQ, and a high mortality rate
    - Affected patients usually unable to walk
- **Functional classification**
  - □ Gross motor and functional classification system (GMFCS) (Fig. 3.34)

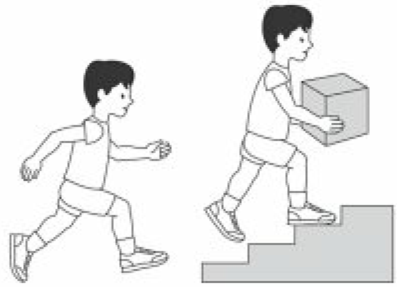
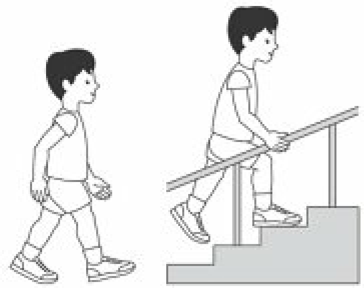
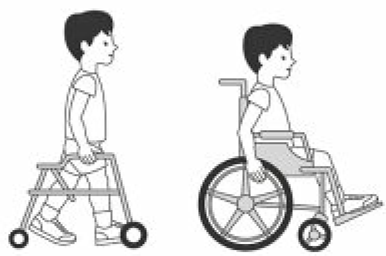
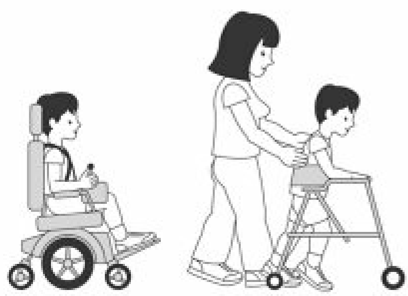
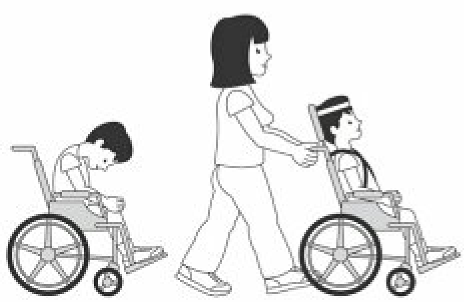
	**GMFCS level I** Children walk indoors and outdoors and climb stairs without limitation. Children perform gross motor skills including running and jumping, but speed, balance, and coordination are impaired.
	**GMFCS level II** Children walk indoors and outdoors and climb stairs holding on to a railing but experience limitations walking on uneven surfaces and inclines and walking in crowds or confined spaces and with long distances.
	**GMFCS level III** Children walk indoors or outdoors on a level surface with an assistive mobility device and may climb stairs holding on to a railing. Children may use wheelchair mobility when traveling for long distances or outdoors on uneven terrain.
	**GMFCS level IV** Children use methods of mobility that usually require adult assistance. They may continue to walk for short distances with physical assistance at home but rely more on wheeled mobility (pushed by an adult or operate a powered chair) outdoors, at school, and in the community.
	**GMFCS level V** Physical impairment restricts voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Children have no means of independent mobility and are transported by an adult.

FIG. 3.34 Gross motor and functional classification system (GMFCS) for children ages 6 to 12 years with cerebral palsy: descriptors and illustrations.

- Classification is based on walking ability and need for assistive devices.
- Functional loss over time or after surgery can be monitored with GMFCS.

Orthopaedic Assessment

- **Based on physical examination and thorough birth and developmental history**
- **A patient's locomotor profile is based on the persistence of primitive reflexes; the presence of two or more usually means the child will not be able to ambulate.**
- **Commonly tested reflexes include the Moro startle reflex (normally disappears by age 6 months) and the parachute reflex (normally disappears by age 12 months).**
- **The ability to sit independently by age 2 years is highly prognostic of ability to walk.**

Spasticity Treatment

- **Botulinum toxin**
  - Intramuscular botulinum A toxin can temporarily decrease dynamic spasticity.
  - Mechanism of action of botulinum toxin is a presynaptic blockade of cholinergic receptors at the neuromuscular junction.
  - Effectiveness of botulinum toxin is limited to 3 to 6 months; therefore, it is not a permanent cure for spasticity.
  - It is used to maintain joint motion during rapid growth when a child is too young for surgery.
- **Dorsal rhizotomy**
  - Selective dorsal root rhizotomy is a neurosurgical procedure designed to decrease lower extremity spasticity.
  - Includes resection of dorsal rootlets that do not exhibit a myographic or clinical response to stimulation
  - Performed primarily in ambulatory patients (age 4–8 years) with spastic diplegia to help reduce spasticity and complement orthopaedic management
  - Requires multilevel laminoplasty, which may lead to late spinal instability and deformity
  - Contraindicated in patients with athetoid disease and nonambulatory patients with spastic quadriplegia (increased spinal deformities)
- **Systemic medication**
  - Oral baclofen used as adjunct therapy to control overall tone
    - Provides decreased tone in all extremities by inhibiting signals through the γ-aminobutyric acid (GABA) pathway
    - Negative effects include increased somnolence and decreased alertness during the day
  - Baclofen pump
    - Surgical implantation of a pump that provides only local

delivery of baclofen to an area of the spinal cord
- Pump delivers a much lower dose of baclofen.
- Pump is then refilled when empty.

- No systemic delivery; thus less somnolence
- May exacerbate scoliosis progression
- Wound problems common in thin children

Gait Disorders

- **Evaluation**
  - Findings are usually the impetus for the orthopaedic consultation.
  - Three-dimensional computerized gait analysis with dynamic electromyography and force-plate studies have allowed a more scientific approach to preoperative decision making and postoperative analysis of the results of surgery for cerebral palsy.
- **Types**
  - Toe-walking—contracted heel cords
    - Treat with ankle foot orthosis (AFO) if passively correctable
    - Posterior leaf-spring orthotic used for excessive ankle plantar flexion in swing phase of gate
    - Surgical treatment includes gastrocnemius recession versus tendo-Achilles lengthening
  - Crouched gait
    - Usually due to hamstring contracture
    - Resultant deformity includes hip flexion, knee flexion, ankle equinus
    - Treated with lengthenings at hip, knee, and ankle.
      - Caution should be exercised with isolated heel cord lengthening—will worsen crouched gait secondary to worsening hip and knee flexion
  - Stiff knee gait
    - Common in spastic diplegia with rectus femoris firing out of phase
    - Treat with transfer of distal rectus tendon to the hamstrings
- **Treatment**
  - Lengthening of continuously active muscles and transfer of muscles out of phase are often helpful.
  - Procedures should usually be done at multiple levels to best correct the problem.
  - In general, surgery is performed at age 4 to 5 years. A few generalized guidelines are given in Table 3.11.

Spinal Disorders

- **Evaluation**
  - Scoliosis can be severe, making proper wheelchair sitting difficult.
  - Risk for scoliosis highest in children with total body involvement (spastic quadriplegia).
  - Surgical indications include curves greater than 45 to 50 degrees, worsening pelvic obliquity, and wheelchair seating problems.
  - Scoliosis more likely to progress than in idiopathic scoliosis
    - 1–2 degrees per year starting at age 8–10 years
    - Bracing is less effective.
- **Treatment**
  - Treatment is tailored to the needs of the patient and must involve all caregivers.
  - Small curves with no loss of function or large curves in severely involved patients may necessitate only observation.
  - Curves in ambulatory patients are treated as idiopathic scoliosis with posterior fusion and instrumentation.
  - Curves in nonambulatory patients and in patients with pelvic obliquity may necessitate posterior fusion with segmental posterior instrumentation from the upper thoracic spine to the pelvis (Luque-Galveston technique), with or without anterior fusion.
  - Kyphosis is also common and may necessitate fusion and instrumentation.
  - It is important to assess nutritional status (albumin level <3.5 g/dL and WBC count <1500 cells/μL) preoperatively and to consider gastrostomy tube placement before spinal surgery if indicated.

Table 3.11

Surgical Options for Gait Disorders.

Problem	Diagnostic Findings	Surgical Option
Hip flexion	Positive result of Thomas test	Psoas tenotomy or recession
Spastic hip	Decreased abduction, uncovered femoral head	Adductor release, osteotomy (late)
Hip adduction	Scissoring gait	Adductor release
Femoral anteversion	Prone internal rotation increased	Osteotomy, varus derotation osteotomy, hamstring lengthening
Knee flexion	Increased popliteal angle	Hamstring lengthening
Knee hypertension	Recurvatum	Rectus femoris lengthening
Stiff-leg gait	Electromyographic study of hamstring and quadriceps; continuous passive knee flexion decreased with hip extension	Distal rectus transfer to hamstrings
Talipes equinus	Toe walking	Achilles tendon lengthening
Talipes varus	Appearance in standing position	Split–anterior or split–posterior tibialis transfer (on the basis of electromyographic findings)
Talipes valgus	Appearance in standing position	Peroneal lengthening, Grice subtalar fusion, calcaneal lengthening osteotomy
Hallux valgus	Appearance on examination and radiographs	Osteotomy, metatarsophalangeal fusion

- □ Much higher complication rate than with idiopathic scoliosis
  - Wound infection (3%–5%)
  - Pulmonary complications
  - Implant failure
  - Increased fatality rate (as high as 7% in some series)

Hip Subluxation and Dislocation

- **Evaluation**
  - □ In many children, pathologic processes of the hip are asymptomatic.
  - □ Caregivers may describe a pain response.
  - □ Difficulty with abduction for peroneal care is the most common problem.
- **Treatment**
  - □ Initial treatment is with a soft tissue release (adductor/psoas) plus

abduction bracing.

- Later, hip subluxation or dislocation may necessitate femoral or acetabular osteotomies (Dega) or both to maintain hip stability.
- The goal is to keep the hip reduced.
- This entity is characterized by four stages:
  - Hip at risk: abduction less than 45 degrees, with partial uncovering of the femoral head on radiographs. This situation is the only exception to the general rule of avoiding surgery in patients with cerebral palsy during the first 3 years of life.
    - Patient may benefit from adductor and psoas release.
  - Hip subluxation: best treated with adductor tenotomy in children with abduction less than 20 degrees, sometimes with psoas release or recession
    - Femoral or pelvic osteotomies may be considered in cases of femoral coxa valga and acetabular dysplasia, which is usually lateral and posterior.
  - Spastic dislocation: patients may benefit from open reduction, femoral shortening, varus derotation osteotomy, Dega osteotomy (Fig. 3.35), triple osteotomy, or Chiari osteotomy.
    - The type of pelvic osteotomy indicated is best determined in a three-dimensional CT scan, which demonstrates the area of acetabular deficiency (anterior, lateral, or posterior) and the congruency of the joint surfaces.
    - Addressing both hips can prevent dislocation of opposite hip.
    - Late dislocations may best be left untreated or treated with a Schanz abduction osteotomy or a modified Girdlestone resection arthroplasty (resection below the lesser trochanter).
  - Windswept hips: characterized by abduction of one hip and adduction of the contralateral hip
    - Bilateral femoral osteotomies to achieve a more varus angle can assist in maintaining reduction.

Knee Abnormalities

- **Evaluation**
  - Usually includes hamstring contractures and decreased ROM

- Crouch gait in spastic diplegia patients
- **Treatment**
    - Hamstring lengthening is often helpful (sometimes increases lumbar lordosis).
        - To prevent peroneal nerve injury, care must be taken not to overextend the knee in the operating room.
    - Distal transfer of an out-of-phase rectus femoris muscle to the semitendinosus or gracilis muscle is indicated when there is loss of knee flexion during the swing phase of gait (stiff knee gait).

Foot and Ankle Abnormalities

- **Goal of treatment is to obtain a plantigrade, painless, braceable foot.**
- **Equinovalgus foot**
    - Most common in spastic diplegia; also in quadriplegia
    - Causes
        - Caused by spastic peroneal muscles, contracted heel cords, and ligamentous laxity
    - Treatment
        - Peroneus brevis lengthening is often helpful in correcting moderate valgus angulation. Lateral column-lengthening calcaneal osteotomy is used to correct hindfoot valgus angulation.
- **Equinovarus foot**
    - Most common in spastic hemiplegia

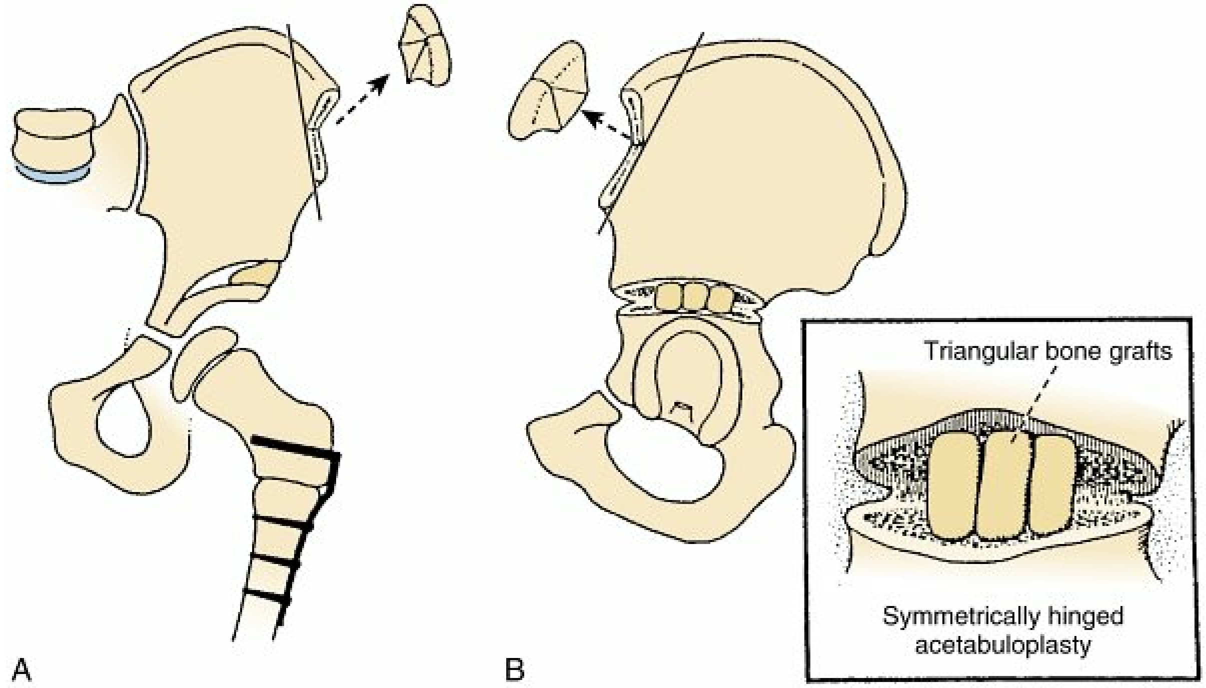


FIG. 3.35 Placement of graft for Dega osteotomy. (A) Bone graft is obtained from the anterosuperior iliac crest and shaped into three small triangles whose bases are 1 cm long. (B) The grafts are placed in the osteotomy site; the largest is placed in the area where maximal improvement of coverage is desired. The triangular wedges are packed close to each other to prevent collapse, turning, or dislodgment; the result is a symmetric hinging on the triradiate cartilage *(inset)*. With the medial wall of the pelvis maintained, the elasticity of the osteotomy keeps the wedges in place. No pins are necessary to maintain the osteotomy.
Adapted from Mubarak SJ et al: One-stage reconstruction of the spastic hip, *J Bone Joint Surg Am* 74:1352, 1992.

- Causes
  - Overpull of the posterior or anterior tibialis tendons (or both)
- Treatment
  - Lengthening of the posterior tibialis is rarely sufficient.
  - Transfers
    - Likewise, transfer of an entire muscle (posterior or anterior tibialis) is rarely recommended.
    - Split-muscle transfers are helpful when the affected muscle is spastic during both the stance and swing phases of gait.
    - Split–posterior tibialis transfer (rerouting half of the tendon dorsally to the peroneus brevis) is used in cases with spasticity of the muscle, flexible varus foot, and weak peroneal muscles.
      - Complications include decreased foot dorsiflexion.
    - Split–anterior tibialis transfer (rerouting half of its tendon laterally to the cuboid) is used in patients with spasticity of the muscle and a

flexible varus deformity.

- Often coupled with Achilles tendon lengthening and posterior tibial tendon intramuscular lengthening (Rancho procedure) to treat the fixed equinus contracture.

- **Hallux valgus**
  - Treatment includes first metatarsophalangeal (MTP) joint fusion
    - Recurrence rate unacceptably high, with bunion deformity correction without fusion
  - Proximal phalanx (Akin) osteotomy
    - Used for hallux valgus interphalangeus in association with hallux valgus and can be done at same time as first MTP fusion

Upper Extremity Management

- **Overview**
  - Treatment divided into procedures to increase hygiene and those to produce better function
  - Functional procedures indicated for patients with voluntary control and better sensibility
- **Shoulder contracture**
  - Internal rotation contracture of the glenohumeral joint
  - Treated with proximal humerus derotational osteotomy
    - Subscapularis and pectoralis lengthening may be needed in addition to biceps/brachialis lengthening and capsulotomy
    - Indications include contractures greater than 30 degrees that interfere with hand function.
- **Elbow contracture**
  - Flexion contracture
    - Treated with:
      - Lacertus fibrosis release
      - Biceps and brachialis lengthening
      - Brachioradialis origin release
  - Pronation deformity
    - Treated with pronator teres release
    - Caution needed with pronator teres transfer to an anterolateral position—can lead to a supination deformity
- **Wrist flexion deformity**
  - Wrist typically has flexion and ulnar deviation contracture.

- May be treated early with flexor carpi ulnaris (FCU) to extensor carpi radialis brevis (ECRB) tendon transfer or FCU to extensor digitorum communis (EDC) transfer in functional patients with voluntary control
- Concomitant proximal row carpectomy may improve wrist position and severe digital finger tightness.

- Wrist arthrodesis done for severe deformity or for hygienic procedure

- **Thumb-in-palm deformity**
  - Flexed thumb prevents grasping and can interfere with hygiene.
  - Treatment with lengthening of adductor pollicis, first dorsal interosseous, flexor pollicis brevis, and flexor pollicis longus muscles
    - Combined with first web space Z-plasty and tendon transfer to augment thumb extension and abduction
- **Finger flexion deformity**
  - Swan-neck deformities can sometimes be corrected with correction of wrist flexion deformity.
  - Fractional or Z-lengthening of tendon (with or without ulnar motor neurectomy) may improve digital flexor tightness and intrinsic spasticity in the patient with a clenched fist.

Neuromuscular Disorders

Arthrogrypotic Syndromes

- **Arthrogryposis multiplex congenita (amyoplasia)**
  - Overview
    - Nonprogressive disorder with multiple joints that are congenitally rigid (Fig. 3.36)
    - Can be myopathic, neuropathic, or both
    - Associated with a decrease in anterior horn cells and other neural elements of the spinal cord
    - Intelligence is normal.
  - Evaluation
    - Evaluation should include neurologic studies, enzyme tests, and muscle biopsy (at 3–4 months of age).
    - Affected patients typically have normal facies, normal intelligence, multiple joint contractures, and no visceral abnormalities.
    - Upper extremity involvement
      - Adduction and internal rotation of the shoulder
      - Extension of the elbow—no appreciable elbow crease
      - Flexion and ulnar deviation of the wrist
    - Lower extremity involvement
      - Teratologic hip dislocations

FIG. 3.36 Arthrogryposis. Typical appearance of a child in whom all four limbs are affected. Note the lack of creases at the elbows, the flexion contractures at the knees, and the severe clubfoot deformities.
From Benson M et al: *Children's orthopaedics and fractures,* New York, 1994, Churchill Livingstone, p 321.

    - Knee contractures (extended is classic, flexed is more common)
    - Resistant clubfoot
    - Vertical talus
  - The spine may be involved, with characteristic C-shaped (neuromuscular) scoliosis (33% of cases).
- □ Treatment
  - Upper extremity
    - Passive manipulation and serial casting to achieve some motion
    - Posterior elbow release with tricepsplasty to improve motion

- Active elbow flexion achieved through:
  - Anterior transfer of long head of triceps *or*
  - Bipolar transfer of latissimus or pectoralis major
- Steindler flexorplasty—transfers origin of flexor pronator to the anterior humerus (rarely indicated because unopposed wrist flexion produces deformity in patients without active extension)
- Osteotomies are also considered after 4 years of age to allow independent eating.
- One upper extremity should be left in extension at the elbow for positioning and perineal care and the other elbow in flexion for feeding.

- Lower extremity
  - Hip dislocation
    - Unilateral: medial open reduction with possible femoral shortening
    - Bilateral: typically left unreduced because ambulation is often preserved
    - Pavlik harness contraindicated
  - Knee contractures are treated with early (age 6–9 months) soft tissue releases (especially hamstrings).
  - Foot deformities (clubfoot and vertical talus) are initially treated with a soft tissue release, but later recurrences may necessitate bone procedures (talectomy).
    - The goal is for the foot to be stiff and plantigrade to enable the patient to wear shoes and possibly ambulate.
  - Knee contractures should be corrected before hip reduction to maintain the reduction.
- Spine
  - Fusion if curve is large (>50 degrees) or progressive
  - Large curve magnitude may impede function and ambulatory ability

▪ **Distal arthrogryposis syndrome**

□ Evaluation

- Autosomal dominant disorder that affects predominantly

hands and feet
- Ulnarly deviated fingers (at metacarpal joints), metacarpal and proximal interphalangeal flexion contractures, and adducted thumbs with web space thickening are common.

Table 3.12

Levels of Myelodysplasia.

Level	Characteristics				
	Hip	**Knee**	**Feet**	**Orthosis**	**Extent of Ambulation**
L1	External rotation/flexed	—	Equinovarus	HKAFO	Nonfunctional
L2	Adduction/flexed	Flexed	Equinovarus	HKAFO	Nonfunctional
L3	Adduction/flexed	Recurvatum	Equinovarus	KAFO	Household
L4	Adduction/flexed	Extended	Cavovarus	AFO	Household, some community
L5	Flexed	Limited flexion	Calcaneal valgus	AFO	Community
S1	—	—	Foot deformities	Shoes	Near normal

HKAFO, hip-knee-ankle-foot orthosis; *KAFO*, knee-ankle-foot orthosis.

- Clubfoot and vertical talus deformities are also common.

□ Treatment
- Comprehensive releases are more often required, combined with bony surgery.

▪ **Larsen syndrome**

□ Evaluation
- Similar to arthrogryposis in clinical appearance, but joints are less rigid
- Characterized primarily by multiple joint dislocations (including bilateral congenital knee dislocations), flattened facies, scoliosis, and clubfeet
- Cervical kyphosis (late myelopathy should be watched for) is important to recognize early.
- Affected patients have normal intelligence.
- Autosomal dominant form linked to mutation of gene encoding filamin B
- Autosomal recessive form linked to carbohydrate sulfotransferase 3 deficiency

□ Treatment
- Posterior cervical fusion for progressive cervical kyphosis

- Knee reduction may necessitate femoral shortening and excision of collateral ligaments; closed reduction often unsuccessful.
- Open hip reduction is required; closed reduction unsuccessful.

- **Multiple pterygium syndrome**
  - Evaluation
    - Autosomal recessive disorder whose name means “little wing” in Greek
    - Characterized by cutaneous flexor surface webs (knee and elbow), congenital vertical talus, and scoliosis
  - Treatment
    - Care must be taken when the webs are elongated because of the superficial nature of the neurovascular bundle.

Myelodysplasia (Spina Bifida)

- **Cause**
  - Disorder of incomplete spinal cord closure or rupture of the developing cord secondary to hydrocephalus
- **Classification**
  - Spina bifida occulta: defect in the vertebral arch, with confined cord and meninges
  - Meningocele: sac without neural elements protruding through the defect
  - Myelomeningocele: in spina bifida, sac with neural elements protrudes through the skin
  - Rachischisis: neural elements exposed, with no covering

Table 3.13

Milestones in Myelodysplasia.

Age (Months)	Function	Treatment
4–6	Head control	Positioning
6–10	Sitting	Supports/orthoses
10–12	Prone mobility	Prone board
12–15	Upright stance	Standing orthosis
15–18	Upright mobility	Trunk/extremity orthosis

  - Function is related primarily to the level of the defect and the associated congenital abnormalities.
  - Myelodysplasia level based on lowest functional level (Table 3.12)

        - L4 is a key level because the quadriceps can function and allow household ambulation.
        - L5 function is a good prognostic indicator of independent ambulation.
- **Evaluation**
    - Diagnosis
        - Can be diagnosed in utero (increased levels of alpha fetoprotein)
        - Related to a folate deficiency in utero
        - Type II Arnold-Chiari malformation is the most common comorbid condition.
    - Central axis
        - Sudden changes in function (rapid increase of scoliotic curvature, spasticity, new neurologic deficit, or increase in urinary tract infections) can be associated with tethered cord, hydrocephalus (most common), or syringomyelia.
        - Head CT (70% of myelodysplastic patients have hydrocephalus) and myelography or spinal MRI are required.
    - Fractures
        - Fractures are also common in myelodysplasia, most often about the knee and hip in children 3 to 7 years of age, and can frequently be diagnosed only if redness, warmth, and swelling are noted.
        - Fractures are commonly misdiagnosed as infection in these patients.
        - Fractures are treated conservatively with well-padded splints.
        - Fractures usually heal with abundant callus.
- **Treatment principles**
    - Careful observation of patients with myelodysplasia is important. Several myelodysplasia “milestones” have been developed to assess progress (Table 3.13).
    - Treatment involves a team approach (urologist, orthopaedist, neurosurgeon, and developmental pediatrician) to allow maximal function consistent with the myelodysplasia level and other abnormalities.
    - Proper use of orthoses is essential in patients with myelodysplasia.
    - Determination of ambulation potential is based on the level of the deficit and motivation of the child.
    - Surgery for myelodysplasia focuses on balancing of muscles and correction of deformities.
    - Increased attention has been focused on latex sensitivity in myelodysplastic patients (immunoglobulin E–mediated allergy).

        - A latex-free environment is necessary to prevent life-threatening allergic reactions.
- **Hip pathology**
    - Wide spectrum of hip disease
        - Flexion contractures
        - Hip subluxation and dislocation
        - DDH
        - Abduction or external rotation contracture
        - Management of the hip in patients with myelomeningocele is controversial.
    - Flexion contractures
        - Occur in patients with thoracic/high lumbar myelomeningocele as a result of unopposed hip flexors or in patients who sit most of the time
        - Treatment
            - Anterior hip release with tenotomy of the iliopsoas, sartorius, rectus femoris, and tensor fasciae latae
            - For patients with lesions at the low lumbar level, the psoas should be preserved for independent ambulation.
            - Hip abduction contracture can cause pelvic obliquity and scoliosis; it is treated with proximal division of the tensor fasciae latae and distal iliotibial band release (Ober-Yount procedure).
        - Adduction contractures are treated with adductor myotomy
    - Hip dislocation
        - Caused by paralysis of the hip abductors and extensors with unopposed hip flexors and adductors
        - Hip dislocation is most common at the level of L3–4.
        - Treatment
            - Containment is controversial, but in general, it is considered for low lumbar levels.
            - Redislocation may occur no matter what treatment is used to maintain the reduction.
            - Principles of treatment should follow those for any paralytic hip dislocation.
            - Late dislocation at the low lumbar level may be caused by a tethered cord, which must be released before the hip is reduced.
            - The functional outcome of thoracic-level myelomeningocele is independent of whether the hips are in proper position or dislocated.

            - Management should focus on limiting soft tissue contractures.
- **Knee problems**
    - Usually include quadriceps weakness (usually treated with knee-ankle-foot orthoses [KAFOs])
    - Flexion deformities are not problematic in patients who use wheelchairs but can be treated with hamstring release and posterior capsular release.
    - Recurvatum is rarely a problem and can be treated early with serial casting and KAFO.
        - Tenotomies (quadriceps lengthening) are sometimes required.
    - Valgus deformities are usually not a problem.
        - Occasionally, iliotibial band release, guided growth, or osteotomies are needed.
- **Ankle and foot deformities**
    - Objectives: (1) braceable and plantigrade feet and (2) muscle balance
    - Calcaneal deformity
        - Often caused by unopposed action of the tibialis anterior in patients with paralysis at the lower lumbar level
        - Predisposes to heel ulcers that can result in osteomyelitis of the calcaneus
        - Passive stretching is initial treatment, but tibialis anterior transfer to calcaneus often required
            - At time of transfer, should not be fixed in equinus position, which would predispose to distal tibial metaphyseal fracture.
    - Valgus foot and ankle
        - Valgus ankle deformity is common in ambulatory patients with the deformity in the distal tibia or subtalar joint (or both).
        - Surgical correction is warranted when pressure sores are present and orthotics fail to hold correction.
        - For skeletally immature patients: distal tibial hemiepiphysiodesis or Achilles tendon–fibular tenodesis
        - For skeletally mature patients: distal tibial osteotomy
        - In subtalar region valgus, AFOs are often helpful, but tendon release (anterior tibialis, Achilles), posterior tibialis lengthening, and other procedures may be required.
        - Triple arthrodesis should be avoided in most patients with myelodysplasia; it is used only for severe deformities with sensate feet.
    - Rigid clubfoot

- Secondary to retained activity or contracture of the tibialis posterior and tibialis anterior; common in patients with L4-level lesions
- Treatment consists of complete subtalar release through a transverse (Cincinnati) incision, lengthening of the tibialis posterior and Achilles tendons, and transfer of the tibialis anterior tendon to the dorsal midfoot.
- Talectomy may be appropriate for refractory clubfoot.

- **Spine problems**
  - Lumbar kyphosis or other congenital malformation of the spine as a result of a lack of segmentation or formation (i.e., hemivertebrae, diastematomyelia, unsegmented bars)
    - Treatment of kyphosis is based on problems with skin breakdown or the necessity of using upper extremities to hold up the torso.
    - Resection of the kyphosis (kyphectomy) with local fusion or fusion to the pelvis with instrumentation is required in severe cases.
  - Scoliosis can also occur with severe lordosis as a result of muscular imbalance that is caused by thoracic-level paraplegia.
    - Scoliosis develops in nearly all patients with thoracic-level paraplegia.
    - Bracing is generally unsuccessful in treating these spinal deformities.
    - Rapid curve progression can be associated with hydrocephalus or a tethered cord, which may manifest as lower extremity spasticity or an increase in urinary tract infections.
    - Severe progressive curves necessitate surgical treatment.
      - Infection rates are high because of frequent septicemia and poor skin quality over the lumbar spine.
- **Pelvic obliquity**
  - Result of prolonged unilateral hip contractures or scoliosis
  - Treatment
    - Custom seat cushions, thoracolumbosacral orthosis, spinal fusion, and ultimately pelvic osteotomies may be required.

Myopathies (Muscular Dystrophies)

- **Introduction**
  - Noninflammatory inherited disorders characterized by progressive

muscle weakness
  - □ Treatment focuses on PT, orthoses, genetic counseling, and surgery.
  - □ Several types of muscular dystrophy are classified on the basis of their inheritance patterns.

- ▪ **Duchenne muscular dystrophy**
  - □ Caused by absence of dystrophin protein
    - • Markedly elevated creatine phosphokinase (CPK) level and absence of dystrophin protein on muscle biopsy and DNA testing
    - • A muscle biopsy sample shows foci of necrosis and connective tissue infiltration.
    - • Dystrophin absence leads to poor muscle fiber regeneration and progressive replacement of muscle tissue with fibrofatty tissue.
    - • X-linked recessive inheritance (Xp21.2 dystrophin gene mutation; one-third of cases are from spontaneous mutation)
    - • Occurs in young boys
  - □ Physical findings
    - • Manifests as muscle weakness (proximal groups weaker than distal)
    - • Clumsy walking
    - • Decreased motor skills
    - • Lumbar lordosis
    - • Calf pseudohypertrophy
    - • Presence of Gowers sign (patient rises by walking the hands up the legs to compensate for gluteus maximus and quadriceps weakness) (Fig. 3.37)
    - • Hip extensors are typically the first muscle group affected.
    - • Also associated with low IQ, megacolon, volvulus, malabsorption
  - □ Treatment
    - • Goal is to keep patients ambulatory as long as possible.
    - • Patients lose independent ambulation by age 10 years.
      - • Although controversial, the use of KAFOs and release of contractures can extend walking ability for 2–3 years.
    - • Patients are usually wheelchair dependent by age 15 years.
    - • Patients usually die of cardiorespiratory complications before age 20 years.
    - • Newer medical treatment includes high-dose steroids, which have been shown to prevent scoliosis formation and prolong walking ability.
    - • Foot deformities

- Treat with tendo Achilles lengthening (TAL), split posterior tibialis tendon transfer into peroneus brevis (if tibialis posterior active in both stance and swing phase).
- Rancho procedure: TAL, tibialis posterior lengthening, split anterior tibialis transfer into dorsal cuboid

- Scoliosis
  - With no muscle support, scoliosis rapidly progresses in virtually all patients by age 14 years.
  - Patients can become bedridden by age 16 years as a result of spinal deformity and are unable to sit for more than 8 hours.
  - FVC decreases by 4% each year and by another 4% for every 10 degrees of thoracic scoliosis.
  - Scoliosis should be treated early (at 20 to 30 degrees of curvature), before pulmonary and cardiac function deteriorate.
  - Surgical approach includes posterior spinal fusion with segmental instrumentation to include the pelvis.

□ Differential diagnosis
- Becker muscular dystrophy (also sex-linked recessive with a decrease in dystrophin)
- Found in boys with red/green color blindness, with a similar but less severe picture

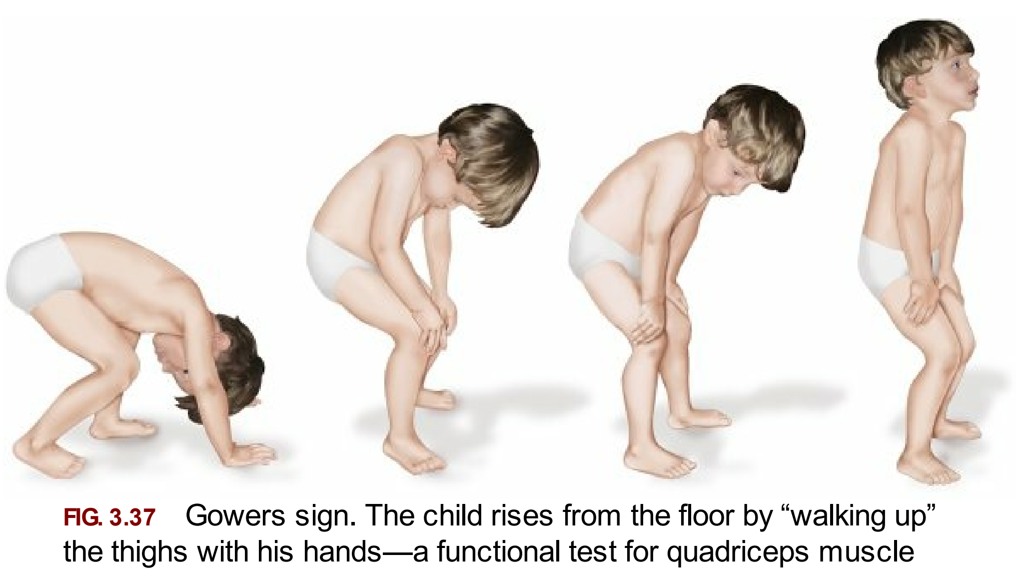


FIG. 3.37 Gowers sign. The child rises from the floor by “walking up” the thighs with his hands—a functional test for quadriceps muscle weakness. Note the bulky calf.
Redrawn from Herring JA, editor: *Tachdjian’s pediatric orthopaedics,* ed 3, Philadelphia, 2002, WB Saunders, p 85.

Table 3.14

Major Hereditary Motor Sensory Neuropathies.

Type	Terminology	Inheritance	Description
I	Charcot-Marie-Tooth syndrome (hypertrophic form)	Autosomal dominant	Peroneal weakness, slow nerve conduction, absence of reflexes
II	Charcot-Marie-Tooth syndrome (neuronal form)	Variable	Peroneal weakness, normal nerve conduction, normal reflexes
III	Dejerine-Sottas disease	Autosomal recessive	Begins in infancy, more severe

- Diagnosis of Becker muscular dystrophy applies to patients with the same examination findings but who live beyond 22 years without respiratory support.

- **Facioscapulohumeral muscular dystrophy**
  - Causes and findings
    - Autosomal dominant disorder typically observed in patients 6 to 20 years of age
    - Slow progression of muscle weakness involving muscles of facial expression and proximal upper extremity
    - Normal CPK level
    - Winging of the scapula
    - Inability to whistle
  - Treated with stabilization by means of scapulothoracic fusion
- **Limb-girdle muscular dystrophy**
  - Causes and findings
    - Autosomal recessive disorder seen in patients 10 to 30 years of age
    - Pelvic or shoulder girdle involvement
    - Increased CPK levels
- **Other muscular dystrophies**
  - Gowers (distal involvement; high incidence in Sweden); ocular, oculopharyngeal (high incidence among French Canadians)

Polymyositis and Dermatomyositis

- **Causes and findings**
  - Manifests as a febrile illness that may be acute or insidious
  - Females are predominantly affected and typically exhibit photosensitivity and increased CPK and ESR values.
  - Muscles are tender, brawny, and indurated.
  - Biopsy findings demonstrate the pathognomonic inflammatory

response.

- **Treatment**
  - Anti–tumor necrosis factor (TNF) medication can decrease symptoms and control flares.

Hereditary Neuropathies

- **Disorders associated with multiple central nervous system lesions**
- **Friedreich ataxia**
  - Causes and findings
    - Autosomal recessive disorder with problems with the frataxin gene (GAA repeat at 9q13)
    - Spinocerebellar degenerative disease with mean onset between 7 and 15 years of age
    - Manifests as staggering wide-based gait, nystagmus, cardiomyopathy, a cavus foot, and scoliosis
    - Involves motor and sensory defects, with an increase in polyphasic potentials on electromyograms
    - Use of a wheelchair is needed by age 15 years; death occurs between ages 40 and 50 years, usually from cardiomyopathy.
  - Treatment
    - Foot deformities treated with plantar release with or without metatarsal and calcaneal osteotomies early, and triple arthrodesis later
    - Spinal fusion when curves progress to 50 degrees; number of levels should be determined as for a neuromuscular curve.
    - Bracing ineffective for treatment of scoliosis
- **Hereditary sensory motor neuropathies: a group of inherited neuropathic disorders with similar characteristics (** Table 3.14)
  - Charcot-Marie-Tooth disease (peroneal muscular atrophy)
    - Causes and findings
      - Autosomal dominant sensory motor demyelinating neuropathy
      - Two forms are described: a hypertrophic form with onset during the second decade of life, and a neuronal form with onset during the third or fourth decade but with more extensive foot involvement.
      - Orthopaedic manifestations include pes cavus, hammer toes with frequent corns and calluses, peroneal weakness, and muscular atrophy usually distal to the knees ("stork legs").

        - Involves motor defects much more than sensory defects
        - Low nerve conduction velocities with prolonged distal latencies are noted in peroneal, ulnar, and median nerves.
        - Diagnosis is made most reliably by DNA testing for a duplication of a genomic fragment that encompasses the peripheral myelin protein-22 *(PMP22)* gene on chromosome 17.
        - Intrinsic wasting is noted in the hands.
        - Most common cause of pes cavus
        - The most severely affected muscles are the tibialis anterior, peroneus longus, and peroneus brevis.
            - Plantar flexion of the first ray is the foot deformity that occurs first, as a result of a weakened tibialis anterior muscle.
    - Treatment for feet
        - Plantar release, posterior tibial tendon transfer (if hindfoot varus is flexible); hindfoot flexibility tested via Coleman block test
            - The Coleman block test—block placed under lateral rays, allowing first ray to plantar flex (see Fig. 3.20)
            - Flexible hindfoot will correct to neutral.
            - Rigid hindfoot will not correct to neutral.
        - Triple arthrodesis (poor long-term results) versus calcaneal and metatarsal osteotomies (if heel varus is fixed and the foot not too short)
        - The Jones procedure for hammer toes, and intrinsic procedures for hand deformity
- □ Dejerine-Sottas disease
    - Causes and findings
        - Autosomal recessive hypertrophic neuropathy of infancy
        - Delayed ambulation, pes cavus foot, footdrop, stocking-glove dysesthesia, and spinal deformities are common.
        - The patient is wheelchair dependent by the third or fourth decade.

▪ **Riley-Day syndrome (dysautonomia)**

- Causes and findings
  - One of five inherited (autosomal recessive) sensory and autonomic neuropathies
  - This disease is found only in patients of Ashkenazi Jewish ancestry.
  - Clinical presentation includes dysphagia, alacrima, pneumonia, excessive sweating, postural hypotension, and sensory loss.

Myasthenia Gravis

- **Causes and findings**
  - Chronic disease with insidious development of easy muscle fatigability after exercise
  - Caused by competitive inhibition of acetylcholine receptors at the motor end plate by antibodies produced in the thymus gland
- **Treatment consists of cyclosporine, antiacetylcholinesterase agents, or thymectomy.**

Anterior Horn Cell Disorders

- **Poliomyelitis**
  - Causes and findings
    - Viral destruction of anterior horn cells in the spinal cord and brainstem motor nuclei
    - This disease all but disappeared in the United States after a vaccine was developed.
    - Still occurs in underdeveloped countries and in locales where vaccination is unpopular
    - *Postpolio syndrome* is an aging phenomenon where more nerve cells become inactive with time.
    - Patients should exercise at subexhaustion levels to tone muscles but prevent muscle breakdown.
    - Many surgical procedures in current use were originally developed for the treatment of polio.
    - The hallmark of polio is muscle weakness with normal sensation.
- **Spinal muscular atrophy**
  - Causes and findings
    - Autosomal recessive, associated with loss of survival motor neuron gene *(SMN)*, which causes lack of SMN-1 protein in all types

- Loss of anterior horn cells from the spinal cord. Three types (Table 3.15):
  - Type I—acute Werdnig-Hoffman: manifestation earlier than age 6 months, absence of deep tendon reflexes, tongue fasciculations; usually deceased by age 2 years
  - Type II—chronic Werdnig-Hoffman: manifestation at 6 to 12 months, muscle weakness worse in lower extremities; patient able to sit, cannot walk, may live into fifth decade
  - Type III—Kugelberg-Welander disease: manifestation in adolescence patients walk as children, use wheelchairs as adults; proximal muscle weakness
    - Patients have symmetric paresis with more involvement of the lower extremity and proximal muscles.
    - All three types lose SMN-1; disease severity depends on the amount of SMN-2 remaining, with type I having the least amount of SMN-2.
    - Hip subluxation or dislocation is common and treated nonoperatively.

□ Scoliosis is treated surgically, like Duchenne muscular dystrophy curves, except that fusion may be required while patient is still ambulatory (may result in loss of ambulatory ability).

- Upper extremity function may decrease after spinal fusion, but this decrease may be temporary.
- Before fusion, the surgeon must ensure that the patient does not have lower extremity muscle contractures that could interfere with sitting balance.

Acute Idiopathic Postinfectious Polyneuropathy (Guillain-Barré Syndrome)

▪ **Causes and findings**

□ Symmetric ascending motor paresis caused by demyelination after viral infection

□ Cerebrospinal fluid protein level typically increased

□ Usually self-limiting; better prognosis with the acute form

Overgrowth Syndromes

- **Proteus syndrome**
  - Causes and findings
    - Overgrowth of hands and feet, with bizarre facial disfigurement
    - Scoliosis, genu valgum, hemangiomas, lipomas, and nevi also common
    - Must be differentiated from neurofibromatosis and McCune-Albright syndrome
- **Klippel-Trénaunay syndrome**
  - Causes
    - Overgrowth caused by underlying arteriovenous malformations
    - Associated with cutaneous hemangiomas and varicosities
  - Treatment
    - Embolization of vascular abnormalities in selected patients
    - Severely hypertrophied extremities often must be amputated.

Table 3.15

Spinal Muscular Atrophy.

Type	Description	Age at Onset	Prognosis
I	Acute Werdnig-Hoffman disease	<6 mo	Poor
II	Chronic Werdnig-Hoffman disease	6–24 mo	May live into fifth decade
III	Kugelberg-Welander disease	2–10 yr	Good: may need respiratory support

    - Epiphysiodesis is mainstay for treatment of deformities of limb length.
- **Hemihypertrophy**
  - Causes
    - Can be caused by various syndromes, but most cases are idiopathic
    - Most commonly known cause is neurofibromatosis.
    - Disorder is often associated with renal abnormalities (especially Wilms tumor).
      - Best evaluated with serial ultrasonography until age 5 years

- Treatment
  - Epiphysiodesis versus lengthening to correct leg length discrepancies
  - Length can be manipulated, but the girth of the limb will always be asymmetric.

Bone Dysplasias

Introduction

- **Definition:** *dysplasia* means abnormal development.
  - Shortening of the involved bones affects specific portions of the growing bone (Fig. 3.38), hence the term *dwarfism*. Most forms of dwarfism are related to genetic defects (single or multiple genes [Table 3.16]).
- **Proportionate dwarfism: symmetric decreases in both trunk and limb length (e.g., as occurs with mucopolysaccharidoses)**
- **Disproportionate dwarfism**
  - Short-trunk variety (e.g., Kniest syndrome–spondyloepiphyseal)
  - Short-limb variety (e.g., achondroplasia, diastrophic dysplasia)
    - Short-limb dwarfism can be subclassified by the region of the limb that is short (e.g., rhizomelic—proximal, mesomelic—middle, acromelic—distal).
    - All types of dwarfism are summarized in Table 3.17.

Achondroplasia

- **Introduction and etiology**
  - Achondroplasia is the most common form of disproportionate short-limbed dwarfism.
  - **Autosomal dominant condition; 80% of cases caused by a spontaneous mutation in the fibroblast growth factor receptor 3 *(FGFR3)***
  - **Leads to a gain-of-function mutation or uncontrolled activation**
  - Abnormal endochondral bone formation that is more affected than appositional growth
  - Achondroplasia is categorized as a physeal dysplasia (cartilaginous proliferative zone)
  - Quantitative, not qualitative, cartilage defect

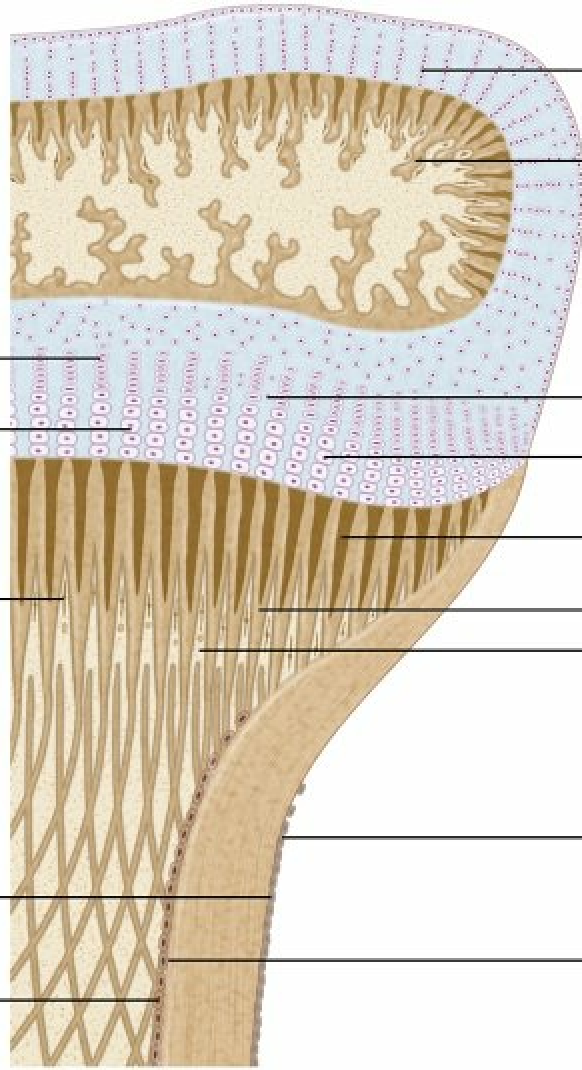


FIG. 3.38 Locations of abnormalities that lead to dysplasias.
Adapted from Rubin P: *Dynamic classification of bone dysplasias,* Chicago, 1964, Year Book Medical Publishers.

- May be associated with advanced paternal age

- **Signs and symptoms**
  - Normal trunk and short limbs (rhizomelic) with hypotonia
  - Frontal bossing, button nose, small nasal bridge, trident hands (inability to approximate extended middle and ring fingers) (Fig. 3.39)

Table 3.16

Pediatric Congenital Disorders and Associated Genetic Defects.

Disorder	Genetic Defect
Achondroplasia	*FGFR3*
Hypochondroplasia	*FGFR3*
Thanatophoric dysplasia	*FGFR3*
Pseudoachondroplasia	*COMP*
Multiple epiphyseal dysplasia type I	*COMP*
Multiple epiphyseal dysplasia type II	Collagen type IX

Spondyloepiphyseal dysplasia congenita	Collagen type II
Kniest syndrome	Collagen type II
Stickler syndrome (hereditary arthroophthalmopathy)	Collagen type II
Diastrophic dysplasia	Sulfate transporter gene
Schmid metaphyseal chondrodysplasia	Collagen type X
Jansen metaphyseal chondrodysplasia	*PTHRP*
Craniosynostosis	*FGFR2*
Cleidocranial dysplasia	*CBFA1*
Hypophosphatemic rickets	*PEX*
Marfan syndrome	Fibrillin-1
Osteogenesis imperfecta	Collagen type I
Ehlers-Danlos syndrome	
Types I and II	Collagen type V
Type IV	Collagen type IV
Types VI and VII	Collagen type I
Duchenne/Becker muscular dystrophies	Dystrophin
Limb-girdle dystrophies	Sarcoglycan and dystroglycan complex
Charcot-Marie-Tooth disease	*PMP22*
Spinal muscular atrophy	Survival motor neuron protein
Myotonic dystrophy	Myotonin
Friedreich ataxia	Frataxin
Neurofibromatosis	Neurofibromin
McCune-Albright syndrome	cAMP

cAMP, Cyclic adenosine monophosphate; *CBFA1,* transcription factor for osteocalcin; *COMP,* cartilage oligomeric matrix protein; *FGFR3* and *FGFR2,* fibroblast growth factor receptors 3 and 2; *PEX,* period-extender gene; *PMP22,* peripheral myelin protein-22; *PTHRP,* parathyroid hormone–related peptide.

- **Thoracolumbar kyphosis (which usually resolves around the age at ambulation)**
- Lumbar stenosis (most likely to cause disability) and excessive lordosis (short pedicles with decreased interpedicular distances)
- Compression at foramen magnum may cause periods of sleep apnea
- Radial head subluxation
- Normal intelligence but delayed motor milestones
- Although sitting height may be normal, standing height is below the

third percentile.

- **Radiographic findings**
  - Spine: narrowed interpedicular distance in the distal spine (L1–S1), T12–L1 wedging, generalized posterior vertebral scalloping
  - **Pelvis: champagne glass pelvic outlet (wider than deep), tombstone pelvis (squaring of iliac wings)**
- **Treatment**
  - Lumbar stenosis: decompression and fusion of the spine for a developing neurologic deficit (usually in children >10 years)
  - Decompression for foramen magnum stenosis
  - Progressive kyphosis: if fail bracing fails, anterior and posterior fusion is indicated for residual kyphosis greater than 60 degrees by age 5 years
  - Genu varum: tibial osteotomies or hemiepiphysiodesis

Pseudoachondroplasia

- **Clinically similar to achondroplasia**
- **Autosomal dominant**
- **Defect of cartilage oligometric matrix protein (COMP) on chromosome 19**
- **Signs and symptoms**
  - Normal facies
  - Cervical instability and scoliosis with increased lumbar lordosis
  - Significant lower extremity bowing
  - Hip, knee, and elbow flexion contractures with precocious osteoarthritis
- **Radiographic findings: metaphyseal flaring and delayed epiphyseal ossification**

Table 3.17

Summary of Major Types of Dwarfism.

Dwarfism Type	Genetic Defect	Inheritance	Pathognomonic Feature
Achondroplasia	*FGFR3*	AD	Trident hands and lumbar kyphosis
Pseudoachondroplasia	*COMP*	AD	Normal facies and cervical instability
Spondyloepiphyseal dysplasia	Type II collagen	Congenita: AD Tarda: X-linked recessive	Epiphyseal fragmentation with spine involvement
Kniest syndrome	Type II collagen	AD	Retinal detachment and dumbbell-shaped bone
Jansen metaphyseal chondroplasia	*PTHRP*	AD	Hypercalcemia with metaphyseal expansion
Schmid metaphyseal chondroplasia	Type X collagen	AD	Coxa vara with proximal femur involvement
McKusick metaphyseal chondroplasia	Unknown *COMP*	AR	Odontoid hypoplasia
Multiple epiphyseal dysplasia	Type II collagen	AD	Bilateral hip involvement
Mucopolysaccharidoses (see Table 3.18)			
Diastrophic dysplasia	Sulfate transport protein	AR	Cauliflower ears and kyphoscoliosis
Cleidocranial dysplasia	*CBFA1*	AD	Aplasia of clavicles and coxa vara

AD, Autosomal dominant; *AR,* autosomal recessive; *CBFA1,* transcription factor for osteocalcin; *COMP,* cartilage oligomeric matrix protein; *FGFR3,* fibroblast growth factor receptor 3; *PTHRP,* parathyroid hormone–related peptide.

Multiple Epiphyseal Dysplasia

- **Clinical features**

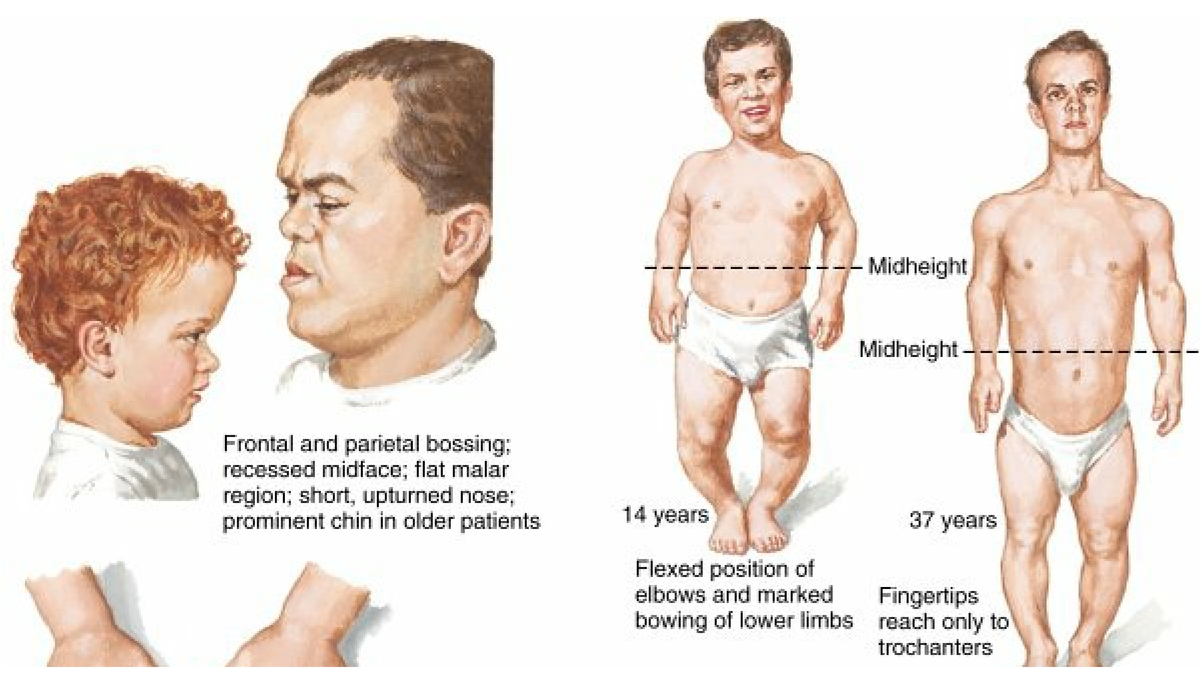
- □ Short-limbed, disproportionate dwarfism that often is not manifested until between the ages of 5 and 14
- □ Multiple epiphyseal dysplasia (MED) be differentiated from spondyloepiphyseal dysplasia
- □ Mild form (Ribbing) and more severe form (Fairbanks)

▪ **Causes**

- □ Gene mutations: most common in COMP, but also in type IX collagen

▪ **Radiographic findings**

- □ MED is characterized by irregular delayed ossification at multiple epiphyses (Fig. 3.40).
- □ Short, stunted metacarpals and metatarsals, irregular proximal femora, abnormal ossification (tibial slant sign and flattened femoral condyles, patella with double layer), valgus knees (early osteotomy should be considered), waddling gait, and early hip arthritis are common.



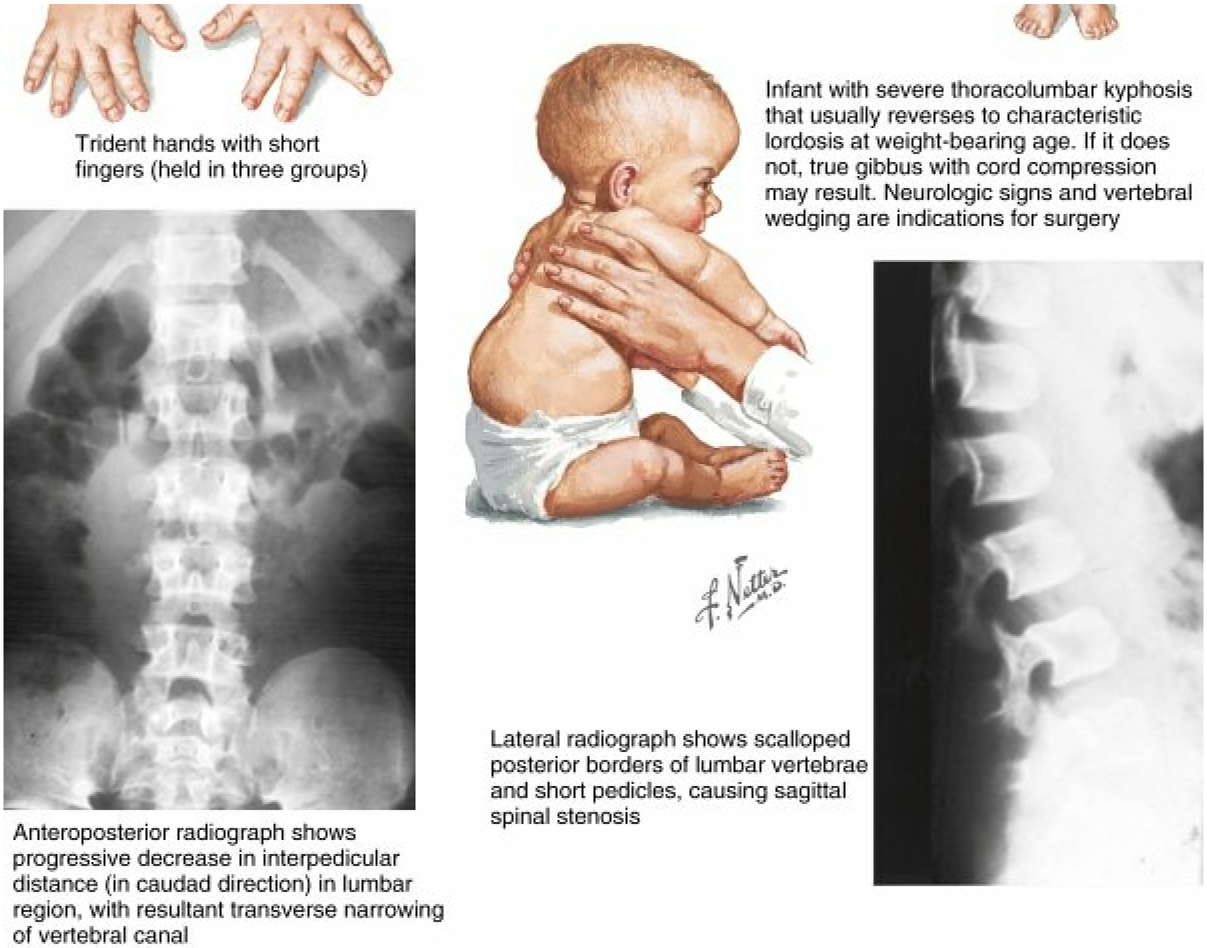


FIG. 3.39 Clinical features of achondroplasia. Note the space between the middle and ring fingers.
From Greene WB: *Netter's orthopaedics,* Philadelphia, 2005, WB Saunders, Fig. 3.6.

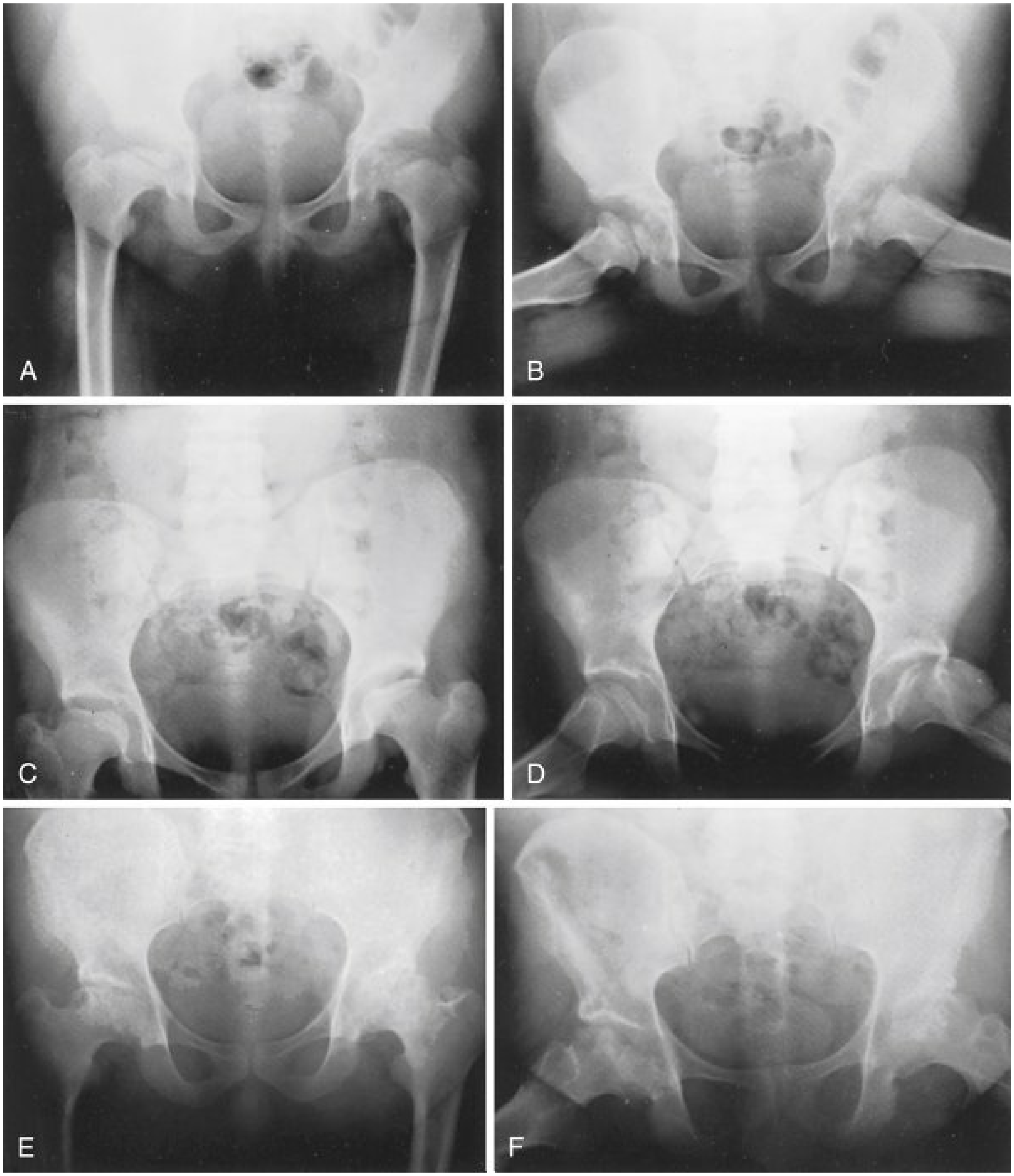


FIG. 3.40 Multiple epiphyseal dysplasia in two sisters and their 40-year-old father. Anteroposterior (AP) (A) and frog-leg lateral (B) radiographs of both hips of a 12-year-old girl. Note the irregularity and flattening of the capital femoral epiphyses. Involvement is bilateral. AP (C) and lateral (D) views of both hips of the 14-year-old sister showing similar changes. AP (E) and lateral (F) radiographs of the father's hips. Note the irregularity of the femoral heads and marked degenerative arthritis in both hips.

From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 40-41.

- ☐ Proximal femoral involvement can be confused with that in Perthes disease.

    - MED is bilateral and symmetric, characterized by early acetabular changes, and not accompanied by metaphyseal cysts.
- **Treatment**
  - Physiodesis or osteotomy for limb alignment deformity
  - PT to maintain joint motion

Spondyloepiphyseal Dysplasia

- **Defect in type II collagen**
- **Must be differentiated from MED**
  - Both MED and spondyloepiphyseal dysplasia (SED) involve abnormal epiphyseal development in the upper and lower extremities.
  - Distinguishing feature of SED is the added spine involvement.
  - Scoliosis: typically with a sharp curve over a small number of vertebrae
    - Atlantoaxial instability with cervical myelopathy
- **Retinal detachment and respiratory problems are common.**

Chondrodysplasia Punctata

- **Characterized by multiple punctate calcifications seen on radiographs during infancy**
- **Autosomal dominant form (Conradi-Hünermann) has a wide variation of clinical expression.**
- **Autosomal recessive rhizomelic form usually fatal during first year of life**
  - Cataracts, asymmetric limb shortening that may necessitate surgical correction, and spinal deformities are common.

Table 3.18

Mucopolysaccharidoses.

Syndrome	Inheritance	Intelligence	Cornea	Urinary Excretion	Other
Hurler	AR	Below normal	Cloudy	Dermatan/heparan sulfate	Worst prognosis
Hunter	XR	Below normal	Clear	Dermatan/heparan sulfate	
Sanfilippo	AR	Below normal	Clear	Heparin sulfate	Normal development until age 2 yr
Morquio	AR	Normal	Cloudy	Keratan sulfate	Most common

AR, Autosomal recessive; *XR*, X-linked recessive.

Kniest Syndrome

- **Autosomal dominant; defect in type II collagen**
- **Short-trunked, disproportionate dwarfism**
- **Joint stiffness/contractures, scoliosis, kyphosis, dumbbell-shaped femora, and hypoplastic pelvis and spine**
- **Recurrent otitis media and loss of hearing are common.**
- **Radiographic findings: osteopenia and dumbbell-shaped bones**
- **Treatment**
    - Early therapy for joint contractures is required.
    - Reconstructive procedures may be required for early hip degenerative arthritis.

Metaphyseal Chondrodysplasia

- **Heterogeneous group of disorders characterized by metaphyseal changes of tubular bones with normal epiphyses**
- **Types**
    - Jansen (rare): most severe form
        - Genetic defect in parathyroid hormone–related peptide
        - Autosomal dominant inheritance
        - Mental retardation, markedly short-limbed dwarfism with wide eyes, monkeylike stance, and hypercalcemia
        - Striking bulbous metaphyseal expansion of long bones is a distinctive radiographic finding.

- Schmid type
  - More common, less severe form
  - Genetic defect is in type X collagen, transmitted by autosomal dominant inheritance; short-limbed dwarfism is not diagnosed until patient is older, as a result of coxa vara and genu varum.
  - Predominantly involves proximal femur. Gait is often Trendelenburg, and patients have increased lumbar lordosis.
  - Condition often confused with rickets, but laboratory test results normal
- McKusick type
  - Autosomal recessive inheritance; cartilage-hair dysplasia (hypoplasia of cartilage and small diameter of hair) is observed most commonly among the Amish population and in Finland.
  - Atlantoaxial instability is common (odontoid hypoplasia).
  - Ankle deformity develops as a result of distal fibular overgrowth.
  - Affected patients may have abnormal immunocompetence and have an increased risk for malignancies, intestinal malabsorption, and megacolon.

Progressive Diaphyseal Dysplasia (Camurati-Engelmann Disease)

- **Clinical features**
  - Autosomal dominant inheritance
  - Affected children are often "late walkers" (because of associated muscle weakness).
  - Symmetric cortical thickening of long bones
  - Tibia, femur, and humerus are most often involved (in that order), with only the diaphyseal portion of bone affected.
  - LLD should be watched for.
- **Radiographic findings**
  - Widened fusiform diaphyses with increased bone formation and sclerosis
- **Treatment**
  - Salicylates, NSAIDs, and steroids for refractory cases

Mucopolysaccharidosis

- **Differentiated on the basis of the presence of complex sugars in the urine**

- **Accumulation of mucopolysaccharides as a result of a hydrolase enzyme deficiency**
- **Produces a proportionate dwarfism**
- **Types (** Table 3.18)
  - Morquio syndrome (autosomal recessive inheritance)
    - Most common form; manifests by age 18 months to 2 years
    - Waddling gait, genu valgum (knock-knee), thoracic kyphosis, cloudy corneas, and normal intelligence
    - Urinary excretion of keratan sulfate
    - Bony changes include a thickening skull, wide ribs, anterior beaking of vertebrae, a wide, flat pelvis, coxa vara with unossified femoral heads, and bullet-shaped metacarpals.
    - **C1–2 instability (caused by odontoid hypoplasia) can be seen, manifesting as myelopathy and necessitating decompression and cervical fusion. Radiographs of the cervical spine to assess for stability are recommended prior to surgery.**
  - Hurler syndrome (autosomal recessive inheritance)
    - Most severe form
    - Urinary excretion of dermatan/heparan sulfate
    - Mental retardation
    - Bone marrow transplantation has increased the lifespan for patients with this disorder.
  - Hunter syndrome (sex-linked recessive inheritance)
    - Urinary excretion of dermatan/heparan sulfate
    - **Approximately 80% of patients have skeletal manifestations**
      - **Joint stiffness and contractures**
      - **Acetabular and femoral head dysplasia is common**
    - Mental retardation
    - Bone marrow transplantation has increased the lifespan for patients with this disorder.
  - Sanfilippo syndrome (autosomal recessive inheritance)

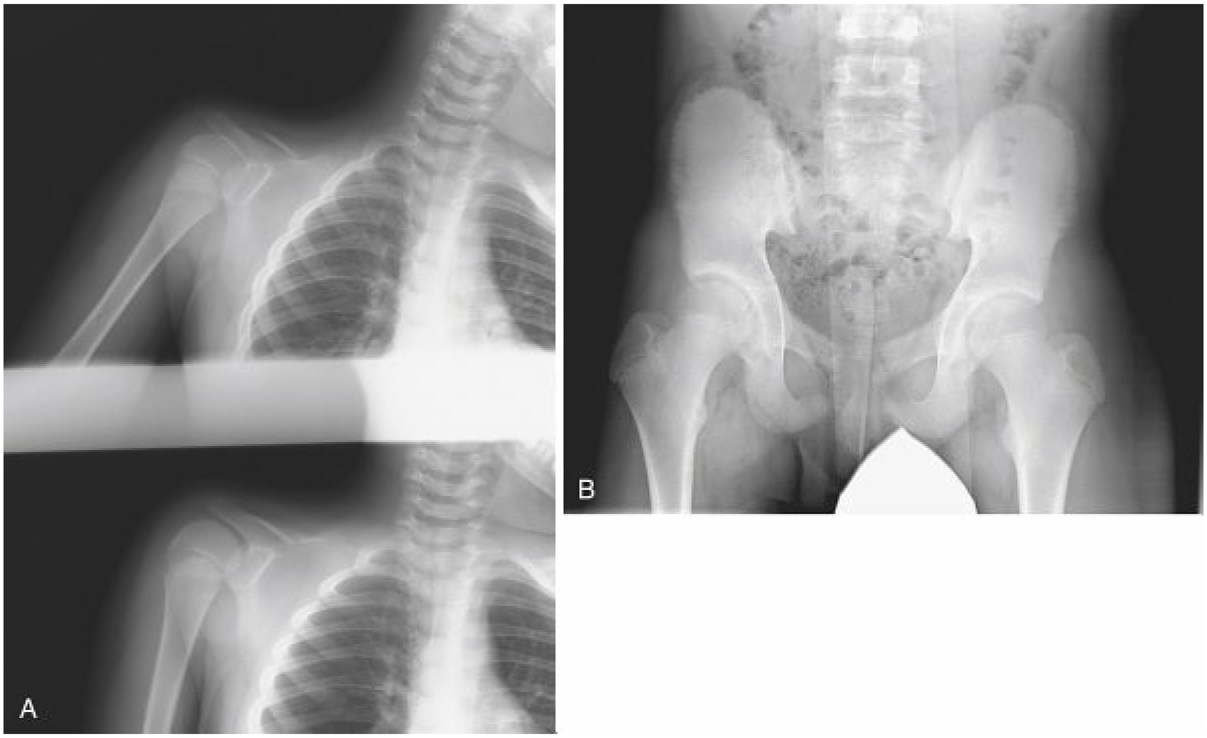


FIG. 3.41 Cleidocranial dysplasia. (A) Anteroposterior (AP) shoulder radiographs show hypoplasia of the clavicle. (B) AP pelvic radiograph shows a lack of ossification of the symphysis pubis.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 40-100.

- Urinary excretion of heparan sulfate
- Associated with mental retardation
- Bone marrow transplantation has increased the lifespan for patients with this disorder.

Diastrophic Dysplasia

- **Autosomal recessive inheritance; severe short-limbed dwarfism**
- **Deficiency in** *DTDST* gene, which codes for sulfate transport protein
- **Cleft palate (59% of cases)**
- **Severe joint contractures (especially hip and knee)**
- **Cauliflower ears (80% of cases), hitchhiker's thumb**
- **Rigid clubfeet**
- **Radiographic findings**
  - Spine radiographs reveal cervical kyphosis (often severe, necessitating immediate treatment), thoracolumbar kyphoscoliosis (83% of cases), spina bifida occulta, and atlantoaxial instability.
- **Treatment**
  - Quadriplegia is a major concern with deformities of the cervical spine.
    - Early fusion required
  - Surgical release of clubfoot deformities
  - Osteotomies for contractures
  - Spinal fusion often required

Cleidocranial Dysplasia (Dysostosis)

- **Autosomal dominant inheritance**
- **Defect in transcription factor for osteocalcin** *(CBFA1)*
- **Proportionate dwarfism that affects bones formed by intramembranous ossification (clavicles, cranium, pelvis)**
- **Radiographic findings**
  - Hypoplasia or aplasia of the clavicle (no intervention necessary) (Fig. 3.41)
  - Delayed closure of skull sutures and frontal bossing
  - Coxa vara
  - Delayed ossification of the pubis with small iliac wings
  - Wormian-type bone
- **Treatment**
  - Intertrochanteric valgus osteotomy if neck-shaft angle is less than 100 degrees

Osteopetrosis

- **Failure of osteoclastic resorption, probably secondary to a defect in the thymus, leading to dense bone (so-called marble bone)**
- **The mild form is autosomal dominant; the "malignant" form is autosomal recessive.**
- **Most common mutation in malignant form is a defect in *TCIRG1* that results in diminished carbonic anhydrase activity**
- **Clinical features**
  - Bone pain
  - Loss of the medullary canal can cause anemia, encroachment on the optic and oculomotor nerves, and blindness.
- **Radiographic findings (** Fig. 3.42)
  - Rugger jersey spine
  - Marble bone
  - Erlenmeyer flask deformity of proximal humerus and distal femur
- **Treatment**
  - Healing is normal, but amount of time for healing may be prolonged.
  - Bone marrow transplantation may be helpful for treating the "malignant" form.

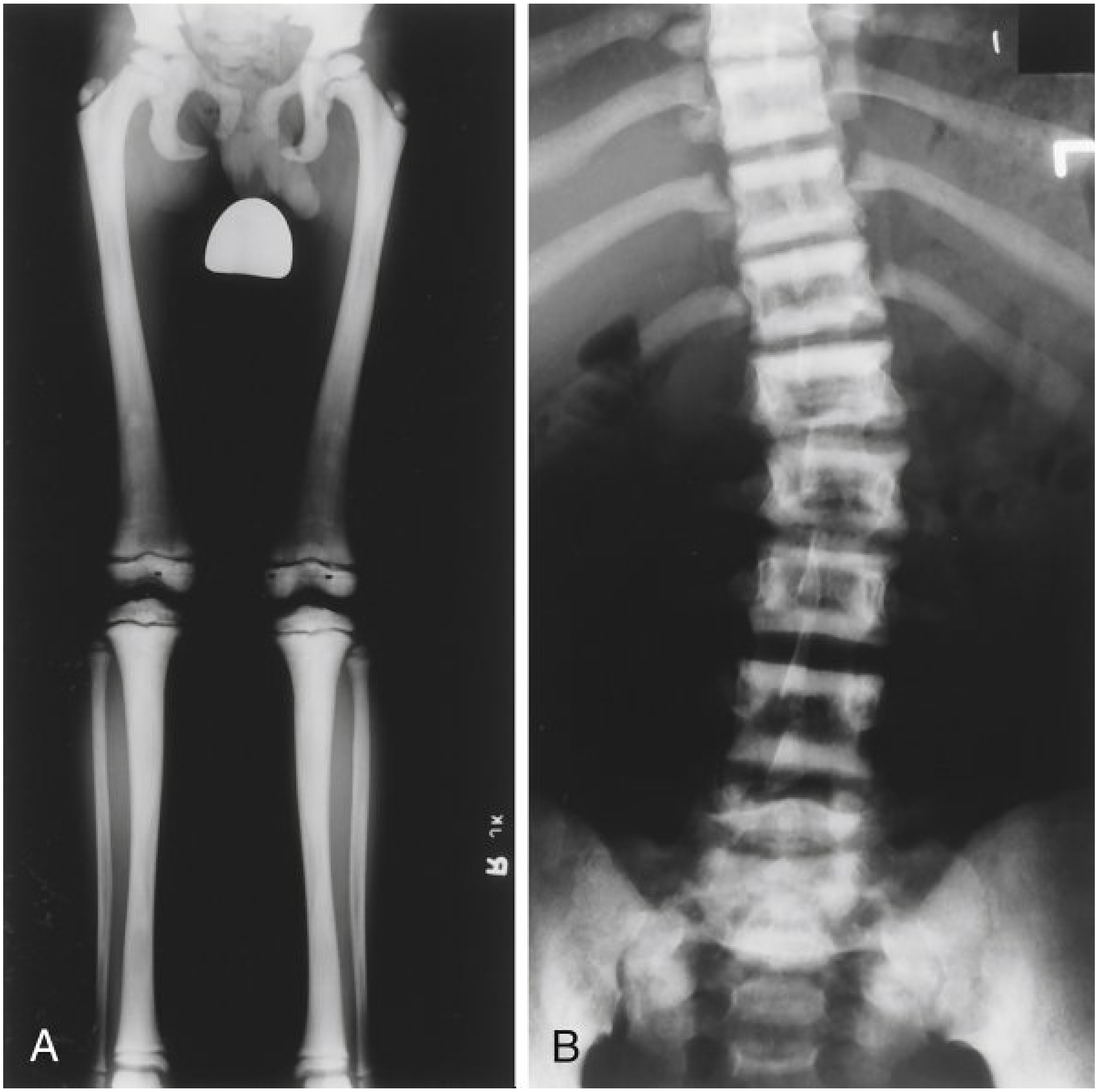


FIG. 3.42 Osteopetrosis. (A) Five-year-old child. The intramedullary canals have been filled with bone. There is no distinction between cortical and cancellous bone. (B) "Rugger jersey" spine in a 16-year-old patient.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics,* ed 5, Philadelphia, 2014, Elsevier Saunders, Figs. 40-77 and 40-79.

Infantile Cortical Hyperostosis (Caffey Disease)

- **Clinical features**
  - □ Soft tissue swelling and bony cortical thickening (especially jaw and ulna) that follow a febrile illness in infants 0 to 9 months old
  - □ This disorder may be differentiated from trauma (and child abuse) on the basis of single-bone involvement.
- **Infection, scurvy, tumor, and progressive diaphyseal dysplasia may be included in the differential diagnosis.**
- **The condition is benign and self-limiting.**

Section 10 Syndromes With Orthopaedic Manifestations

Down Syndrome (Trisomy 21)

- **Most common chromosomal abnormality**
- **Incidence increases with advancing maternal age**
- **Chromosome 21 is the location of genes that encode for type VI collagen (** *COL6A1* and *COL6A2*)
  - Abnormal type VI collagen is thought to be cause of generalized joint laxity and other orthopaedic problems
- **Clinical features**
  - Orthopaedic problems
    - Metatarsus primus varus and pes planus
    - Spinal abnormalities: atlantoaxial instability (Fig. 3.43), scoliosis (50% of cases), spondylolisthesis (6% of cases)
    - Hip instability
    - SCFE
    - Patellar dislocation
    - Generalized ligamentous laxity
  - Associated problems
    - Hypotonia and mental retardation
    - Heart disease with atrial septal defect (50% of cases)
    - Endocrine disorders (hypothyroidism and diabetes) and premature aging
- **Treatment**
  - Cervical spine instability
    - Usefulness of screening controversial, with exception of preoperative assessment before administration of anesthetic
    - Special Olympics requires cervical spine x-ray screening for participation in selected sports.
    - General recommendations
      - ADI < 4.5 mm: no restrictions
      - ADI 4.5–10 mm: avoidance of contact sports, diving, and gymnastics
      - ADI > 10 mm or symptoms/cord signal changes on MRI: C1–2 fusion
        - Complication rate of up to 50% reported
  - Scoliosis
    - Bracing for 25- to 30-degree curves
    - Surgery for 50- to 60-degree curves
  - Hip: initially may be treated with closed reduction, but capsulorrhaphy,

pelvic osteotomy, and femoral osteotomy may be required
  - Patellar instability: if symptomatic, then lateral release, medial reefing, or bony realignment of the patellar tendon should be considered.

Turner Syndrome

- **45XO genotype**
- **Clinical features**
  - Short stature, lack of sexual development, webbed neck, and cubitus valgus
  - Idiopathic scoliosis is common. Growth hormone therapy can exacerbate scoliosis.
  - Malignant hyperthermia is common with anesthetic use.
  - Must be differentiated from Noonan syndrome (same appearance except for normal gonadal development, mental retardation, and more severe scoliosis)
  - Osteoporosis is common.
  - Genu valgum and shortening of fourth and fifth metacarpals, which usually necessitate no treatment

Prader-Willi Syndrome

- **Partial chromosome 15 deletion (missing portion from father)**

FIG. 3.43 Gross atlantoaxial instability in an 11-year-old boy with Down syndrome. His gait was clumsy, and he had poor coordination of the extremities. Therefore, he underwent posterior stabilization.
From Benson M et al: *Children's orthopaedics and fractures,* New York, 1994, Churchill Livingstone, p 590.

- **Clinical features**
  - □ Floppy, hypotonic infant
  - □ Intellectual impairment
  - □ Insatiable appetite resulting in significant obesity
  - □ Growth retardation
  - □ Hypoplastic genitalia
  - □ Hip dysplasia and juvenile-onset scoliosis

Marfan Syndrome

- **Defect in fibrillin-1 *(FBN1)***
- **Autosomal dominant inheritance**
- **Clinical features**
  - □ Arachnodactyly (long, slender fingers; peeking thumb sign)
  - □ Pectus deformities
  - □ Scoliosis (50% of cases)
  - □ Acetabular protrusion (15%–25%)
  - □ Cardiac abnormalities (aortic dilation)
  - □ Ocular abnormalities (superior lens dislocation in 60%)
  - □ Dural ectasia and meningocele
  - □ Joint laxity
- **Treatment**
  - □ Joint laxity is treated conservatively.
  - □ Bracing for scoliosis is usually ineffective.
  - □ Curves may necessitate anterior and posterior fusion.
  - □ **Echocardiographic and cardiologic evaluations are required before surgery.**

- Acetabular protrusion should be observed unless the patient has severe symptoms.

Homocystinuria

- **Autosomal recessive inborn error of methionine metabolism (decreased enzyme cystathionine β-synthase)**
  - Accumulation of the intermediate metabolite homocysteine
  - Diagnosis is made through demonstration of increased homocysteine in urine (cyanide-nitroprusside test).
- **Clinical features**
  - Osteoporosis
  - Marfanoid habitus (but with stiffening joints)
  - Inferior lens dislocation
  - Differentiated from Marfan syndrome on the basis of the direction of lens dislocation and the presence of osteoporosis in homocystinuria
  - Central nervous system effects, including mental retardation, are common in this disorder.
- **Early treatment with vitamin B_6** and a diet with decreased amounts of methionine are often successful.

Ehlers-Danlos Syndrome

- **Autosomal dominant disorder of type V collagen (coexpressed with type I collagen)**
- **Clinical features**
  - Hyperextensibility and cigarette paper skin
  - Joint hypermobility and dislocation
  - Beighton score used to assess hypermobility (value of 5 or greater generally considered hypermobile)
    - Patient is able to palm floor when bending forward with knees extended (1 pt)
    - Elbow hyperextension >10 degrees (1 pt for each elbow)
    - Knee hyperextension >10 degrees (1 pt for each knee)
    - Passive apposition of thumb to volar forearm (1 pt for each thumb)
    - Passive extension of the small finger >90 degrees (1 pt for each small finger)
  - Poor wound healing
  - Soft tissue and bone fragility, and soft tissue calcification
  - Pes planus
  - Kyphoscoliosis

- **Treatment**
    - PT and orthosis for pes planus and joint laxity
    - Soft tissue–only procedures often fail in the setting of joint hyperlaxity.
    - Fusion for scoliosis often requires longer construct to avoid junctional kyphosis.

Fibrodysplasia Ossificans Progressiva

- **Defect in the gene encoding activin receptor type IA/activin-like kinase 2** *(ACVR1/ALK2)*, a bone morphogenetic protein type 1 (BMP-1) receptor
- **Also linked to overproduction of BMP-4**
- **Clinical features**
    - Congenital malformation of the great toe (short, valgus position with an abnormally shaped proximal phalanx)
    - Progressive heterotopic ossification of tendons, ligaments, fascia, and skeletal muscle, which ultimately eliminates motion of the jaw, neck, spine, shoulders, hips, and more distal joints
    - Any form of trauma may precipitate new ossification.
    - Also called *myositis ossificans progressiva* or *stone man syndrome*
- **Treatment**
    - No clearly effective medical treatment
    - Goal to minimize the risk of injury without compromising the patient's functional level and independence
    - Surgical excision not indicated; may precipitate new ossification

Rett Syndrome

- **Family of deletion mutations of the X-linked gene encoding a protein called methyl-CpG-binding protein 2** *(MECP2)*
- **Clinical features**
    - Progressive impairment and stereotaxic abnormal hand movements (like those in autism)
    - Manifests in girls at 6–18 months of age
    - Loss of developmental milestones that is rapid and then stabilizes
    - Scoliosis with a C-shaped curve that is unresponsive to bracing
- **Treatment**
    - Spinal instrumentation must include all of the kyphosis and the scoliosis.
    - Spasticity results in joint contractures, which are treated as they are in cerebral palsy.

Beckwith-Wiedemann Syndrome

- **Mutation of chromosome 11 near *IGF* gene**
- **Clinical features**
    - **Organomegaly, omphalocele, and a large tongue**
    - Orthopaedic manifestations include hemihypertrophy with spasticity
        - Spasticity is thought to be the result of infantile hypoglycemic episodes secondary to pancreatic islet cell hypertrophy
    - Growth arrest may be necessary in large limb
    - **Predisposition to Wilms tumor (patient must be screened regularly with kidney ultrasonography)**

Nail-Patella Syndrome (Hereditary Onychoosteodysplasia)

- **Autosomal dominant**
- **The gene for nail-patella syndrome is** *LMX1B,* located on chromosome 9
- **Clinical features**
    - Nail deformity (present in 98% of patients) is greatest in the thumbnails and becomes less severe in the more ulnar digits.
    - Absence or hypoplasia of patella, hypoplastic lateral femoral condyle, and genu valgum may all contribute to patellar instability.
    - Hypoplasia of the lateral side of the elbow, cubitus valgus
    - Iliac horns (conical bony projections on posterior ilia)
    - Nephropathy present in up to 40% of patients
- **Treatment**
    - There is no specific treatment for the disorder.
    - The iliac horns do not affect gait and should not be resected.
    - Recurrent dislocation of the patella is treated by proximal or distal realignment.

Section 11 Hematopoietic and Metabolic Disorders and Arthritides

Gaucher Disease

- **Autosomal recessive lysosomal storage disease**
- **Deficiency of the enzyme β-glucocerebrosidase**
    - Results in accumulation of cerebroside in the reticuloendothelial system
- **Clinical features**
    - Osteopenia
    - Bone pain (Gaucher crisis) and bleeding abnormalities
    - Hepatosplenomegaly (characteristic finding)
    - Types
        - Type I: most commonly in persons of Ashkenazi Jewish descent
        - Type II: infantile
        - Type III: chronic neuropathic
- **Radiographic findings**
    - Metaphyseal enlargement (failure of remodeling)
    - Femoral head necrosis (may be confused with Perthes disease or MED)
    - Moth-eaten trabeculae, patchy sclerosis, and Erlenmeyer flask deformity of the distal femora (70% of cases)
- **Treatment is supportive; enzyme replacement and bone marrow transplant are options**

Niemann-Pick Disease

- **Autosomal recessive disorder**
- **Accumulation of sphingomyelin in reticuloendothelial system cells**
- **Occurs commonly in Jews of eastern European descent**
- **Marrow expansion and cortical thinning common in long bones; coxa valga also seen**

Sickle Cell Anemia

- **Mutation in the β-globin gene, resulting in sickle hemoglobin (HbS)**
- **When the cell becomes deoxygenated, HbS molecules assemble into fibers that produce a sickle-shaped red blood cell.**
- **Sickle cell trait: one abnormal HbS allele**

- More common but less severe than sickle cell anemia (8% prevalence)
- Patient at risk for exertional sickling; treated with oxygen and hydration
- Patient also at risk for sudden death

- **Clinical features**
  - Sickle cell disease affects 1% of African Americans
  - Sickle cell crises usually begin at ages 2 to 3 years
    - Caused by substance P
    - May lead to bone infarctions
    - Hydroxyurea has produced dramatic relief of bone in crises
  - Osteomyelitis
    - *Salmonella* infection more commonly seen than in normal population but *S. aureus* still most common etiology
    - Differentiation of bone infarction and osteomyelitis
      - Sequential radionuclide bone marrow and bone scans (crises show decreased bone marrow uptake)
      - Aspiration and culture may be necessary
  - Avascular necrosis of the femoral and humeral head
  - Acetabular protrusion

Thalassemia

- **Similar to sickle cell anemia in manifestation**
- **Most commonly observed in people of Mediterranean descent**
- **Common symptoms include bone pain and leg ulceration.**
- **Radiographic findings**
  - Long-bone thinning, metaphyseal expansion, osteopenia, and premature physeal closure

Hemophilia

- **X-linked recessive disorder**
- **Hemophilia A: decreased amounts of factor VIII**
- **Hemophilia B: decreased amounts of factor IX**
- **Can be mild (5%–25% of normal amounts of factor present), moderate (1%–5% present), or severe (<1% present)**
- **Clinical features**
  - Hemarthrosis manifests as painful swelling and decreased ROM of affected joints
    - Knee most commonly affected
  - Deep intramuscular bleeding is also common and can lead to

formation of a pseudotumor (blood cyst).

- Intramuscular hematomas can cause compression of adjacent nerves (iliacus hematoma that compresses femoral nerve).

- **Radiographic findings**
  - □ Squaring of patellae and condyles, epiphyseal overgrowth with LLD
  - □ Generalized osteopenia with resulting fractures
  - □ Cartilage atrophy resulting from enzymatic matrix degeneration and chondrocyte death
- **Treatment**
  - Factor VIII should be administered in the following situations (target increase shown in parentheses)
    - Vigorous PT (20%)
    - Treatment of hematoma (30%)
    - Acute hemarthrosis or soft tissue surgery (>50%)
    - Skeletal surgery (approaching 100% preoperatively and maintained at >50% for 10 days postoperatively)
  - Acute treatment of hemarthrosis is crucial and should begin immediately with administration of factor VIII or factor IX
    - Administration should continue for 3 to 7 days after cessation of bleeding and should be followed by PT.
    - Home transfusion therapy, with the advantage of immediate treatment when bleeding occurs, has reduced the severity of the arthropathy
    - Aspiration of a hemarthrosis is controversial.
    - Synovectomy
      - Indicated for hemarthroses that recur despite optimal medical management
      - Arthroscopy has better results with motion and duration of hospitalization than does open synovectomy.
      - Radiation synovectomy: useful in patients with antibody inhibitors and poor medical management
  - Contracture release and osteotomies
  - Total joint arthroplasty for hemophilic arthropathy

Leukemia

- □ Most common malignancy of childhood
- □ Acute lymphocytic leukemia represents 80% of cases of leukemia.
- □ Incidence peaks at 4 years of age.

- One fourth to one third of affected children have musculoskeletal complaints (back, pelvic, leg pains).
- Radiographic findings
  - Demineralization of bones, periostitis, and, occasionally, lytic lesions
  - Radiolucent “leukemia lines” may be seen in the metaphyses of affected bones in older affected children.
- Treatment
  - Chemotherapy, which may predispose the patient to pathologic fractures

Rickets

- **Clinical features**
  - Short stature
- **Limb angulation (usually varus)**
  - Bone pain
- **Causes**
  - **Deficiency of calcium (and sometimes phosphorus), which affects mineralization at the epiphyses of long bones**
  - X-linked hypophosphatemic (vitamin D–resistant) rickets: defect in cellular endopeptidase (phosphate-regulating neutral endopeptidase)
- **Histologic findings: widened osteoid seams and Swiss cheese trabeculae are characteristic in bone.**
  - Growth plate abnormalities include an enlarged and distorted maturation zone (zone of hypertrophy) and a poorly defined zone of provisional calcification.
- **Radiographic findings**
  - Brittle bones with physeal cupping/widening, bowing of long bones, transverse radiolucent Looser lines, ligamentous laxity, flattening of the skull, enlargement of costal cartilages (rachitic rosary), and dorsal kyphosis (cat back) (Fig. 3.44)
- **Treatment**
  - Based on the underlying abnormality (e.g., kidney, diet, gastrointestinal, and organ); see Chapter 1, Section 1

Osteogenesis Imperfecta (Table 3.19)

- **Causes**
  - **Defect in type I collagen (** *COL1A1* and *COL1A2* genes) that causes abnormal cross-linking and leads to decreased collagen secretion
- **Histologic findings: increased diameters of haversian canals and osteocyte**

lacunae, increased numbers of cells, and replicated cement lines, which result in the thin cortices seen on radiographs

- **Classification**
  - ▫ Multiple types have been identified.
    - Sillence originally described four types; now at least eight forms recognized
  - ▫ Disorder probably best considered a continuum with different inheritance patterns and severity (Table 3.19).

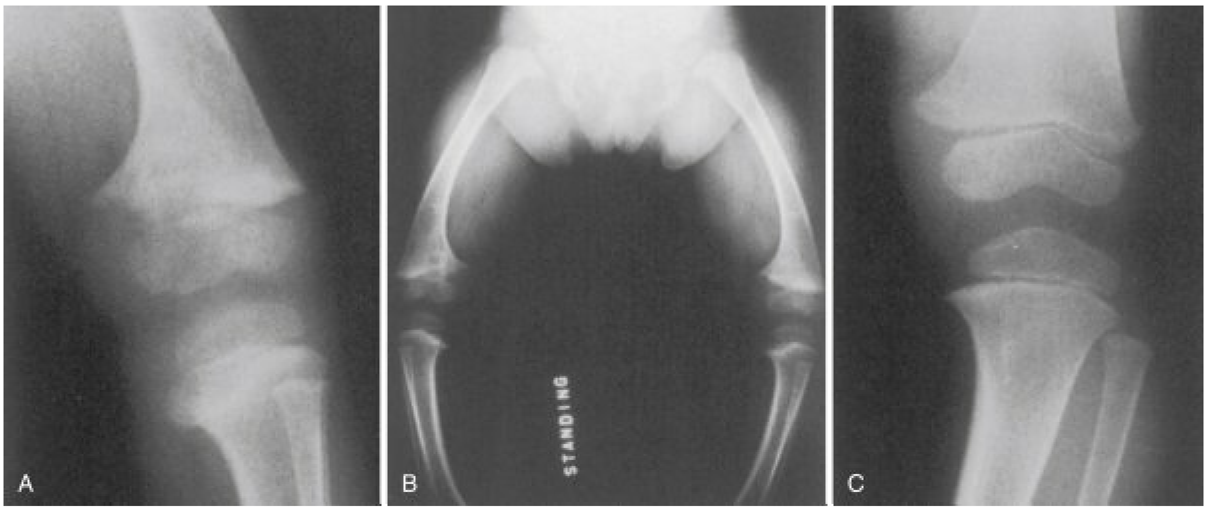


FIG. 3.44 Rickets. (A) Hazy metaphysis with cupping in a young boy with rickets. (B) Accentuated genu varum is present. (C) With vitamin D replacement therapy, the bony lesions healed in 6 months.
From Herring JA, editor: *Tachdjian's pediatric orthopaedics*, ed 5, Philadelphia, 2014, Elsevier Saunders, Fig. 42-4.

Table 3.19

Osteogenesis Imperfecta.

Type	Inheritance	Sclerae	Features
IA, IB	Autosomal dominant	Blue	Onset at preschool age (tarda); hearing loss; involvement of teeth (type IA only)
II	Autosomal recessive	Blue	Lethal; concertina femur, beaded ribs
III	Autosomal recessive	Normal	Fractures at birth, progressively short stature
IVA, IVB	Autosomal dominant	Normal	Milder form; normal hearing, involvement of teeth (type IVA only)

- **Clinical features**
  - ▫ Bone fragility (brittle wormian bone), short stature

- Scoliosis
- Tooth defects (dentinogenesis imperfecta)
- Hearing defects
- **Blue sclerae in types I and II**
- Ligamentous laxity
- Basilar invagination is common in more severe clinical phenotypes.
- Fractures are common.
  - Healing is normal, but bone typically does not remodel
  - Fractures occur less frequently with advancing age (usually cease at puberty)
  - Compression fractures (codfish vertebrae) are also common.
  - Olecranon apophyseal fractures more commonly seen in OI than in the general population
- Bowing results from multiple transverse fractures of the long bones and muscle contraction across the weakened diaphysis.
  - Typically an anterolateral bow or proximal varus deformity of the femur develops.
  - An anterior or anteromedial bow of the tibia may develop.

- **Treatment**
  - Bracing of extremities early to prevent deformity and minimize fractures
  - Sofield osteotomies—"shish kebab" osteotomies; multiple long-bone osteotomies with either fixed-length Rush rods or telescoping (Bailey-Dubow or Fassier-Duval) intramedullary rods—are sometimes required for progressive bowing of long bones.
  - Fractures
    - Treatment in children younger than 2 years similar to that in children without osteogenesis imperfecta
      - After age 2 years, telescoping intramedullary rods can be considered.
    - Bisphosphonates have been shown to decrease the number of fractures in these patients.
      - Characteristic dense parallel metaphyseal bands may be seen on x-ray. Distance between bands corresponds to time between treatments.
      - Iatrogenic osteopetrosis can occur with high-dose, long-term use of bisphosphonates.
  - Scoliosis
    - Bracing generally ineffective
    - Fusion associated with large blood loss

Juvenile Idiopathic Arthritis

- **Clinical features**
  - Persistent noninfectious arthritis lasting 6 weeks to 3 months and diagnosed after other possible causes have been ruled out
  - Affects girls more than boys and typically manifests before age 4 years
  - Can be polyarticular, pauciarticular, or systemic
  - **Commonly involves the knee, wrist (flexed and ulnar deviated), and hand (fingers extended, swollen, radially deviated)**
  - To confirm diagnosis, one of the following must be present: presence of rheumatoid factor, iridocyclitis, cervical spine involvement, pericarditis, tenosynovitis, rash, intermittent fever, or morning stiffness.
    - **Ophthalmology consultation with slit-lamp examination is required twice yearly because progressive iridocyclitis can lead to rapid loss of vision if left untreated.**
  - In 50% of affected patients, symptoms resolve without sequelae; 25% of patients are slightly disabled, and 20%–25% have crippling arthritis, blindness, or both.
  - **Cervical spine involvement can lead to kyphosis, facet ankylosis, and atlantoaxial subluxation.**
  - Lower extremity problems include flexion contractures (hip and knee flexed, ankle dorsiflexed), subluxation, and other deformities (hip protrusion, valgus knees, equinovarus feet)
- **Treatment**
  - NSAIDS or steroids
  - Disease modifying antirheumatic drugs (DMARDs)
    - Methotrexate
    - TNF blockers (etanercept, infliximab)
    - Rituximab (chimeric anti-CD20 monoclonal antibody)
  - Surgical interventions
    - Joint injections and (rarely) synovectomy for chronic swelling refractory to medical management
    - Arthrodesis and arthroplasty may be required for severe juvenile idiopathic arthritis
- **Systemic-onset JIA (Still disease): approximately 10%–20% of patients**
  - Systemic involvement: *can be fatal*
  - Diurnal fevers (rabbit-ear graph)
  - Nonpruritic salmon-pink macular evanescent rash
  - Lymphadenopathy, hepatosplenomegaly, serositis
  - Macrophage activation syndrome (MAS)
    - Cytokine storm caused by T-cell activation
    - Disseminated intravascular coagulation (DIC) causes bruising and mucosal bleeding
    - Causes elevated ferritin value but decreased ESR

Ankylosing Spondylitis

- **Systemic autoimmune spondyloarthropathy**
- **HLA-B27 present in 90%–95% of patients**
  - The antigen is also present in 4%–8% of all white Americans; thus its usefulness as a screening tool is limited.
- **Clinical features**
  - Typically affects adolescent boys
  - Asymmetric, lower-extremity, large-joint arthritis
  - Heel pain
  - Hip and back pain (cardinal symptoms) may develop later.
  - Progressive kyphosis
  - Limitation of chest wall expansion is a more specific finding than is a positive result of HLA-B27 test.
  - Uveitis and iritis
- **Radiographic findings**
  - Bilateral symmetric sacroiliac erosion followed by joint space narrowing, subsequent ankylosis, and late vertebral scalloping (bamboo spine). Radiographs typically lack sensitivity in early stages of the condition.
  - Early sacroiliitis evident on MRI may allow for diagnosis far earlier than was previously possible.
- **Treatment**
  - NSAIDs and PT mainstays of treatment
  - TNF antagonists such as etanercept, infliximab, and adalimumab are used if NSAIDs are ineffective.
  - Management of spinal deformity is discussed in Chapter 8, Spine.

Testable Concepts

Section 1 Upper Extremity

- Lack of biceps function 6 months after injury and presence of Horner syndrome carry a poor prognosis in brachial plexus palsy.
- Sprengel deformity is highly associated with Klippel-Feil syndrome.
- Apert syndrome is due to an autosomal dominant mutation in *FGFr2* gene.

Section 2 Lower Extremity: General

- In-toeing due to increased femoral anteversion (most common), internal tibial torsion, and metatarsus adductus
- Out-toeing due to hip external rotation contracture (infants) and external tibial torsion
- Limb length discrepancies can be calculated on the basis of remaining growth with the assumptions that females mature at age 14 years and males at age 16 years:
  - Proximal femur: 1⁄8 inch (3 mm) per year
  - Distal femur: 3⁄8 inch (9 mm) per year
  - Proximal tibia: 1⁄4 inch (6 mm) per year

Section 3 Hip and Femur

- Risk factors for DDH include breech positioning, firstborn child, female gender, and family history.
- Obstructions to closed reduction for DDH include iliopsoas tendon, pulvinar, hypertrophied ligamentum teres, contracted inferomedial capsule, transverse acetabular ligament, inverted labrum
- Pavlik harness treatment used first line for DDH in newborns
  - Hyperflexion can cause femoral nerve palsy
  - If unsuccessful in helping with reduction, can cause posterior wear of the acetabulum
- Most prognostic classification for Legg-Calvé-Perthes disease is the lateral pillar classification, based on the height of the lateral pillar (>50%).
- Maintaining sphericity of the femoral head is the most important factor in achieving a good result in Legg-Calvé-Perthes disease.
- SCFE occurs with weakness in the perichondral ring and slippage through the hypertrophic zone of the growth plate.
- Approximately 25% of SCFE cases are bilateral.
- Treatment for SCFE includes pinning in situ; advanced treatments including

surgical dislocation and reorientation are associated with significant risk for avascular necrosis
- Blood culture medium is needed to isolate infections due to *Kingella kingae*
- Methicillin-resistant *S. aureus* (MRSA) with a *PVL* gene mutation is associated with deep venous thrombosis and septic emboli.
- Joints with intraarticular metaphyses are the hip, elbow, shoulder, and ankle.

Section 4 Knee and Leg

- Blount disease treatment includes bracing for patient with stage I or II disease who is younger less than 3 years; patients with stages IV and V frequently require multiple procedures.
- Posteromedial bowing is associated with calcaneovalgus foot; the bowing commonly self-corrects, but the patient has a large residual limb length discrepancy that will require treatment.
- Anteromedial bowing is associated with fibular hemimelia and linked to the sonic hedgehog gene.
- Anterolateral bowing is associated with congenital pseudoarthrosis of the tibia.
- Healing rates for osteochondritis dissecans are highest with open physes.

Section 5 Foot

I. Clubfoot

- CAVE—cavus, adduction of forefoot, varus of hindfoot, equinus
  - Also represents order of correction in Ponseti method
  - Most cases require Achilles tenotomy at end of casting
- Associated with absence of or diminutive anterior tibial artery
- PITX1-TBX4 transcriptional pathway implicated
- Foot abduction brace critical for preventing recurrence
  - Recurrence treated with trial of recasting

II. Pes Cavus

- Up to 67% of cases due to neurologic disorder
  - Charcot-Marie-Tooth disease most common (*PMP22*)
  - Spinal MRI required to evaluate

III. Congenital Vertical Talus

- Irreducible dorsal dislocation of the navicular on the talus
- Navicular does not reduce on forced plantar-flexion lateral view.

- Initial treatment with serial manipulation and casting followed by limited surgery consisting of percutaneous Achilles tenotomy and minimal talonavicular capsulotomies and pin fixation

IV. Tarsal Coalition

- Can be associated with autosomal dominant craniosynostosis syndromes (*FGFR-1*, *FGFR-2*, and *FGFR-3* mutations)
- Sinus tarsi pain caused by peroneal spasticity, flatfoot, multiple ankle sprains
- Limited subtalar motion on examination
- CT best study for assessing talocalcaneal (TC) coalitions
- Treatment for TC coalitions:
    - Less than 50% of the middle facet involved: resection and interposition
    - More than 50% of the middle facet involved: subtalar arthrodesis preferred

V. Calcaneovalgus Foot

- Dorsiflexed (calcaneus) hindfoot
    - In contrast to CVT, in which hindfoot is plantar flexed (equinus)
- Associated with posteromedial bowing of tibia and LLD (most common cause of surgical treatment)

VI. Kohler Disease (Osteonecrosis of Navicular)

- Sclerosis and flattening of navicular
- Spontaneous resolution; can be treated with immobilization

VII. Pes Planus

- Asymptomatic patients should be monitored with observation.
- Symptomatic patients: arch supports and shoes with stiffer soles may offer pain relief but do not result in deformity correction.

Section 6 Spine

I. Adolescent Idiopathic Scoliosis

- Abnormal neurologic findings, left thoracic curves, or painful or rapidly progressive curves should prompt an MRI study.
- Observation
    - Skeletally immature patients with curves less than 20–25 degrees
    - Skeletally mature patients with curves less than 45–50 degrees

- Bracing for curves of more than 25 degrees or of 20 degrees with documented progression in skeletally immature patients (Risser stages 0–2)
    - 90% effective when worn more than 12–13 hours/day
- Surgery (posterior spine fusion) for curves greater than 50 degrees
    - Intraoperative spinal cord monitoring is crucial.
    - If changes occur intraoperatively, the surgical team should check leads, raise blood pressure, transfuse, reverse steps of surgery, and reassess.

II. Infantile Idiopathic Scoliosis

- Idiopathic scoliosis that manifests before age 4 years
- Most curves resolve spontaneously.
- Rib-vertebra angle difference predicts risk of progression
    - Less than 20 degrees: low risk (<20%)
    - More than 20 degrees: high risk (80%)
- Initial treatment with Mehta derotational cast

III. Congenital Spinal Deformities

- High incidence of associated abnormalities
    - Intraspinal abnormality: 20%–40%; MRI required
    - Cardiac system: 12%–26%
    - Genitourinary system: 20%
- Unilateral bar with contralateral fully segmented hemivertebrae associated with rapid and severe progression

IV. Neuromuscular Scoliosis

- Duchenne muscular dystrophy
    - Surgery indicated when curve is progressive and more than 25–30 degrees in patients whose forced vital capacity (FVC) is greater than 40% of normal.
    - Curve progression is rapid, and pulmonary and cardiac conditions worsen with time, precluding surgery.
- Cerebral palsy
    - Fusion from T2 to the pelvis in nonambulatory children
    - High complication rate

V. Cervical Spine Disorders

A. Klippel-Feil

- Abnormalities in multiple cervical segments as a result of failure of normal segmentation or formation of cervical somites at 3–8 weeks' gestation

- Associated with renal and congenital heart disease, auditory issues, and Sprengel deformity
- With multilevel fusion of the cervical spine, any involvement of C2, or limited cervical motion, collision sports should be avoided.

B. Atlantoaxial Rotatory Displacement or Subluxation

- Treatment
    - Symptoms for less than 1 week: cervical collar, analgesics, heat
    - Symptoms for between 1 and 4 weeks: traction and collar immobilization
    - Symptoms for longer than 1 month: traction, reduction, and halo immobilization
    - Irreducible or recurrent instability: surgical reduction and fusion (C1–2) for

VI. Spondylolysis and Spondylolisthesis

- Seen in athletes who use hyperextension
- Patient with high-grade listhesis (>50%) may have flexed hip and knee posture with equinus, sacral prominence, and proximal hyperlordosis.
- Slip angle
    - Most important determinant for nonunion and pain
    - Angle larger than 45–50 degrees associated with greater risk of slip progression, instability, and development of postoperative pseudarthrosis
- Pelvic incidence (PI)
    - Sum of pelvic tilt (PT) and sacral slope (SS): PI = PT + SS
    - Increased PI may predispose to spondylolisthesis.
- Acute spondylolysis treated with an antilordotic brace (TLSO with thigh extension)

VII. Other Spinal Conditions

A. Infectious Spondylitis

- Loss of lumbar lordosis is first radiographic finding

B. Osteoid Osteoma

- Night pain relieved by NSAIDs; central nidus < 2 cm with ring of lucency on imaging
- Can be associated with scoliosis

C. Sacral Agenesis

- Associated with maternal diabetes
- Motor impairment is at the level of the agenesis, but sensory innervation is largely spared.

Section 7 Cerebral Palsy

- MRI of the brain in children with cerebral palsy (CP) commonly reveals periventricular leukomalacia.
- Botulinum toxin's mechanism of action is presynaptic blockade of cholinergic receptors at the neuromuscular junction.
- CP hips at risk include those with abduction of less than 45 degrees and those with uncovering of the femoral head on radiographs

Section 8 Neuromuscular Disorders

- Lowest functional level in myelodysplasia: L4 is a key level because it indicates quadriceps function with some ambulation; L5 has a good prognosis for independent ambulation with bracing.
- Myelomeningocele is associated with folate deficiency in utero and a high prevalence of IgE-mediated latex allergy.
- Duchenne muscular dystrophy is an X-linked recessive disorder due to a mutation of the dystrophin gene.
- Friedreich ataxia is an autosomal recessive disorder originating from the frataxin gene (*GAA* repeat at 9q13).

Section 9 Bone Dysplasias

I. Achondroplasia

- Most common disproportionate short-limbed dwarfism
- Most commonly caused by mutation in fibroblast growth factor receptor 3 (*FGFR3*) gene
    - Leads to a gain-of-function mutation or uncontrolled activation
- Thoracolumbar kyphosis usually resolves at time of ambulation.
- Pelvic radiographs: champagne glass pelvic outlet (wider than deep), tombstone pelvis (squaring of iliac wings)

II. Psuedoachondroplasia

- Defect of cartilage oligometric matrix protein (COMP) on chromosome 19

III. Multiple Epiphyseal Dysplasia

- Most common gene mutation is in *COMP* but also affects type IX collagen.
- Can be confused with Legg-Calvé-Perthes disease. MED is bilateral and symmetric, characterized by early acetabular changes, and not accompanied by metaphyseal cysts.

IV. Mucopolysaccharidosis

- Most autosomal recessive (except Hurler syndrome, which is X-linked recessive)
- Preoperative cervical spine radiographs should always be obtained in the patient with Morqui syndrome, who may have upper cervical instability.

V. Diastrophic Dysplasia

- Deficiency in *DTDST* gene, which codes for sulfate transport protein
- Associated with rigid clubfeet, cauliflower ears, and hitchhiker's thumb

VI. Osteopetrosis

- Failure of osteoclastic resorption leading to dense bone (so-called marble bone)
- The mild form is autosomal dominant; the "malignant" form is autosomal recessive.
- Most common mutation in malignant form is a defect in *TCIRG1* that results in diminished carbonic anhydrase activity

Section 10 Syndromes With Orthopaedic Manifestations

I. Down Syndrome

- Most common chromosomal abnormality
- Incidence increases with advancing maternal age
- Associated with generalized laxity, pes planus, patellar and hip instability
- Cervical spine instability general recommendations:
    - ADI < 4.5 mm: no restrictions
    - ADI 4.5 to 10 mm: patient should avoid contact sports, diving, and gymnastics.
    - ADI >10 mm or symptoms/cord signal changes on MRI: C1–2 fusion
    - Complication rate of up to 50% reported

II. Marfan Syndrome

- Defect in fibrillin-1 *(FBN1)*

- Autosomal dominant inheritance
- Associated with pectus deformities, scoliosis, acetabular protrusion
- Echocardiographic and cardiologic evaluation are required before surgery

III. Beckwith-Wiedemann Syndrome

- Mutation of chromosome 11 near *IGF* gene
- Hemihypertrophy, spasticity, organomegaly, omphalocele, macroglossia
- Predisposition to Wilms tumor (patient must be screened regularly with kidney ultrasonography)

Section 11 Hematopoietic and Metabolic Disorders and Arthritides

I. Sickle Cell Anemia

- Mutation in both alleles of the β-globin gene, resulting in sickle hemoglobin (HbS)
- Sickle cell trait: one abnormal HbS allele
    - More severe but less common than sickle cell anemia (8% prevalence)
    - At risk for exertional sickling (treat with oxygen and hydration) and sudden death
- Osteomyelitis: *Salmonella* infection more commonly seen than in normal population but *S. aureus* still most common etiology

II. Rickets

- Short stature and genu varum
- Physeal widening and metaphyseal cupping on radiographs
- X-linked hypophosphatemic (vitamin D–resistant) rickets: defect in cellular endopeptidase (phosphate-regulating neutral endopeptidase)

III. Osteogenesis Imperfecta

- Defect in type I collagen (*COL1A1* and *COL1A2* genes) that causes abnormal cross-linking and leads to decreased collagen secretion
- Blue sclerae in types I and II
- Basilar invagination in more severe types
- Bisphosphonates reduce incidence of fractures

IV. Juvenile Idiopathic Arthritis

- Persistent noninfectious arthritis without other etiology lasting longer than 6 weeks

- Commonly involves the knee, wrist (flexed and ulnar deviated), and hand (fingers extended, swollen, radially deviated).
- Ophthalmology consultation with slit-lamp examination is required twice yearly because progressive iridocyclitis can lead to rapid loss of vision if left untreated.
- Cervical spine involvement can lead to kyphosis, facet ankylosis, and atlantoaxial subluxation.

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* See Chapter 7, Hand, Upper Extremity, and Microvascular Surgery.

CHAPTER 4

Sports Medicine

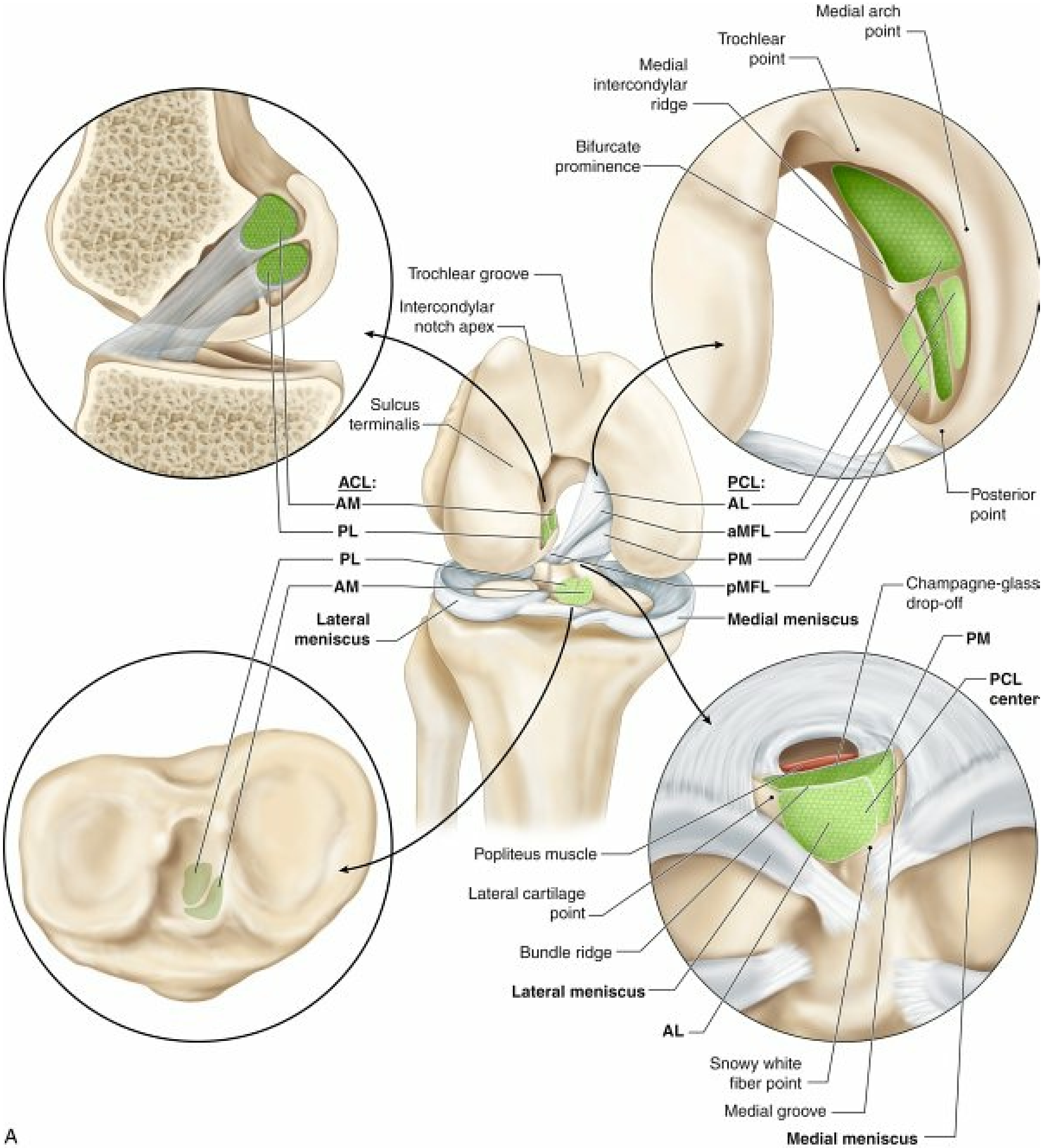
James E. Christensen, Brian C. Werner, Stephen R. Thompson, and Mark D. Miller

Section 1 Knee

Anatomy (Fig. 4.1)

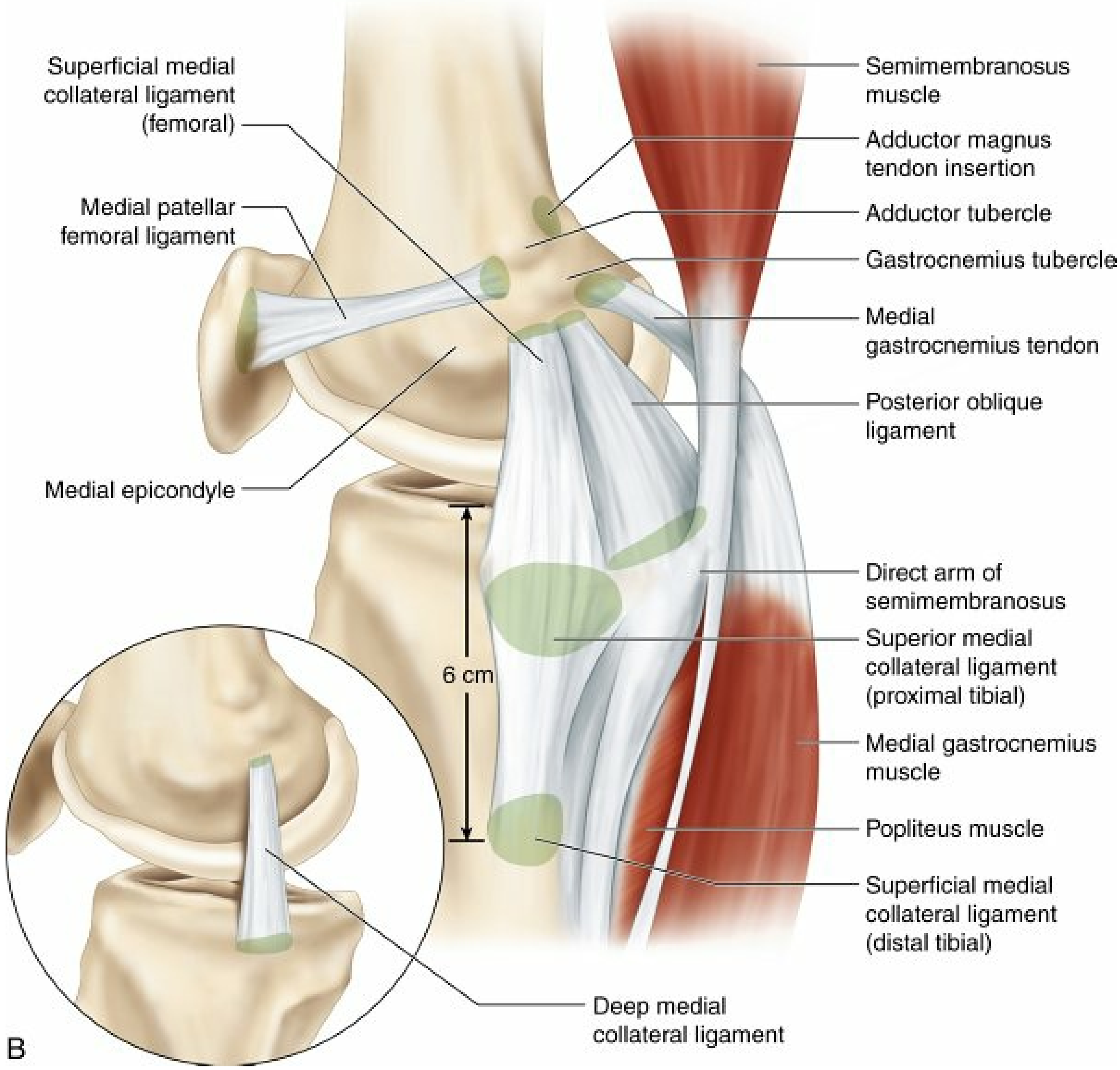
See Chapter 2, Anatomy, for a thorough discussion of knee anatomy.

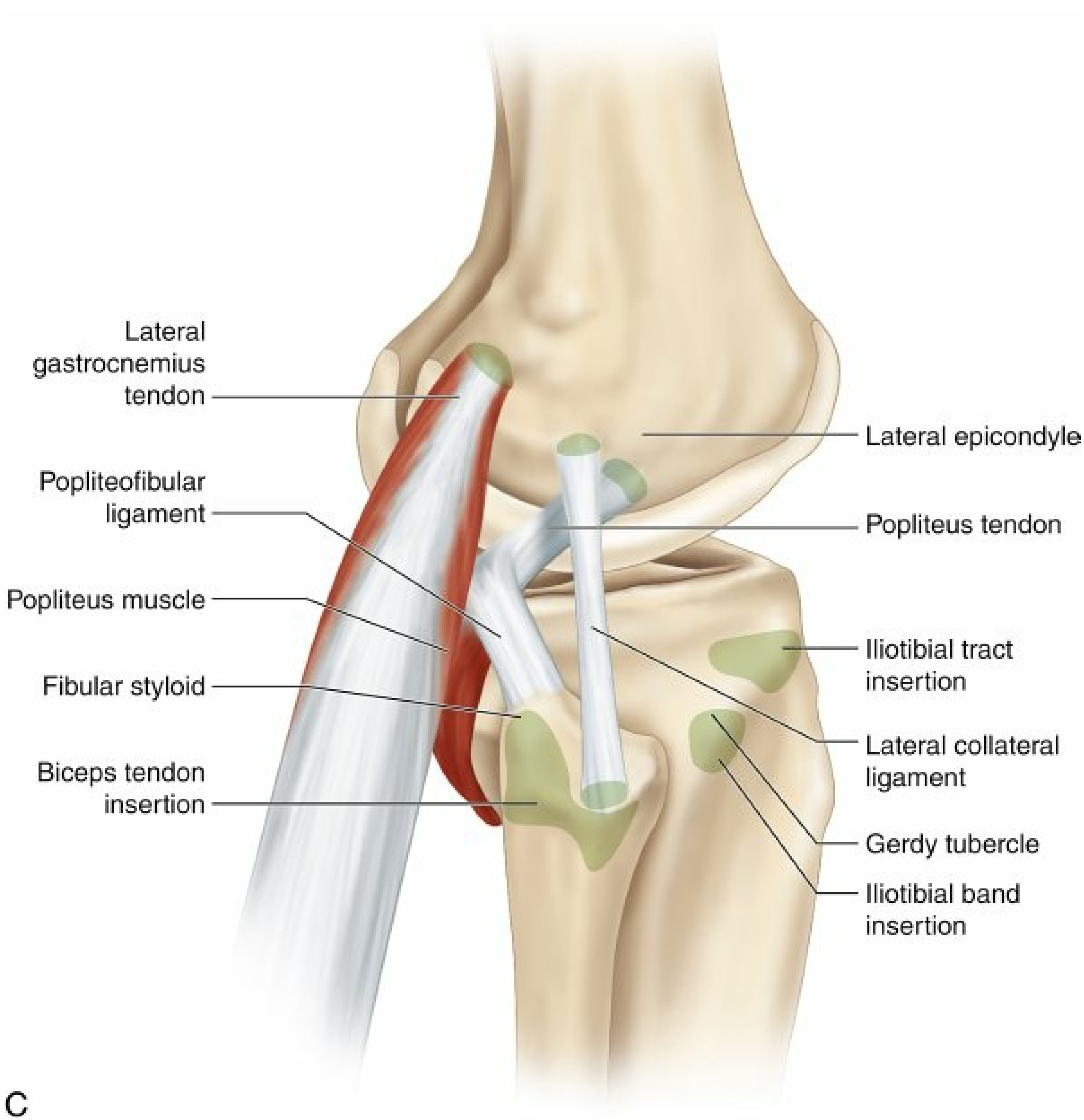
- **Hinge joint that also incorporates both gliding and rolling, which are essential to its kinematics**
- **"Screw-home" mechanism: tibia externally rotates 5 degrees in the final 15 degrees of extension.**
- **Ligaments (** Table 4.1)
  - Anterior cruciate ligament
    - Femoral attachment: semicircular area on the posteromedial aspect of the lateral femoral condyle; divided by the **bifurcate ridge and bordered by the intercondylar ridge (** Fig. 4.2 **)**
    - Tibial insertion: broad, irregular, oval area immediately medial to the attachment of the anterior horn of the lateral meniscus and posterior to the tubercle of the anterior horn of the medial meniscus (Figs. 4.3 and 4.4)
    - Has two bundles named according to their tibial insertions
      - **Anteromedial bundle**: originates proximal to the bifurcate ridge; tight in flexion (anterior bundles in ACL and PCL tight with knee flexion); primarily an anterior restraint; evaluated by Lachman and anterior drawer tests
      - **Posterolateral bundle**: originates distal to the bifurcate ridge; tight in extension; primarily a rotatory restraint; evaluated by pivot shift test
    - Length 30 mm; diameter 11 mm
    - Composition: 90% type I collagen and 10% type III collagen
    - Blood supply: Both cruciate ligaments receive their blood supply via branches of the middle genicular artery and the fat pad.
    - Mechanoreceptor nerve fibers have been found within the ACL and may have a proprioceptive role.



Medial arch point
Trochlear point
Medial intercondylar ridge
Bifurcate prominence
Trochlear groove
Intercondylar notch apex
Sulcus terminalis
ACL:
AM
PL
PL
AM
Lateral meniscus
PCL:
AL
aMFL
PM
pMFL
Medial meniscus
Posterior point
Champagne-glass drop-off
PM
PCL center
Popliteus muscle
Lateral cartilage point
Bundle ridge
Lateral meniscus
AL
Snowy white fiber point
Medial groove
Medial meniscus

A


Superficial medial collateral ligament (femoral)
Medial patellar femoral ligament
Medial epicondyle
Semimembranosus muscle
Adductor magnus tendon insertion
Adductor tubercle
Gastrocnemius tubercle
Medial gastrocnemius tendon
Posterior oblique ligament
Direct arm of semimembranosus
Superior medial collateral ligament (proximal tibial)
Medial gastrocnemius muscle
Popliteus muscle
Superficial medial collateral ligament (distal tibial)
6 cm
Deep medial collateral ligament
B


Lateral gastrocnemius tendon
Popliteofibular ligament
Popliteus muscle
Fibular styloid
Biceps tendon insertion
Lateral epicondyle
Popliteus tendon
Iliotibial tract insertion
Lateral collateral ligament
Gerdy tubercle
Iliotibial band insertion

C

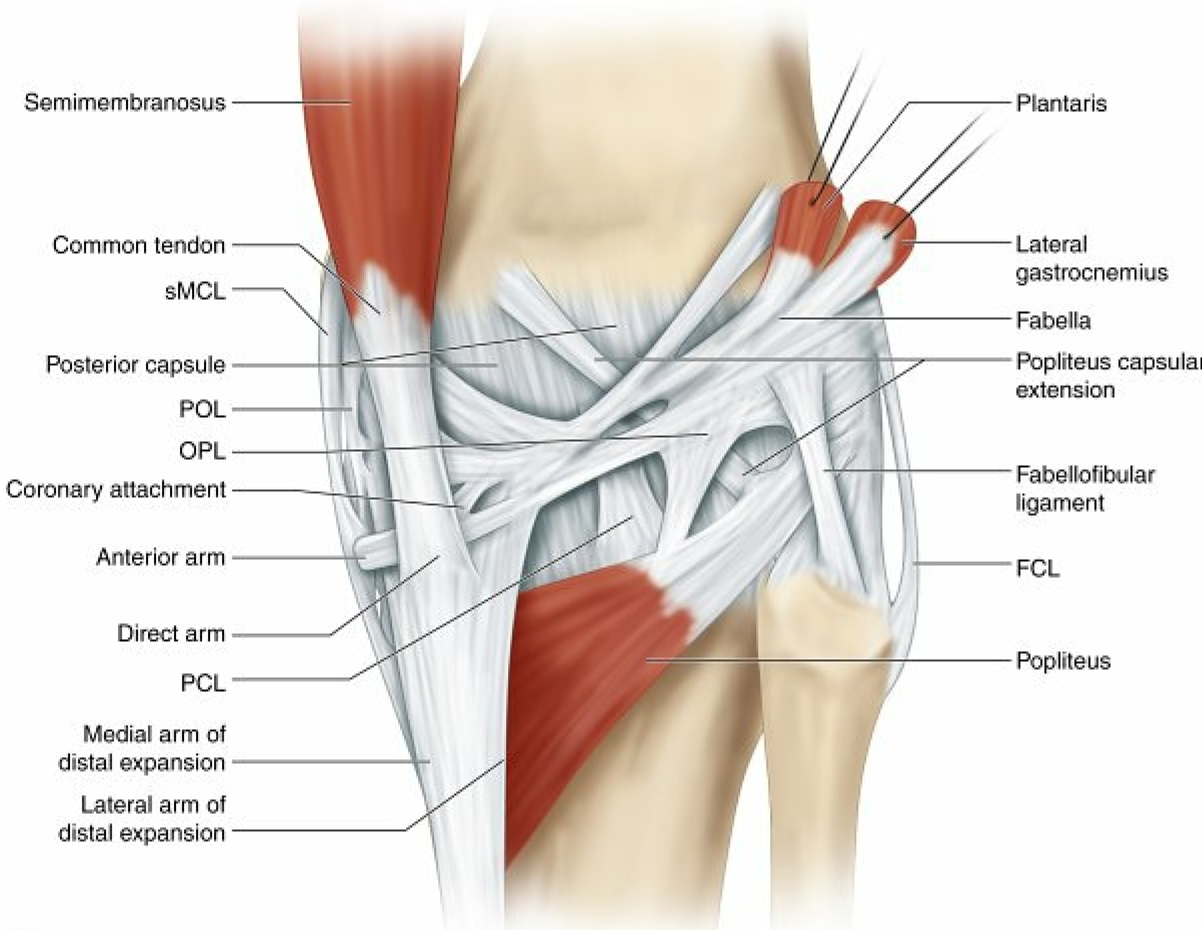


FIG. 4.1 Ligamentous anatomy of the knee. (A) Cruciate anatomy. *ACL*, Anterior cruciate ligament; *AL*, anterolateral; *AM*, anteromedial; *aMFL*, anterior meniscofemoral ligament; *PCL*, posterior cruciate ligament; *PL*, posterolateral; *PM*, posteromedial; *pMFL*, posterior meniscofemoral ligament.

Table 4.1

Stabilizing Functions of the Ligaments of the Knee

Ligament	Primary Function	Secondary Function
Anterior cruciate ligament		
Anteromedial bundle	Resists anterior tibial translation in knee flexion	Resists varus translation in knee extension
Posterolateral bundle	Resists rotatory loads in knee extension	Resists varus translation in knee extension
Posterior cruciate ligament (AL and PM bundles codominant)	Resists posterior tibial translation at all degrees of knee flexion	Resists tibial internal and external rotation beyond 90 degrees of knee flexion; resists varus translation
Medial collateral ligament		
sMCL, proximal division from femur to proximal tibial attachment	Resists valgus tibial translation	Resists tibial external rotation
sMCL, distal division from proximal tibial attachment to distal tibial attachment	Resists tibial external rotation in knee extension	Resists tibial internal rotation
Deep MCL	Resists valgus translation	Resists tibial internal and external rotation
Posterior oblique ligament	Resists tibial internal rotation (especially in knee extension)	Resists tibial external rotation
Lateral collateral ligament	Resists varus tibial translation	Resists tibial external rotation (especially at 30 degrees of knee flexion)
Popliteus tendon	Resists tibial external rotation (especially in knee flexion)	Resists varus tibial translation
Popliteofibular ligament	Resists tibial external rotation (especially in knee flexion)	Resists posterior tibial displacement
Oblique popliteal ligament	Resists knee hyperextension	Resists varus tibial translation

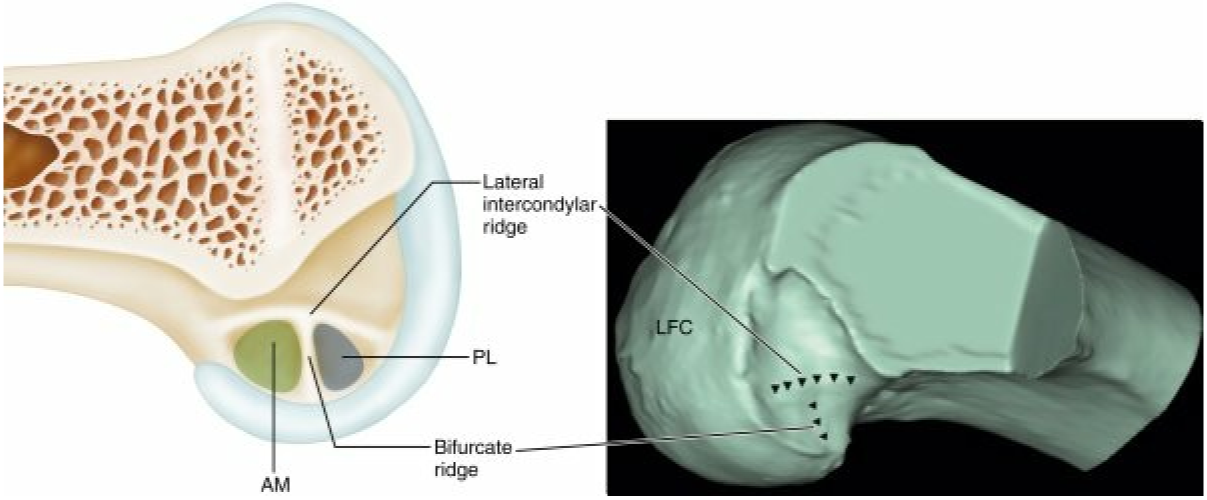


FIG. 4.2 Anatomic osseous landmarks of the ACL origin on the lateral aspect of the intercondylar ridge of the lateral femoral condyle *(LFC).* The lateral bifurcate ridge divides the AM bundle from the PL bundle. The lateral intercondylar ridge forms the superior border of the ACL insertion.

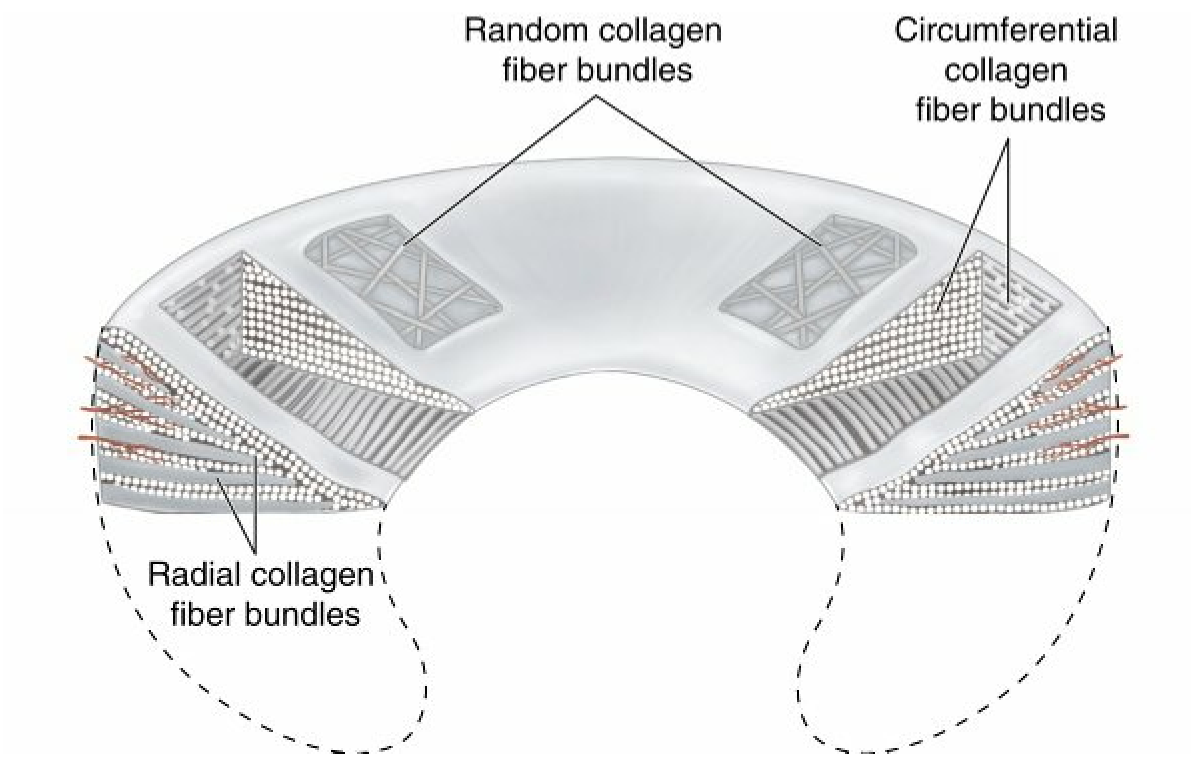


FIG. 4.3 Anatomy of the meniscus.

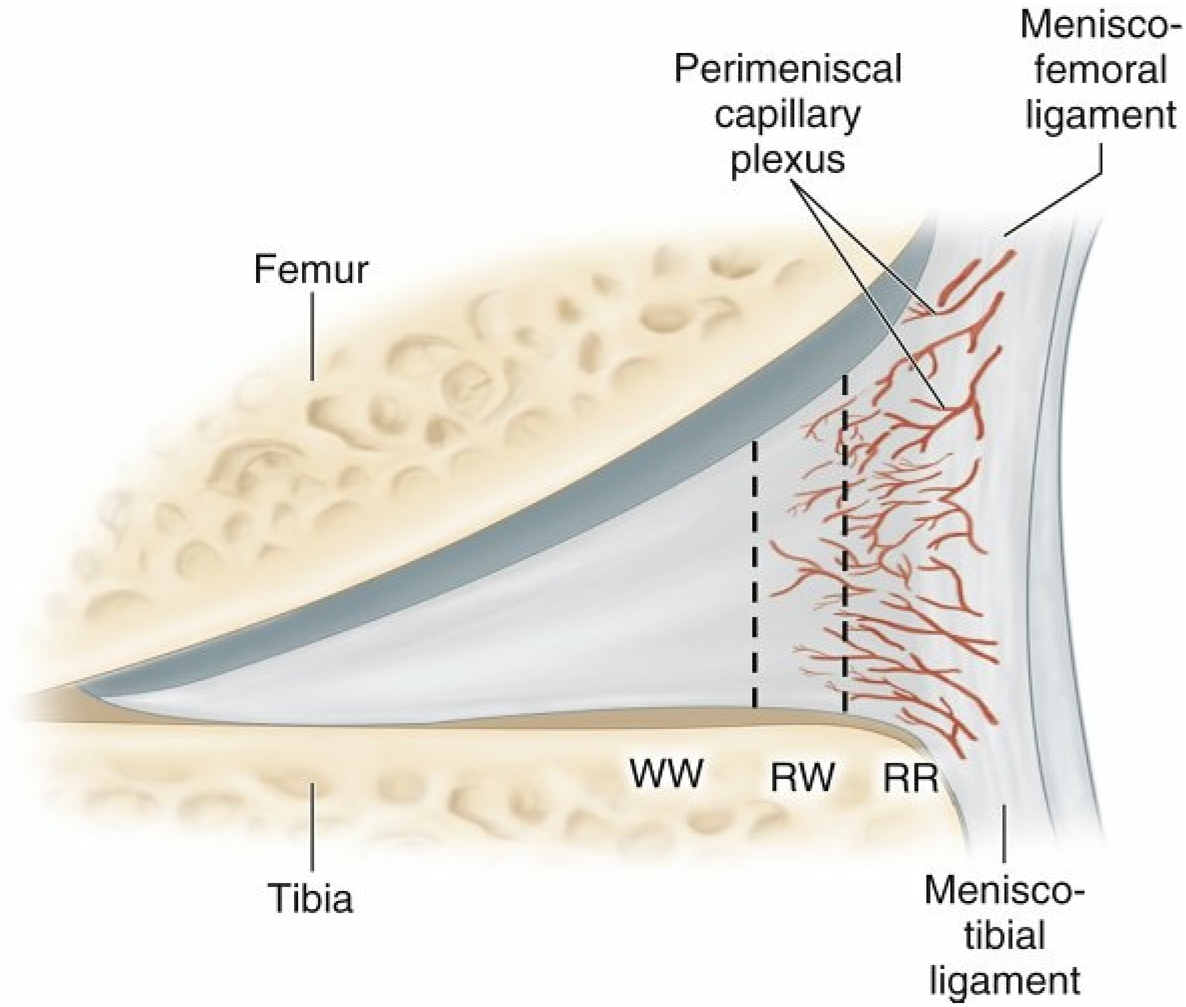


FIG. 4.4 Blood supply of the meniscus. *RR,* Red-red; *RW,* red-white; *WW,* white-white.

- Posterior cruciate ligament
  - Femoral attachment: broad crescent-shaped area on the anterolateral medial femoral condyle; divided by the bifurcate prominence and bordered by the medial intercondylar ridge
  - Tibial insertion: tibial sulcus **below articular surface**; center of insertion is in line with the posterior attachment of medial meniscus.
  - Has two bundles named according to their tibial insertions:
    - **Anterolateral bundle**: originates anterior to the bifurcate prominence; tight in flexion
      - Mnemonic: PCL is your "PAL": the important AL bundle is tight in flexion
    - **Posteromedial bundle**: originates posterior to the bifurcate prominence; tight in extension
    - The two bundles are codominant and function to resist posterior tibial translation at all degrees of knee flexion.
  - Length 38 mm; diameter 13 mm

- Same vascular supply as ACL

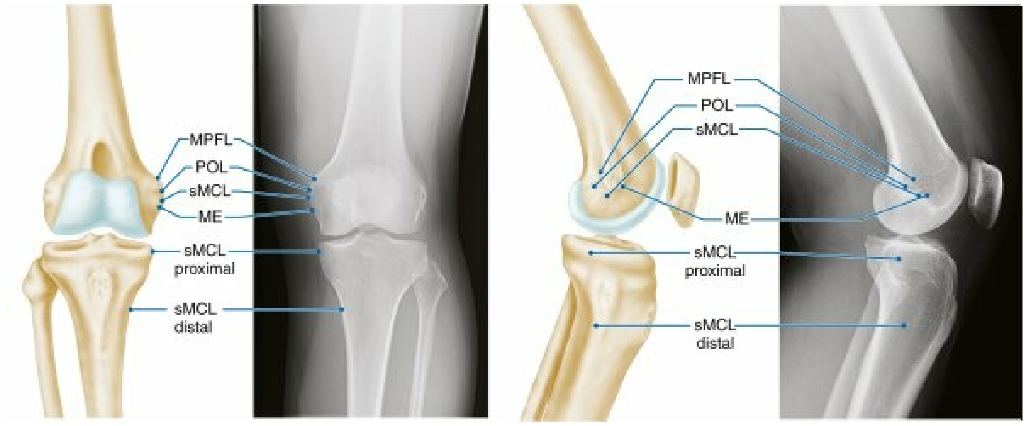


FIG. 4.5 Radiographic landmarks of medial structures of the knee. *ME,* Medial epicondyle; *MPFL,* medial patellofemoral ligament; *POL,* posterior oblique ligament; *sMCL,* superficial medial collateral ligament.

- Meniscofemoral ligaments
  - Variably present
  - Insert on the posterior horn of the lateral meniscus and originate on either side of the posteromedial bundle
  - Humphrey ligament: anterior to PCL
  - Wrisberg ligament: posterior

□ Medial collateral ligament

- Superficial and deep components
- Superficial
  - Lies deep to the sartorial fascia, gracilis tendon, and semitendinosus tendon
  - Femoral origin: **proximal and posterior to the medial epicondyle of the femur;** radiographically, originates slightly anterior to the junction of the posterior femoral cortex reference line and Blumensaat line.
  - Tibial insertion: two separate attachments
    - Proximally inserts onto soft tissue overlying anterior arm of semimembranosus
    - Distally inserts directly to bone, just anterior to the posterior cortex of the tibia, 6–7 cm distal to the joint line (Fig. 4.5)
  - Length: 100–120 mm
  - Anterior fibers tighten during first 90 degrees of

motion; posterior fibers tighten during extension.
    - Deep (midthird medial capsular ligament [dMCL])
        - Thickening of the medial joint capsule
        - Distinct meniscofemoral and meniscotibial components
        - Intimately associated with the medial meniscus
- □ Posteromedial corner
    - Structures between the posterior border of the superficial MCL and medial border of the PCL
    - Four important structures
        - Capsular thickenings of the multiple insertions of semimembranosus muscle
        - Posterior horn of the medial meniscus
        - Posterior oblique ligament
        - Oblique popliteal ligament
    - POL:
        - Three components: superficial, central, and capsular arms
        - Central arm is most important and inserts onto posteromedial tibia
        - Originates proximal and posterior to the origin of the superficial medial collateral ligament (sMCL) as well as distal and posterior to the adductor tubercle
        - Primary stabilizer against internal rotation and valgus between 0 and 30 degrees of knee flexion
        - Increasingly important factor in the treatment of medial knee injuries
- □ Medial patellofemoral ligament (MPFL)
    - Femoral attachment: anterior and distal to the adductor tubercle; or proximal to the attachment of the sMCL; or proximal and posterior to the medial epicondyle
        - Radiographically, originates slightly anterior to the posterior femoral cortex reference line and immediately posterior to the most posterior aspect of the Blumensaat line (**Schottle point**) (see Fig. 4.5)
    - Patellar attachment: junction of proximal and middle thirds on the medial border of the patella as well as the undersurface of the vastus medialis oblique (VMO) muscle
    - Length: 53–55 mm
    - Primary passive restraint to lateral patellar translation; contributes 50%–60% of restraint at 0–30 degrees of knee

flexion

- ◻ Lateral collateral ligament (a.k.a. FCL)
    - Femoral origin: proximal and posterior to the lateral femoral epicondyle; or posterior, superficial, and proximal to the insertion of the popliteus tendon
    - Tibial insertion: anterior to the midpoint of the lateral aspect of the fibular head; most anterior structure inserting on the proximal fibula.
    - Length: 63–71 mm
    - Tight in extension and lax in flexion because of its location behind the axis of knee rotation
    - Primary restraint to varus stress in all degrees of knee flexion
- ◻ Posterolateral corner (PLC)
    - Primary structures:
        - Lateral collateral ligament
        - Popliteus tendon
        - Popliteofibular ligament
    - Additionally cited structures:
        - Iliotibial band
        - Biceps femoris
        - Fabellofibular ligament
        - Arcuate ligament complex (variably present)
        - Lateral gastrocnemius tendon
        - Midthird lateral capsular ligament
        - Coronary ligament of the lateral meniscus
    - Primary stabilizer of external tibial rotation; also resists varus stress and posterior tibial translation
    - Popliteus tendon
        - Muscle originates on posterior tibia above soleal line
        - **Femoral insertion is distal, anterior, and deep to the LCL (see Fig. 4.1C).**
            - Mnemonic: Popliteus is "**DAD**": distal, anterior, and deep
        - Internally rotates the tibia
    - Popliteofibular ligament
        - Originates from musculotendinous junction of popliteus muscle
        - Inserts on medial aspect of fibular head and styloid, posterior to LCL and anterior to biceps femoris
        - Role remains debated in the literature.
    - Order of insertion of structures on the proximal fibula is,

from anterior to posterior: LCL, popliteofibular ligament, and biceps femoris

- Anterolateral ligament (ALL)
  - Newly described structure located anterior to the LCL
  - Femoral origin: immediately anterior to popliteus tendon insertion
  - Tibial insertion: posterior to Gerdy tubercle; firm attachments to lateral meniscus
  - Role uncertain; clinical significance currently under investigation; thought to be a stabilizer against internal tibial rotation

- **Menisci**
  - Crescent-shaped fibrocartilaginous structures; triangular in cross section
  - Composed primarily of type I collagen
  - Collagen fibers are arranged in a variety of patterns (see Fig. 4.3)
    - **Circumferentially to disperse hoop stresses; vertical mattress sutures capture these fibers.**
    - Radially to resist longitudinal tearing
    - Randomly at the surface to disperse sheer stresses caused by knee flexion
  - The two menisci are connected anteriorly by the transverse (intermeniscal) ligament
  - They are attached peripherally by coronary ligaments
  - Only the peripheral 20%–30% of the medial meniscus and 10%–25% of the lateral meniscus are vascularized; blood supply is from the medial and lateral genicular arteries, respectively.
    - Three vascular zones (see Fig. 4.4)
      - Red-red
        - Completely within the vascular zone
        - Tears within this zone have the highest healing potential
      - Red-white
        - Intermediate vascularity
        - Less predictable healing
        - Red-red and red-white constitute the outer 4 mm of the meniscus
      - White-white
        - Avascular
        - Nutrition derived solely from synovial fluid via passive diffusion
        - Poor healing response
  - 50% of medial tibial plateau and, 59% of lateral tibial plateau covered

by meniscus

- Role: to function in stability, lubrication, and joint nutrition and to deepen the articular surfaces of the tibial plateau, making the surfaces more congruent and decreasing contact forces on the articular cartilage
- The menisci move anteriorly in extension and posteriorly with flexion. The lateral meniscus has fewer soft tissue attachments and is more mobile than the medial meniscus.

Biomechanics

- **Ligament biomechanics: Role of ligaments of the knee is to provide passive restraints against abnormal motion.**
  - Structural properties of ligaments: tensile strength of a ligament—maximal stress a ligament can sustain before failure—has been characterized for all knee ligaments. Age, ligament orientation, preparation of the specimen, and other factors must be considered in the choice of graft.
    - ACL: approximately 2200 N; up to 2500 N in young individuals
      - Tensile strength of a 10-mm patellar tendon graft (young specimen) is more than 2900 N and is about 30% stronger when it is rotated 90 degrees. However, this strength quickly diminishes in vivo.
      - Studies suggest that the quadrupled hamstring graft has even greater tensile strength (up to 4000 N) but the strength depends on graft fixation.
    - PCL: approximately 2500–3000 N
    - MCL: approximately 5000 N
      - sMCL: approximately 550 N
      - dMCL: approximately 100 N
      - POL: approximately 250 N
    - LCL: approximately 750 N
- **Kinematics: Motion of knee and interplay of ligaments have been described as a four-bar linkage system.**
  - As the knee flexes, the center of joint rotation (intersection of the cruciate ligaments) moves posteriorly, causing rolling and gliding at the articulating surfaces.
  - Reconstructed ligaments should approximate normal anatomy and lie within the flexion axis in all positions of knee motion.
  - As the joint flexes, ligaments anterior to the flexion axis stretch and ligaments posterior to the axis shorten.
- **Meniscal biomechanics**

- The menisci transmit 50%–75% of axial loads across the knee in full extension, and 85% of axial loads in 90 degrees of knee flexion.
  - Medial meniscus bears 30%–40% of the tibiofemoral load.
  - Lateral meniscus bears 70% of the load.
- Menisci also decrease peak contact stresses at the articular surface by 100%–200%.
  - Resection of 75% of the radial meniscal width results in an increase in peak contact stresses equivalent to that after a segmental or total meniscectomy.
  - Posterior and peripheral zones are the most important in decreasing contact stresses

Table 4.2

Key Historical Points That Indicate Mechanism of Knee Injury

History	Significance
Pain after sitting or climbing stairs	Patellofemoral cause
Locking or pain with squatting	Meniscal tear
Noncontact injury with popping sound/sensation	ACL tear, patellar dislocation
Contact injury with popping sound	Collateral ligament tear, meniscal tear, fracture
Acute swelling	ACL tear, peripheral meniscal tear, osteochondral fracture, capsule tear
Knee gives way	Ligamentous laxity, patellar instability
Anterior force: dorsiflexed foot	Patellar injury
Anterior force: plantar-flexed foot	PCL injury
Dashboard injury	PCL or patellar injury
Hyperextension, varus angulation, and tibial external rotation	PLC injury

- Lateral meniscus has twice the excursion of the medial meniscus during knee flexion.
- Studies have shown that an ACL deficiency may result in abnormal meniscal strain, particularly in the posterior horn of the medial meniscus.
  - Posterior horn of the medial meniscus is a major secondary stabilizer against anterior tibial translation in an ACL-deficient knee.
- Meniscal root tears completely disrupt the circumferential fibers of the meniscus, leading to meniscal extrusion.
- Biomechanical studies have shown similar load patterns in posterior root tear and complete meniscectomy.

Diagnostic Techniques

- **History**
  - Key historical points that indicate the mechanism of injury in the knee are summarized in Table 4.2.
- **Physical examination**
  - Important physical examination methods, findings, and their significance are shown in Table 4.3.
  - Opening to varus or valgus stress testing at only 30 degrees of knee flexion indicates an isolated collateral injury. Opening in full extension indicates a combined cruciate and collateral injury.
- **Instrumented measurement of knee laxity**
  - KT-1000 and KT-2000 arthrometers are the devices most commonly used for standardized laxity measurement.
  - A difference of more than 3 mm between sides is considered significant.
  - Reproducible measurement tools for rotational stability are under development.
- **Radiographs**
  - Standard views
    - AP view
    - Weight-bearing 45-degree knee flexion posteroanterior (PA) view (Rosenberg)
      - Most sensitive view for revealing early osteoarthrosis
    - Lateral view
    - Merchant/Laurin/sunrise view of the patella
    - Additional views include lower extremity hip-to-ankle views, oblique views, and stress radiographs.
      - Lower extremity hip-to-ankle views are required to calculate the mechanical axis of the knee.
        - A line is drawn from the center of the femoral head to the center of the ankle.
        - In a neutrally aligned limb, this line should pass through the middle of the knee.
      - Stress radiographs
        - **Used in pediatric patients to evaluate injury to the femoral physis and to differentiate it from an MCL injury**
        - Used to characterize PCL, MCL, LCL, and PLC injuries

- Radiographic findings in knee injuries and their significance are listed in Table 4.4 and illustrated in Fig. 4.6.
- Evaluation of patella height is accomplished by one of three commonly used methods (Fig. 4.7).
  - The Caton-Deschamps method may be the most reliable, but this issue is controversial.

- **Nuclear imaging**
  - Technetium (Tc) 99m bone scans are useful in diagnosing stress fractures, early degenerative joint disease, and complex regional pain syndrome.
- **Magnetic resonance imaging**
  - Imaging modality of choice for diagnosis of ligament injuries, meniscal injury, avascular necrosis, spontaneous osteonecrosis of the knee, and articular cartilage defects
    - Occult fractures of the knee can be identified by the finding of a double fluid-fluid layer, which signifies lipohemarthrosis.
- **Magnetic resonance arthrography**
  - Intraarticular MR arthrography is the most accurate imaging method for confirming the diagnosis of repeat meniscal tears after repair.
  - A variety of classic MRI findings in the knee are shown in Fig. 4.8.
- **Computed tomography**
  - CT has been replaced largely by MRI but is still useful in the evaluation of bony tumors, patellar tilt, tibial tuberosity–trochlear groove (TT-TG) distance, tunnel size in revision ACL reconstruction, and fractures.
- **Arthrography**
  - Useful historically for diagnosis of MCL tears; has been supplanted by MRI. However, arthrography can be useful when MRI is not available or tolerated by the patient, and it can be combined with CT.
- **Ultrasonography**
  - Useful for detecting soft tissue lesions about the knee, including patellar tendinitis, hematomas, and extensor mechanism ruptures
- **Arthrocentesis and intraarticular knee injection**
  - Most accurately administered with the knee in extension; a superolateral entry point is used.

Knee Arthroscopy

- **Portals**
  - Standard portals
    - Inferomedial and inferolateral portals
      - Made with the knee in flexion; for instrument

placement and the arthroscope, respectively (Fig. 4.9)

- Superomedial and superolateral outflow portals
  - Made with the knee in extension but typically not necessary with newer pump systems

Table 4.3

Knee: Key Examination Points

Examination or Test	Method or Appearance	Significance
Standing and gait deformity	Observation of gait	Based on pathologic process
	Observation of patient standing	Based on pathologic process; valgus/varus deformity should be checked for
Effusion	Patella: ballottement/milking	Ligament/meniscal injury (acute), arthritis (chronic)
Point of maximal tenderness	Palpation for tenderness	Based on location (joint line tenderness can indicate meniscal tear)
ROM	Active and passive	Block indicates meniscal (bucket handle) injury, loose body, impingement of ACL tear
Patellar crepitus	Passive ROM	Patellofemoral pathologic process
Patellar grind	Pushing of patella with quadriceps contraction	Patellofemoral pathologic process
Patellar apprehension	Pushing of patella laterally at 20–30 degrees of flexion	Patellar subluxation or dislocation
Q angle	ASIS–patella–tibial tubercle	Increased with patellar malalignment (normal <15 degrees); most pronounced in flexion
Flexion Q angle	ASIS–patella–tibial tubercle	Increased with patellar malalignment
J sign	Lateral deviation of the patella in extension	Patellar instability
Patellar tilt	Patella tilted up laterally	>15 degrees indicates laxity; <0 degrees indicates tight lateral constraint
Patellar glide	Patella pushed laterally at 20–30 degrees of flexion	>50 degrees indicates increased laxity of medial constraint
Active glide	Lateral excursion with quadriceps contraction	Lateral excursion > proximate excursion indicates increased functional Q angle of quadriceps
Quadriceps circumference	10 cm (VMO), 15 cm (quadriceps)	Atrophy from inactivity
Symmetric extension	Difference between limbs in distance of back of knee	Contracture, displaced meniscal tear, or other mechanical block

	from ground or in prone heel height	
Varus/valgus stress	Laxity at 30 degrees of flexion	MCL/LCL laxity (grade I: opening 1–5 mm; grade II: opening 6–10 mm; grade III [complete]: opening >10 mm)
	Deformity at 0 degrees of flexion	MCL/LCL and PCL laxity
Apley	Prone-flexion compression	DJD, meniscal disease
Lachman	Tibia forward at 30 degrees of flexion	ACL injury (most sensitive test)
Finacetto	Lachman test with tibia subluxation beyond posterior horns of menisci	ACL injury (severe)
Anterior drawer	Tibia forward at 90 degrees of flexion	ACL injury
Internal rotation drawer	Foot internally rotated with drawer test	Tighter is normal; looser indicates ACL injury
External rotation drawer	Foot externally rotated with drawer test	Loose is normal; looser indicates ACL/MCL injury
McMurray	Internal and external tibial rotation while leg is moved from a starting point of maximal flexion into extension of the knee	Meniscal pathologic process
Pivot-shift [a]	Flexion with internal rotation and valgus angulation	ACL injury
Pivot-jerk [a]	Extension with internal rotation and valgus angulation	ACL injury
Posterior drawer	Tibia can be moved backward at 90 degrees of flexion	PCL injury
Tibial sag	Flexion to 90 degrees, observation	PCL injury
90-degree quadriceps active test	Extension of flexed knee	PCL injury
Asymmetric external rotation	Feet are “dialed” externally at 30 and 90 degrees of flexion	Asymmetric increased external rotation of >10–15 degrees indicates injury of PLC difference is 30 degrees only; difference at both 30 and 90 degrees indicates injury of PCL and PLC
External rotation	Great toes picked up	PCL injury, PLC injury

recurvatum		
Reversed pivot	Extension with external rotation and valgus	PCL injury
Posterolateral drawer	Posterior drawer, lateral > medial	PCL injury

ASIS, Anterior-superior iliac spine; DJD, degenerative joint disease.

[a] Examination performed with the patient under anesthesia.

Table 4.4

Knee Injuries: Radiographic Findings

View/Sign	Finding(S)	Significance
Lateral-high patella	Patella alta	Patellofemoral pathologic process
Congruence angle	μ = −6 degrees (SD = 11 degrees)	Patellofemoral pathologic process
Tooth sign	Irregular anterior patella	Patellofemoral chondrosis
Varus/valgus stress view	Opening	Collateral ligament injury; Salter-Harris fracture
Lateral capsule (Segond) sign	Small tibial avulsion off lateral tibia	ACL tear
Arcuate sign	Small fibular avulsion	PLC injury
Pellegrini-Stieda lesion	Avulsion of medial femoral condyle	Chronic MCL injury
Lateral-stress view: stress to anterior tibia with knee flexed 70 degrees	Asymmetric posterior tibial displacement	PCL injury
Weight-bearing flexion PA view	Fairbank changes: square condyle, peak eminences, ridging, narrowing	Early DJD, OCD, notch evaluation
	Square lateral condyle	Early DJD (post-meniscectomy)
	Thickened joint space	Discoid meniscus

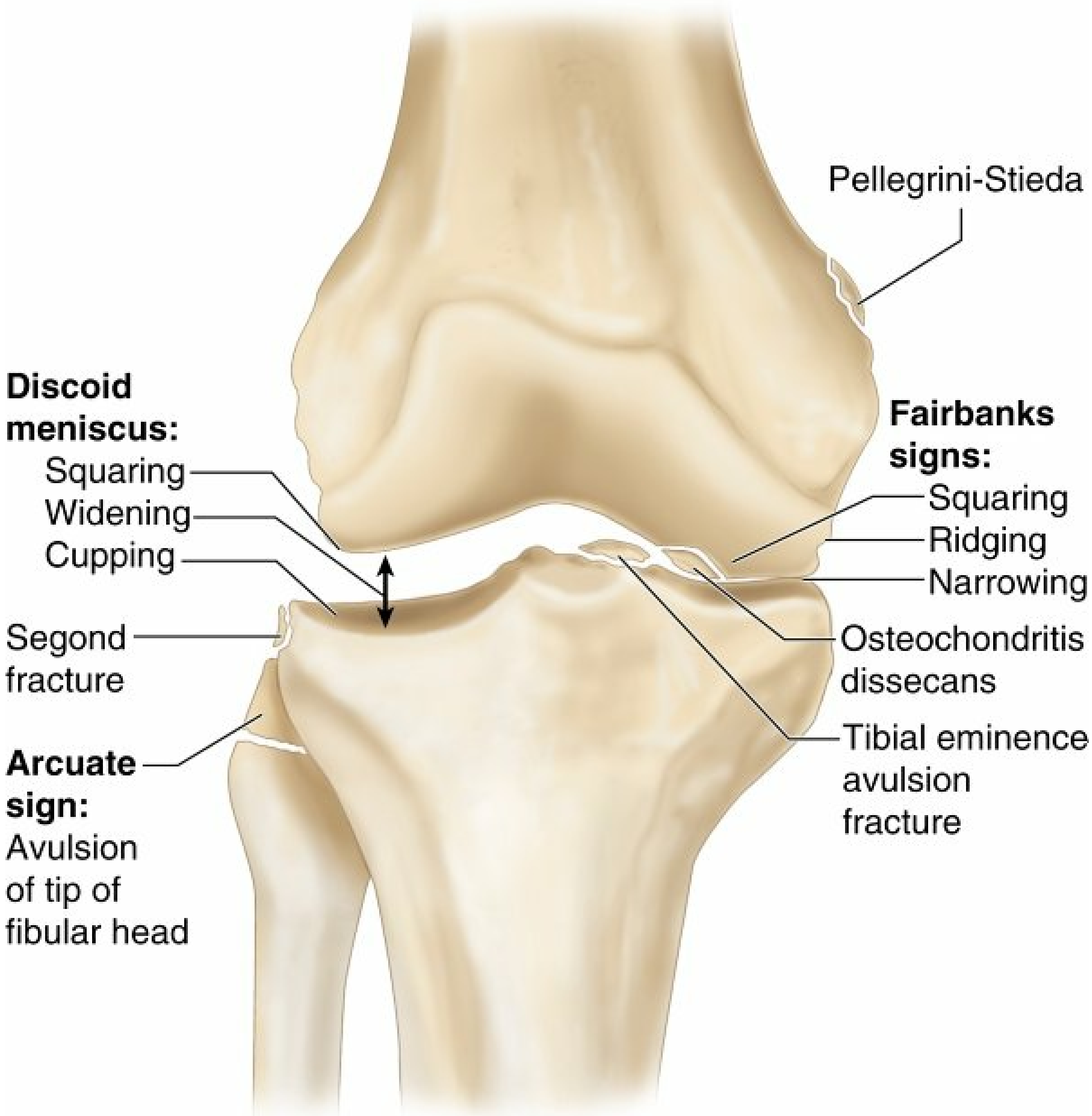


FIG. 4.6 Common findings visualized on knee radiographs.

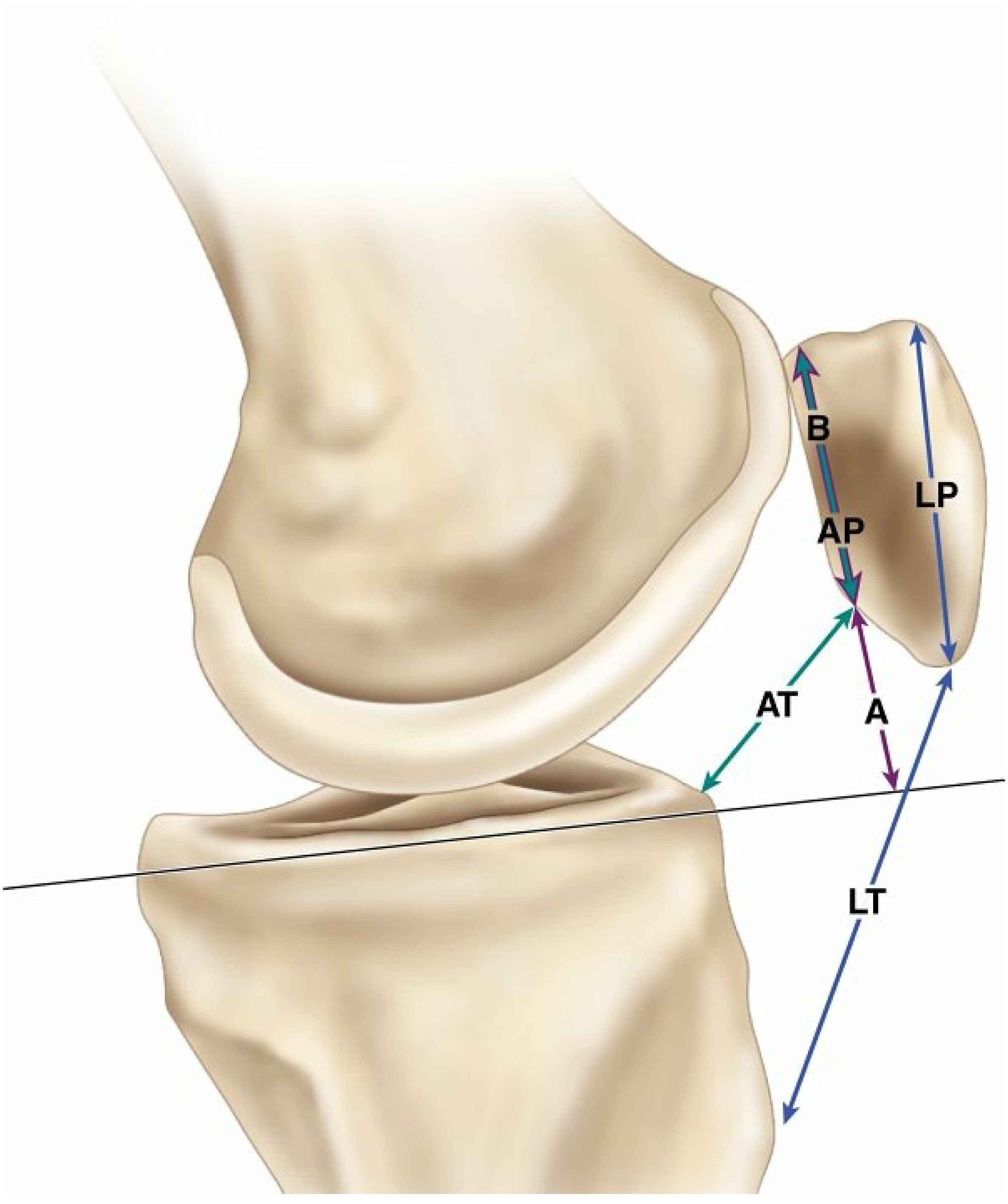

B
LP
AP
AT
A
LT

FIG. 4.7 Three common methods for calculating patellar height. The Caton-Deschamps index (AT/AP) is the ratio between the distance from the lower edge of the patella's articular surface to the anterosuperior angle of the tibia outline *(AT)* and the length of the articular surface of the patella *(AP).* The Insall-Salvati index (LT/LP) is the ratio between the length of the patellar tendon *(LT)* and the longest sagittal diameter of the patella *(LP)*. The Blackburne-Peel index (A/B) is the ratio between the length of a perpendicular line drawn from the tangent to the tibial plateau to the inferior pole of the articular surface of the patella *(A)* and the length of the articular surface of the patella *(B)*.

- □ Accessory portals
  - Helpful for visualizing the posterior horns of the menisci and PCL
  - Posteromedial portal
    - 2.5 cm inferior and 2.5 cm posterior to the medial epicondyle with knee in 90 degrees of flexion
  - Posterolateral portal
    - 1 cm above the joint line between the LCL and biceps tendon (avoiding the common peroneal nerve); spinal needle used to localize
  - Transpatellar portal
    - 1 cm distal to the patella, longitudinally splitting the patellar tendon fibers
    - Can be used for central viewing or grabbing
      - Can be used for classic Gillquist maneuver for posterior viewing
- □ Less commonly used portals
  - Medial and lateral midpatellar portals
  - Proximal superomedial and superolateral portals (4 cm proximal to patella)
    - Used for patellofemoral compartment visualization
  - Far medial and far lateral portals
    - Used for accessory instrument placement (loose-body removal)

▪ **Technique**

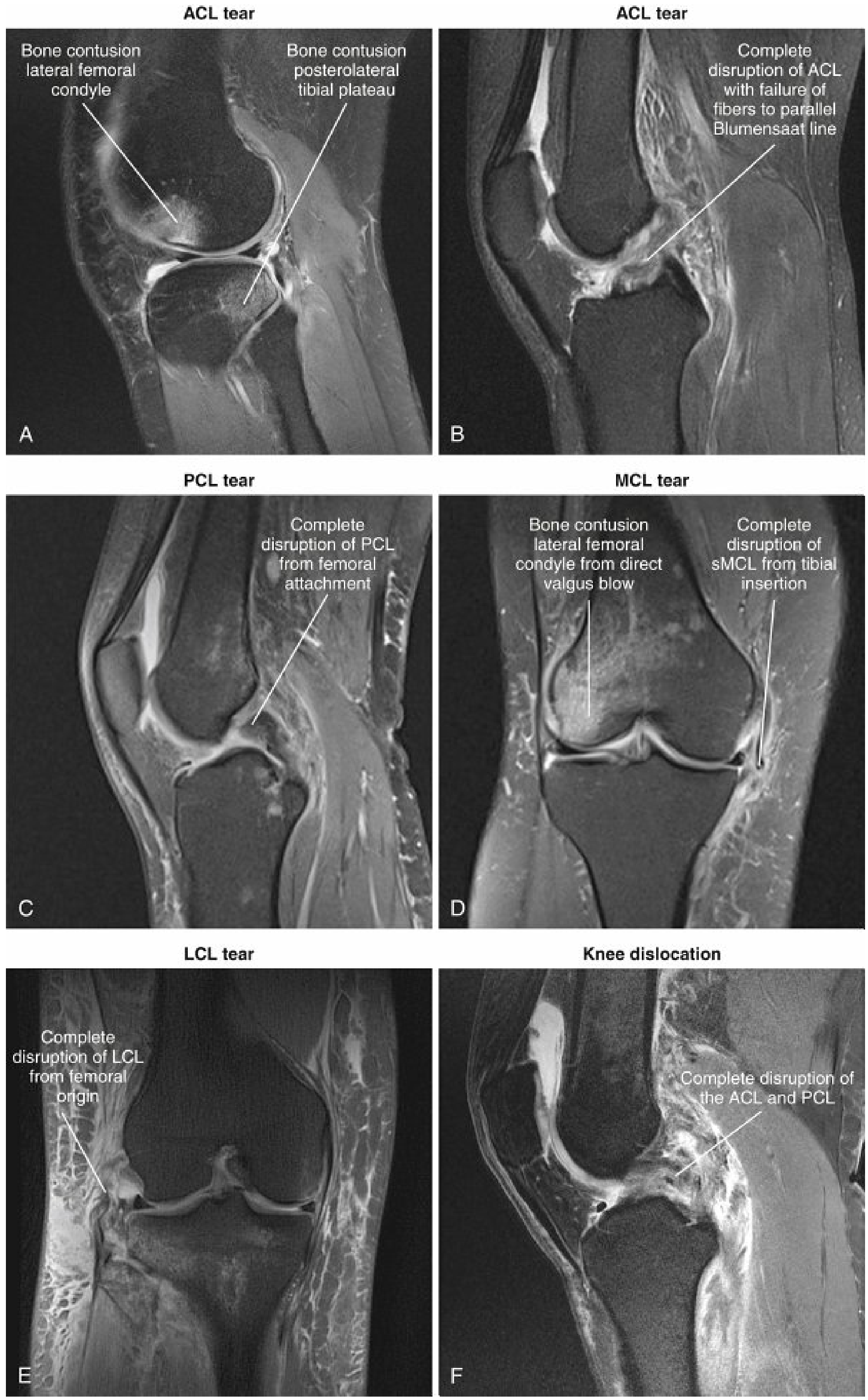
- □ Each knee arthroscopic procedure should include an evaluation of the suprapatellar pouch; patellofemoral joint and tracking; medial and lateral gutters; medial compartment, including the medial meniscus and the articular surface; the lateral compartment, including the lateral meniscus and the articular surface; and the intercondylar ridge to visualize the ACL and PCL (Fig. 4.10).
- □ The posteromedial compartment can be best visualized with a 70-

degree arthroscope placed through the interval of the PCL and medial femoral condyle (modified Gillquist view) or a posteromedial portal. The posterolateral compartment can be best visualized with placement of the arthroscope through the interval of the ACL and lateral femoral condyle or a posterolateral portal.

- **Arthroscopic complications**
  - Most common: iatrogenic articular cartilage damage
  - Additional complications: instrument breakage, hemarthrosis, infection, arthrofibrosis, deep venous thrombosis (DVT), and neurovascular injury (especially injury to infrapatellar branches of saphenous nerve)

Meniscal Injuries

- **Meniscal tears**
  - Overview
    - Meniscal tear is the most common injury to the knee that necessitates surgery.
    - The medial meniscus is torn approximately three times more often than the lateral meniscus.
      - However, lateral meniscus tears occur more commonly with acute ACL tears.
    - There is an increased rate of osteoarthritis in knees after meniscal tears and meniscectomy, particularly on the lateral side.
    - Traumatic meniscal tears are common in young patients with sports-related injuries.
    - Degenerative tears usually occur in older patients and can have an insidious onset.



ACL tear
Bone contusion lateral femoral condyle
Bone contusion posterolateral tibial plateau
A
ACL tear
Complete disruption of ACL with failure of fibers to parallel Blumensaat line
B
PCL tear
Complete disruption of PCL from femoral attachment
C
MCL tear
Bone contusion lateral femoral condyle from direct valgus blow
Complete disruption of sMCL from tibial insertion
D
LCL tear
Complete disruption of LCL from femoral origin
E
Knee dislocation
Complete disruption of the ACL and PCL
F

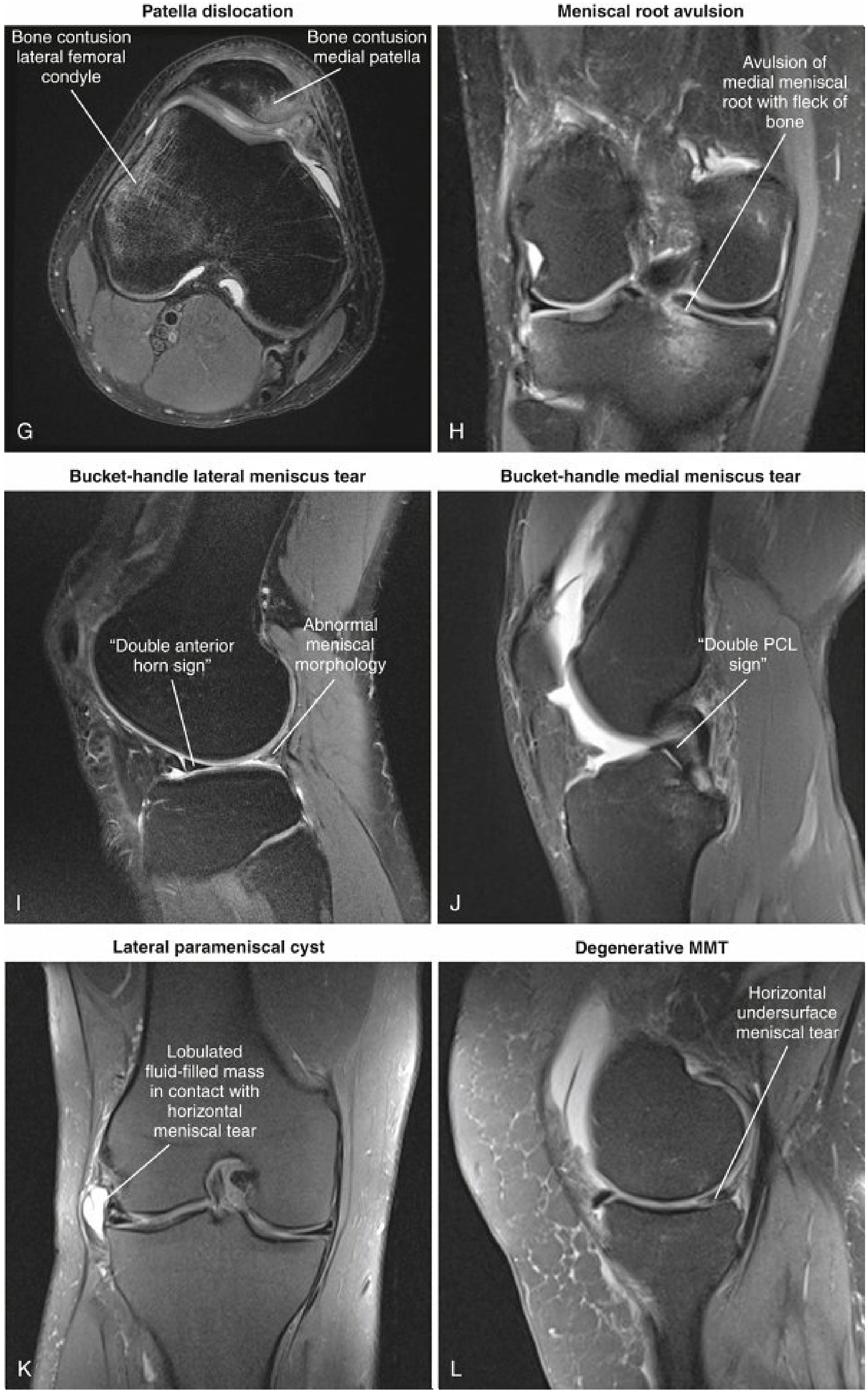


FIG. 4.8 MRI of the knee. (A) ACL tear with bone contusion. (B) ACL tear with complete disruption. (C) PCL tear with complete disruption. (D) MCL tear. (E) LCL tear. (F) Knee dislocation with ACL and PCL tear.(G) Patellar dislocation. (H) Meniscal root avulsion. (I) Bucket-handle lateral meniscus tear. (J) Bucket-handle medial meniscus tear (*MMT*). (K) Lateral parameniscal cyst. (L) Degenerative MMT.

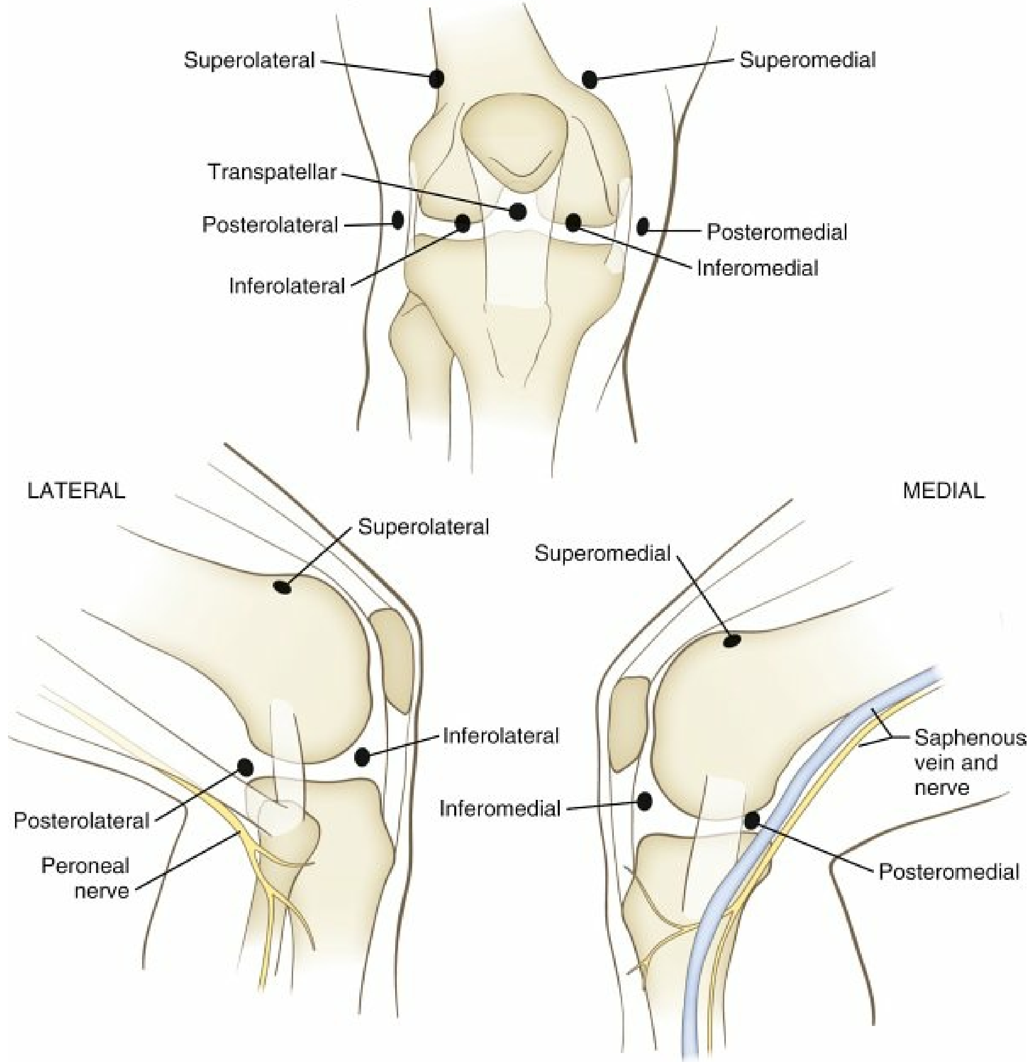


FIG. 4.9 Knee arthroscopy portals.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders.

- Meniscal tears can be classified according to:
  - Location in relation to the vascular supply (see Fig. 4.3)
  - Position (anterior, middle, posterior third, root)
  - Appearance and orientation (Fig. 4.11)
- Meniscal root tear
  - Defined as a radial tear or avulsion of the meniscal root from the tibial plateau
  - Completely disrupts the circumferential fibers of the meniscus
  - Biomechanically, results in a loss of hoop stresses and an increase in contact forces
  - **Functionally equivalent to a total meniscectomy**
  - Lateral root tears are associated with ACL tears.
  - Medial root tears are associated with chondral injuries.
  - Acute root tears should be repaired whenever possible.

- Indications for repair of degenerative root tears continue to evolve.
- The vascular supply of the meniscus is a primary determinant of healing potential.
    - Tears in the peripheral third have the highest potential for healing.

□ Principles of treatment

- **In the absence of intermittent swelling, catching, and locking, meniscal tears—particularly degenerative tears—may be treated conservatively**.
- Younger patients with acute tears, patients with tears causing mechanical symptoms, and patients with symptoms that fail to improve with conservative measures may benefit from operative treatment.
- Acute meniscal root tears should be repaired early. The treatment of chronic tears is more controversial.

□ Partial meniscectomy

- Tears that are not amenable to repair (e.g., peripheral, longitudinal tears)—excluding those that do not necessitate any treatment (e.g., partial-thickness tears, those <5-10 mm in length, and those that cannot be displaced >1–2 mm)—are best treated with partial meniscectomy.
- In general, complex, degenerative, and central/radial tears are treated with resection of a minimal amount of normal meniscus.
- Partial meniscectomy increases peak stresses in the affected compartment.

□ Meniscal repair

- Indications (general)
    - Tear between 1 and 4 cm
    - Vertical tear

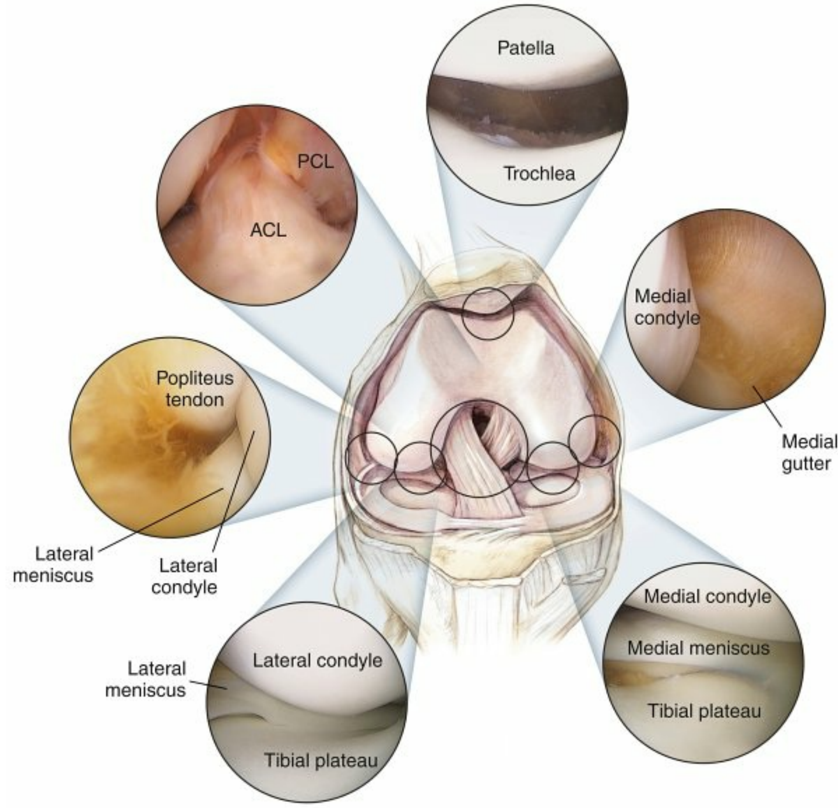


FIG. 4.10 Normal arthroscopic anatomy of the knee. From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, ed 2, 2015, Saunders.

    - Red-red tear
    - Meniscal root tear
    - Patient younger than 40 years
- Concomitant ACL reconstruction may extend the indications because results are typically better.
- Augmentation techniques (fibrin clot, platelet-rich plasma clot, vascular access channels, synovial rasping) may extend the indications for repair.
- Four techniques are commonly used: open, "outside-in," "inside-out," and "all-inside" (Fig. 4.12).
- Newer techniques for all-inside repairs are popular because of their ease of use.
    - The latest generation of "all-inside" devices allows tensioning of the construct.
- The gold standard for meniscal repair remains the inside-out technique with vertical mattress sutures.
- Regardless of the technique used, it is essential that the saphenous nerve branches (anterior to both the semitendinosus and gracilis muscles and posterior to the inferior border of the sartorius muscle) be protected during medial repairs, and the peroneal nerve (posterior to the biceps femoris) during lateral repairs (Fig. 4.13).
- Rehabilitation following meniscus repair should involve

avoidance of knee flexion beyond 90 degrees. The level of allowed weight bearing is controversial.

- Results of meniscal repair
  - In several studies, 80%–90% success rates with meniscal repairs have been reported. However, success depends on location, type of tear, and chronicity.
  - It is generally accepted that the results of meniscal repair are best with acute peripheral tears in young patients undergoing concurrent ACL reconstruction.
  - In general, success rates are 90% when meniscal repair is performed in conjunction with an ACL reconstruction, 60% when meniscal repair is performed in a knee with an intact ACL, and 30% when meniscal repair is performed in a knee with a deficient ACL.

- **Meniscal cysts**
  - Occur primarily in conjunction with **horizontal cleavage tears of the lateral meniscus**
  - Operative treatment, consisting of arthroscopic partial meniscectomy or repair and decompression through the tear (sometimes including “needling” of the cyst), has been shown to be effective.

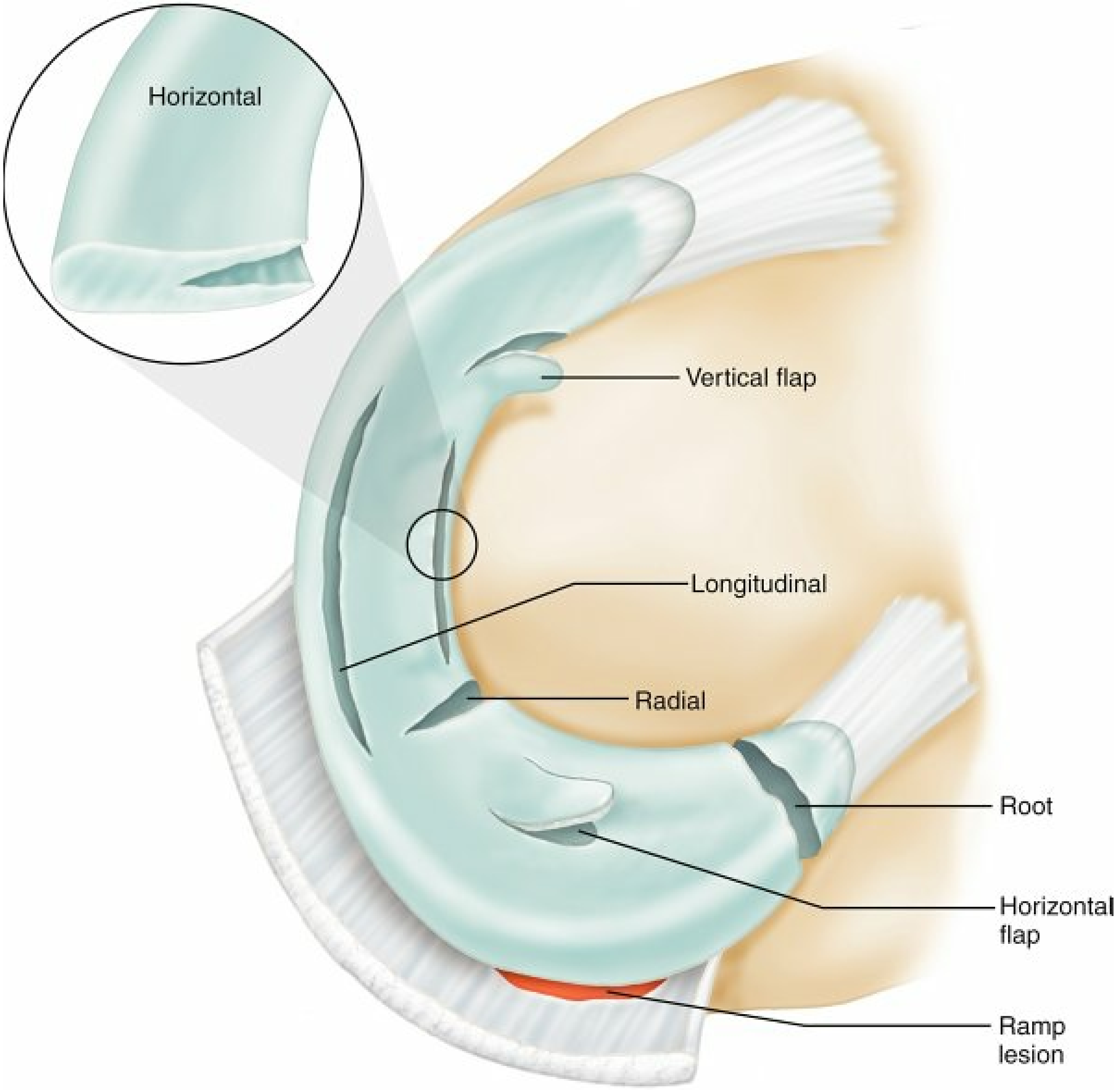


FIG. 4.11 Types of meniscal tears.
From Miller MD et al: *Essential Orthopaedics,* ed 2, Philadelphia, 2019, Saunders.

- □ En bloc excision is no longer favored for most meniscal cysts.
- □ Popliteal (Baker) cysts are commonly related to meniscal disorders and usually resolve with treatment of the primary disorder.
- □ Usually located between the semimembranosus and the medial head of the gastrocnemius
- □ Arthroscopic decompression using a posteromedial portal has been advocated by some, with reports of at least a reduction in recurrence.

▪ **Discoid menisci (popping knee syndrome)**

- □ Can be classified as (I) incomplete, (II) complete, or (III) the Wrisberg variant
  - • A Wrisberg variant lacks coronary ligaments and represents an unstable meniscus.
- □ The patient may experience mechanical symptoms or "popping" with the knee in extension.
- □ Plain radiographs may demonstrate a widened joint space, squaring of

the lateral femoral condyle, cupping of the lateral tibial plateau, and a hypoplastic lateral intercondylar spine.

- Appearance of a **contiguous lateral meniscus on three consecutive sagittal images on MRI** is diagnostic; MRI may also demonstrate associated tears.
- Treatment
  - Observation if asymptomatic
  - Partial meniscectomy (saucerization) for tears
  - Meniscal repair for peripheral detachments (Wrisberg variant)

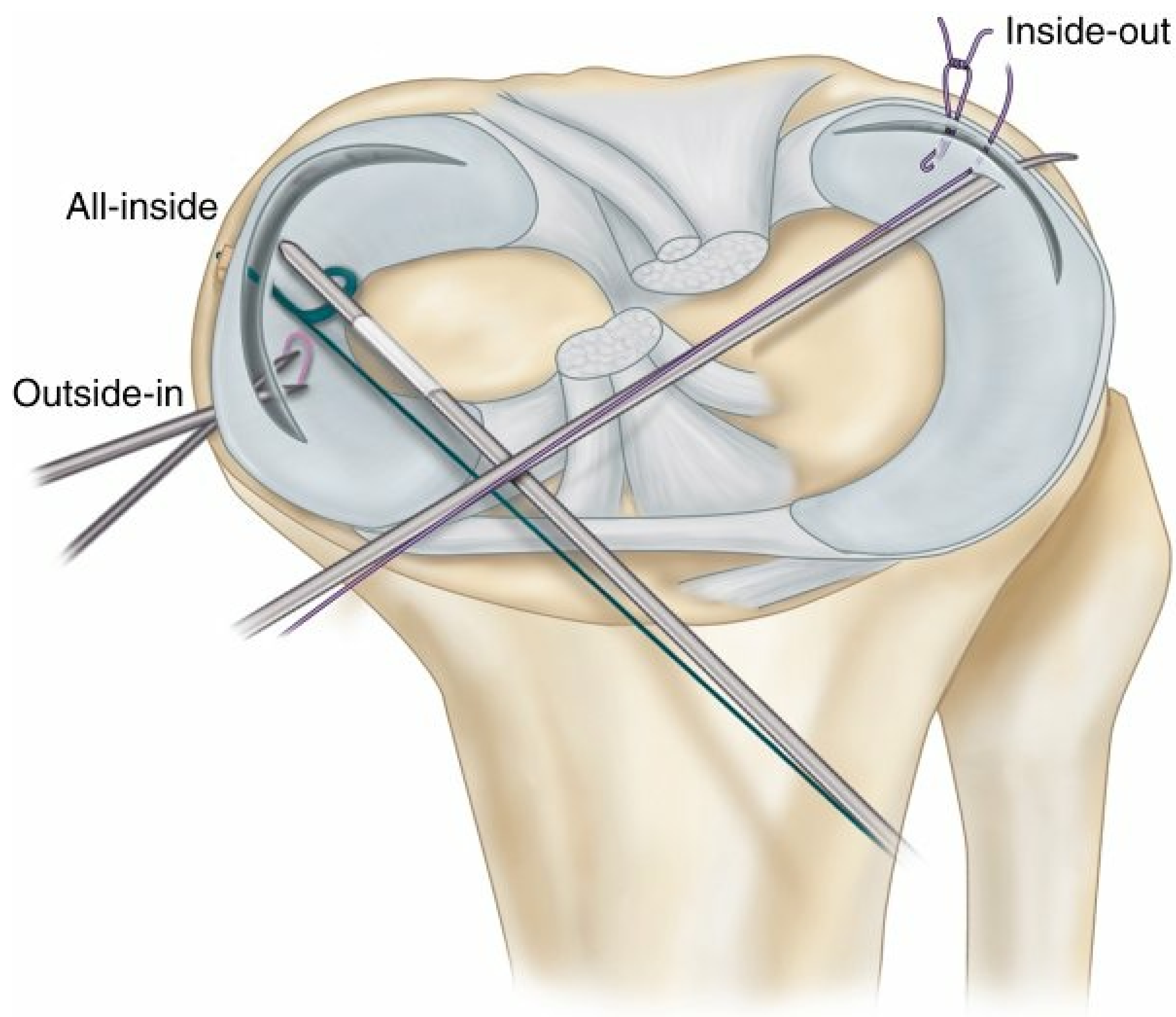


FIG. 4.12 Meniscal repair techniques.

- **Meniscal transplantation**
  - Controversial; all nonoperative management modalities should be exhausted prior to consideration of meniscal transplantation.
  - Indications
    - Prior total or near-total meniscectomy (especially lateral)
    - Pain in the involved compartment

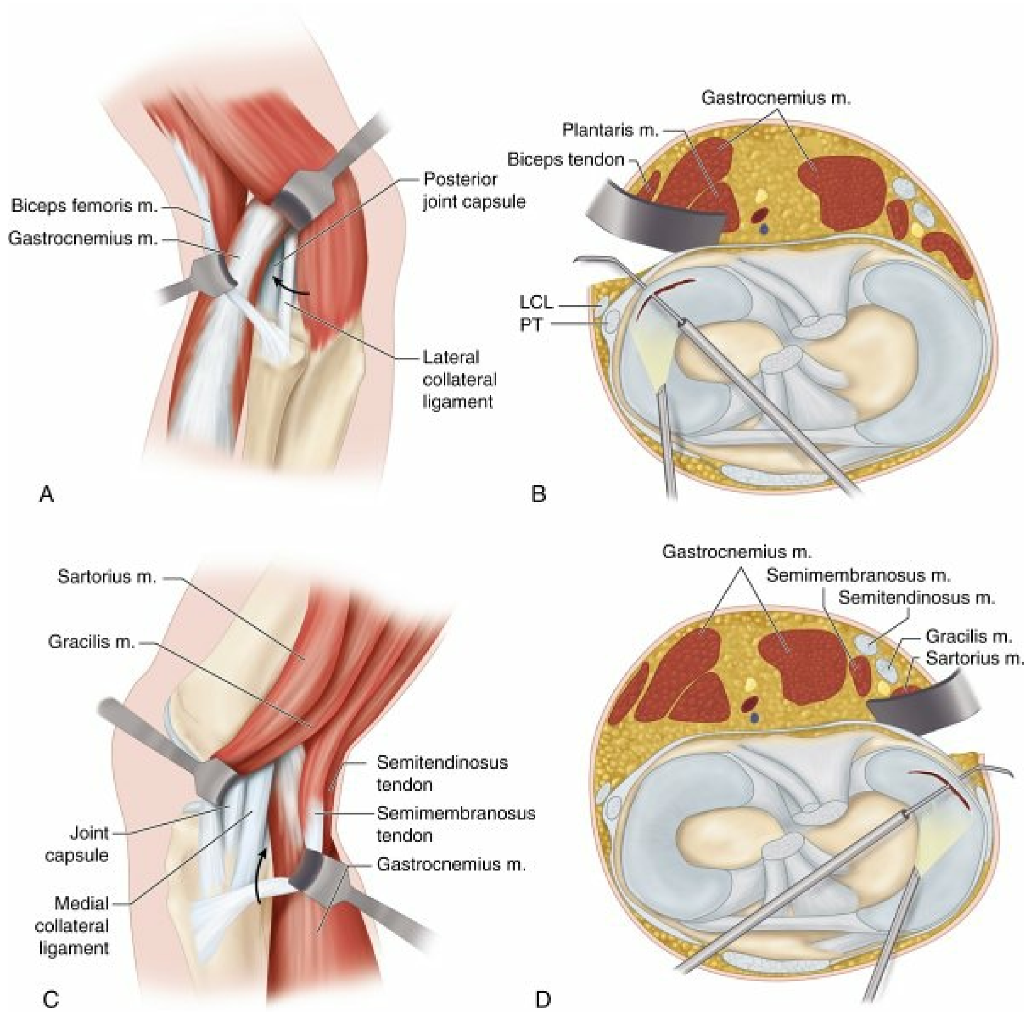


FIG. 4.13 Approaches for inside-out lateral (A and B) and medial (C and D) meniscal repairs. *PT,* Popliteus tendon.
From DeLee JC et al, editors: *DeLee & Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2009, Elsevier.

- BMI less than 30
- Patient younger than 50 years
- Addressable full-thickness chondral lesions
- Normal alignment
- Ligamentous stability

□ Ligamentous deficiency and limb malalignment must be addressed to improve success rates of meniscal transplantation.

□ Contraindications
- **Diffuse grades III and IV chondral changes**
- Kissing lesions
  - Chondral lesions adjacent to each other on the femur and tibia
- Advanced patient age
- Inflammatory arthritis
- Synovial disease
- Uncorrected mechanical axis that lies in the affected compartment

□ Graft size accurate to within 5% of the native meniscus is crucial to success. Sizing is typically done using radiographs but may also be accomplished using MRI.

- Undersized grafts result in poor congruity and increased load transmission.
- Oversized grafts result in meniscal extrusion and impaired ability to transmit compressive loads.

□ Techniques for implantation include use of individual bone plugs for the anterior and posterior horns and use of a bone bridge, especially laterally.

□ Pain relief is the most consistent benefit; most studies have short-term to 5-year data available, but the chondroprotective effect of meniscal transplantation has yet to be demonstrated clinically.

□ Meniscal allograft tissue often remains hypocellular or acellular, particularly at the core.

□ Collagen meniscal implantation has yielded promising initial results for irreparable medial meniscal tears with new meniscus-like matrix formation, in comparison with partial meniscectomy. However, long-term results, especially from independent sources, have not been reported.

Ligament Injuries

▪ **ACL injury**

□ Introduction

- Common injury accounting for between 40% and 50% of all knee ligament injuries
- Female athletes have a 2–8 times higher risk of ACL tear than male athletes.
  - Thought to occur because women have different landing biomechanics
    - Women have a greater total valgus knee loading in landing and land more erectly.
    - Women have increased quadriceps-to-hamstring strength, causing greater anterior sheer.
  - **Smaller notches, smaller ligaments (reduced area in cross section), greater generalized ligament laxity, increased knee laxity, and absence of the COLA5A1 gene are additional proposed factors.**
- Skiing, soccer, basketball, and football are the highest-risk sports.

- Mechanism of injury is typically a valgus load with internal tibial rotation and anterior tibial translation while the knee is in almost full extension.
- The in situ force of the ACL is highest at 30 degrees of flexion in response to anterior tibial load. Associated injuries are common.
    - Acute lateral meniscal tears are more common than acute medial tears, whereas medial tears occur more often with chronic ACL deficiency.
    - MCL injuries occur in approximately 25% of cases.
        - MCL injuries typically treated nonoperatively
    - PLC injuries occur in approximately 10% of cases.
        - Lack of recognition of a PLC injury has been cited as a common cause of ACL reconstruction failure.
- Chronic ACL deficiency is associated with higher incidences of both complex meniscal tears not amenable to repair and chondral injury.
- Controversy continues regarding the development of late arthritis in ACL-deficient versus reconstructed knees.
    - Currently there is no high-level evidence to suggest that ACL reconstruction reduces the risk of development of arthritis.
    - Chondral and meniscal injuries that occur at the time of initial ACL rupture have been demonstrated to be the main predictors of arthritic change.
- ACL injury prevention programs emphasize proprioceptive training and the strengthening of knee flexors.
- The most common reasons for failure to return to play/sport after ACL reconstruction are pain and fear of reinjury.

□ History and physical examination

- ACL injuries are often the result of **noncontact pivoting injuries.**
- They are commonly associated with an audible **pop and a hemarthrosis** that begins within 12 hours of injury.
- Instability and **inability to return to sport** are the most frequent complaints.
- The **Lachman test** is the most sensitive examination for acute ACL injuries.
- Performance on the pivot shift test is most closely correlated with outcome after ACL reconstruction.

- The pivot shift is a reduction of the subluxated lateral tibial plateau by the iliotibial band when the knee is moving from full extension to flexion.
- KT-1000 and KT-2000 arthrometers are useful in quantifying laxity but unnecessary in diagnosis.

□ Imaging

- Plain radiographs are essential in evaluating ACL injuries.
  - A **Segond fracture** may be present and may represent avulsion of either the anterolateral ligament or the lateral capsule.
  - Lateral radiographs should be carefully scrutinized for **posterior tibial slope.** Values greater than 12 degrees have been associated with ACL graft failure.
- MRI is useful in confirming the diagnosis.
  - On sagittal imaging, fibers of an intact ACL should parallel Blumensaat line.
  - Signs of an ACL tear:
    - Disruption of ACL fibers
    - Fibers no longer parallel to Blumensaat line
    - Inability to visualize fibers of ACL
    - "Empty lateral wall" or "empty notch" sign on coronal MRI, which indicates avulsion of ACL from the femoral origin
  - **Bone bruises (trabecular microfractures) occur in more than half of acute ACL injuries.**
    - Bone bruises are typically located near the sulcus terminalis on the lateral femoral condyle and the posterolateral aspect of the tibia.
    - Although the long-term significance of these injuries is controversial, they may be related to late cartilage degeneration.

□ Treatment

- Initial management consists of physical therapy to restore motion. Immobilization is avoided.
  - **Full ROM and good quadriceps control should be achieved prior to surgery.**
- Individualize treatment based on age, activity level, instability, associated injuries, and other medical factors.

- Primary repair of ACL tears is not currently recommended.
    - Myofibroblasts "coat" the ends of the ACL stumps, making primary healing unlikely.
- Surgical technique
    - Single-bundle reconstruction is still the most commonly performed reconstruction. Significant controversy exists regarding double-bundle ACL reconstruction.
        - Currently there is no difference in patient-reported outcomes between single-bundle and double-bundle techniques.
    - Placement of a more horizontal femoral tunnel (10- or 2-o'clock position, or "**anatomic ACL reconstruction**") to center the graft in the middle of the femoral ACL footprint has been the focus of newer, independent femoral tunnel drilling techniques (in contrast to traditional transtibial-femoral drilling techniques).
        - A more horizontal graft position may reduce rotational instability.
    - Graft selection depends on patient factors and surgeon's preference, and choices usually include (1) a bone–patellar tendon–bone (BPTB) autograft, (2) a four-strand hamstring autograft, (3) a quadriceps tendon autograft, and (4) an allograft.
        - BPTB demonstrates faster incorporation into the bone tunnels than hamstring autograft and, for the authors of this chapter, is often the graft of choice in patients who desire an early return to sports activity.
        - Several studies, however, have demonstrated a higher incidence of arthritis associated with the use of BPTB autograft than with hamstring autograft 5–7 years after ACL reconstruction.
        - BPTB autograft harvest carries the risk of anterior knee pain, pain with kneeling, loss of extension, and poorer recovery of quadriceps

strength.
- Hamstring autograft is similar in strength to the native ACL but is less stiff.
- Hamstring autograft harvest carries the risk of weakness of knee flexion and internal rotation, along with injury to branches of the saphenous nerve.
- Both BPTB and quadriceps tendon with bone block grafts carry the risk of patellar fracture.
- **Use of allograft with ACL reconstruction in younger, more active patients is associated with a higher rate of rerupture.**
- Chemically processed and irradiated allografts have demonstrated higher rates of failure than fresh frozen allografts.
- Allografts have been demonstrated to incorporate into bone tunnels more slowly.
- Use of allograft also includes infection risk (e.g., with *Clostridium* species, hepatitis, and HIV), although rates are low (1:1.6 million).
    - Preimplantation culture of allografts not widely recommended

- Postoperative rehabilitation
    - Rehabilitation has evolved, and early motion (emphasis on extension) and weight bearing are encouraged in most protocols.
    - Exercises that do not endanger the ACL graft:
        - Are dominated by the hamstrings (isometric hamstrings)
        - Result in quadriceps activity with the knee flexed beyond 60 degrees
        - Involve active knee ROM between 35 and 90 degrees of flexion
    - Closed kinetic chain rehabilitation (fixation of terminal segment of extremity [i.e., with foot

planted]) and compressive loading have been emphasized because they allow physiologic co-contraction of the muscles around the knee.
    - **Open kinetic chain extension exercises, particularly with the knee near full extension, place increased stress on the reconstructed ACL and should be avoided for the first 6 weeks.**
    - No difference in outcome has been found between accelerated and nonaccelerated rehabilitation programs.
    - Postoperative bracing has not proved beneficial after ACL reconstruction *except* in downhill skiers.
    - Early progressive eccentric exercise has yielded good initial results in terms of quadriceps and gluteus maximus muscle size and function after ACL reconstruction.
  - Complications (Fig. 4.14)
    - Graft failure
      - **The most common technical error is tunnel malposition.**
        - Vertical graft placement results in decreased rotational stability.
        - Anterior placement of the femoral tunnel results in flexion loss.
    - Arthrofibrosis is the most common complication following ACL reconstruction and often occurs with reconstruction for acute ACL tears.
      - Risk is minimized by the achievement of full ROM prior to surgery.
    - Aberrant hardware placement (interference screw divergence of >30 degrees [for femoral tunnels] or >15 degrees [for tibial tunnels]) can also result in complications.
    - Infection occurs in less than 1% of cases.
      - Irrigation and débridement with graft retention are successful in up to 85% of cases.

□ Revision ACL reconstruction
  - All causes of graft failure must be considered, including technical issues, unrecognized concomitant ligament

injuries, coronal or sagittal malalignment, biological failure of graft incorporation, and other patient-related issues (Fig. 4.15)
    - A thorough workup of failed ACL reconstruction should include acquiring prior operative notes, evaluating tunnel placement and size, and assessing coronal alignment, posterior tibial slope, and collateral ligament sufficiency.
    - All causes for failure should be addressed as a one- or two-stage procedure, depending on which factors must be corrected.
    - **Autograft is still preferred for revision ACL reconstruction**; options include ipsilateral hamstrings, patellar tendon, and quadriceps tendon in addition to contralateral grafts.
    - Osteolysis is a particular problem in revision ACL reconstruction and may necessitate a two-stage approach.
  - Partial ACL tears
    - The existence and treatment of "partial" ACL tears is controversial, although clinical examination and functional stability remain the most important considerations in determining the need for reconstruction.
    - Single-bundle tears may be addressed with reconstruction of the injured bundle and preservation of the intact bundle, but preservation of the ACL remnant and removal of the remnant with standard reconstruction demonstrate equivalent clinical outcomes.
- **PCL injury**
  - History
    - Injuries occur most commonly as a result of a **direct blow to the anterior tibia** with the knee flexed (the "dashboard injury"), with hyperflexion, or with hyperextension.
    - A fall onto the ground with a plantar-flexed foot is also a mechanism of injury for PCL tears.
  - Physical examination and classification
    - Key examination maneuver is the **posterior drawer test**; diagnostic results are absence of or posteriorly directed tibial step-off.
    - Grade I injury: an isolated PCL injury in which the tibia remains anterior to the femoral condyles
    - Grade II injury: an isolated complete PCL injury in which the anterior tibia becomes flush with the femoral condyles
    - Grade III injury: an injury in which the tibia is posterior to the femoral condyles; usually indicative of associated ACL or PLC injury or both

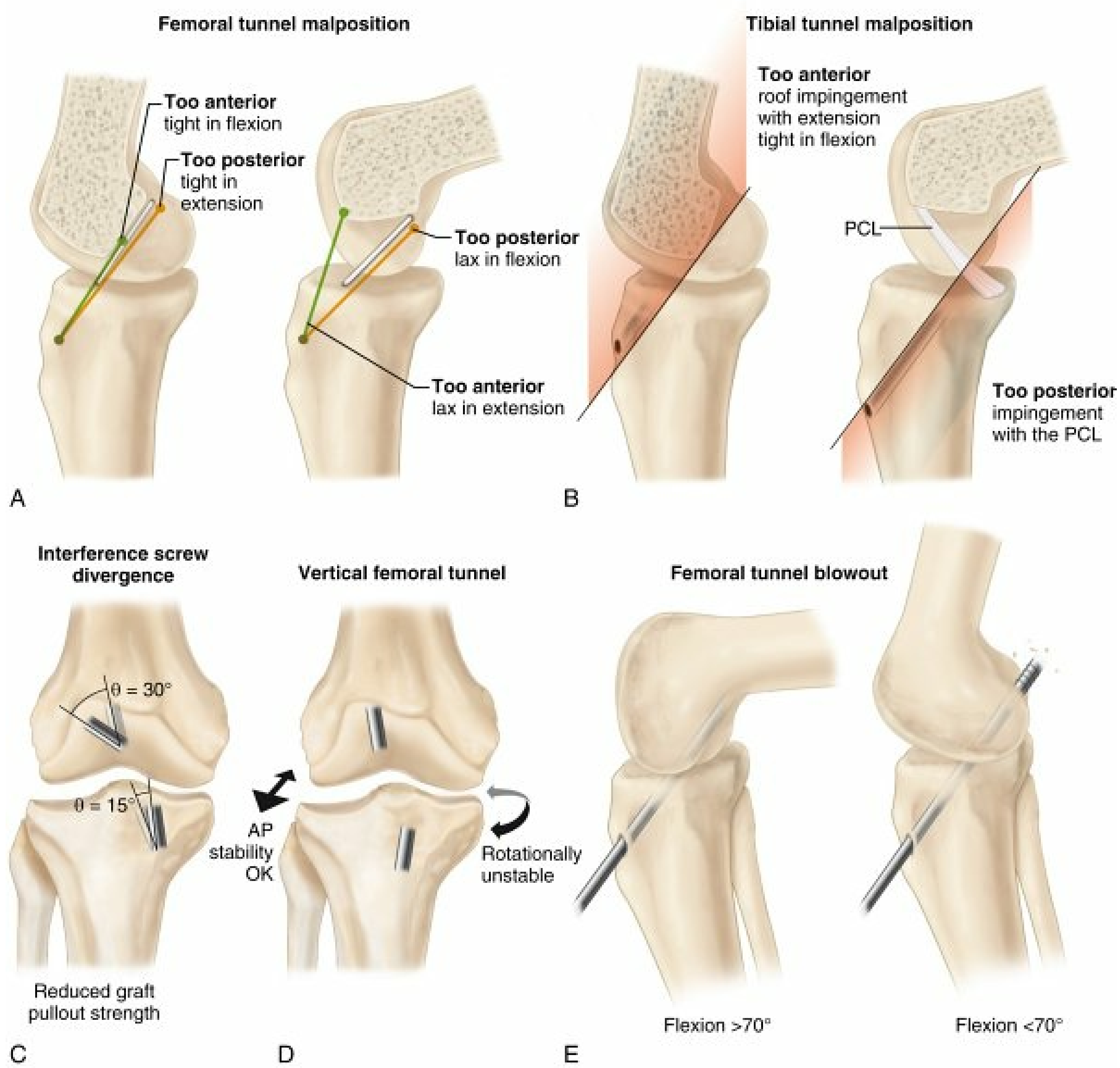


FIG. 4.14 Common complications of ACL reconstruction. (A) Femoral tunnel malposition. (B) Tibial tunnel malposition. (C) Interference screw divergence. (D) Vertical femoral tunnel. (E) Femoral tunnel blowout.

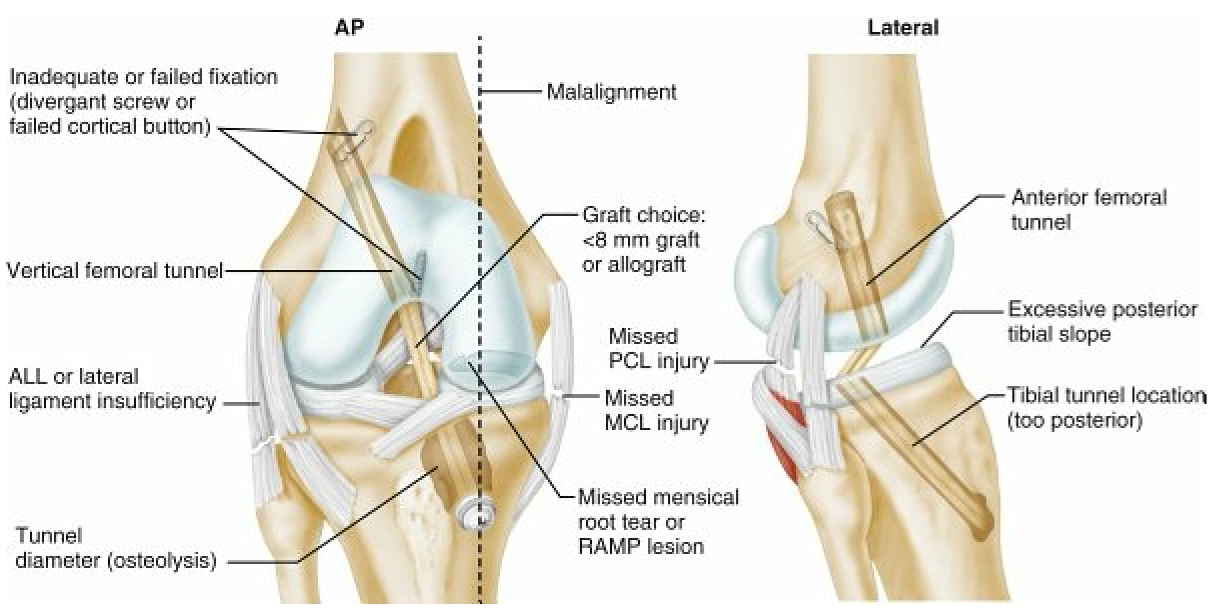


FIG. 4.15 Considerations in revision ACL reconstruction.

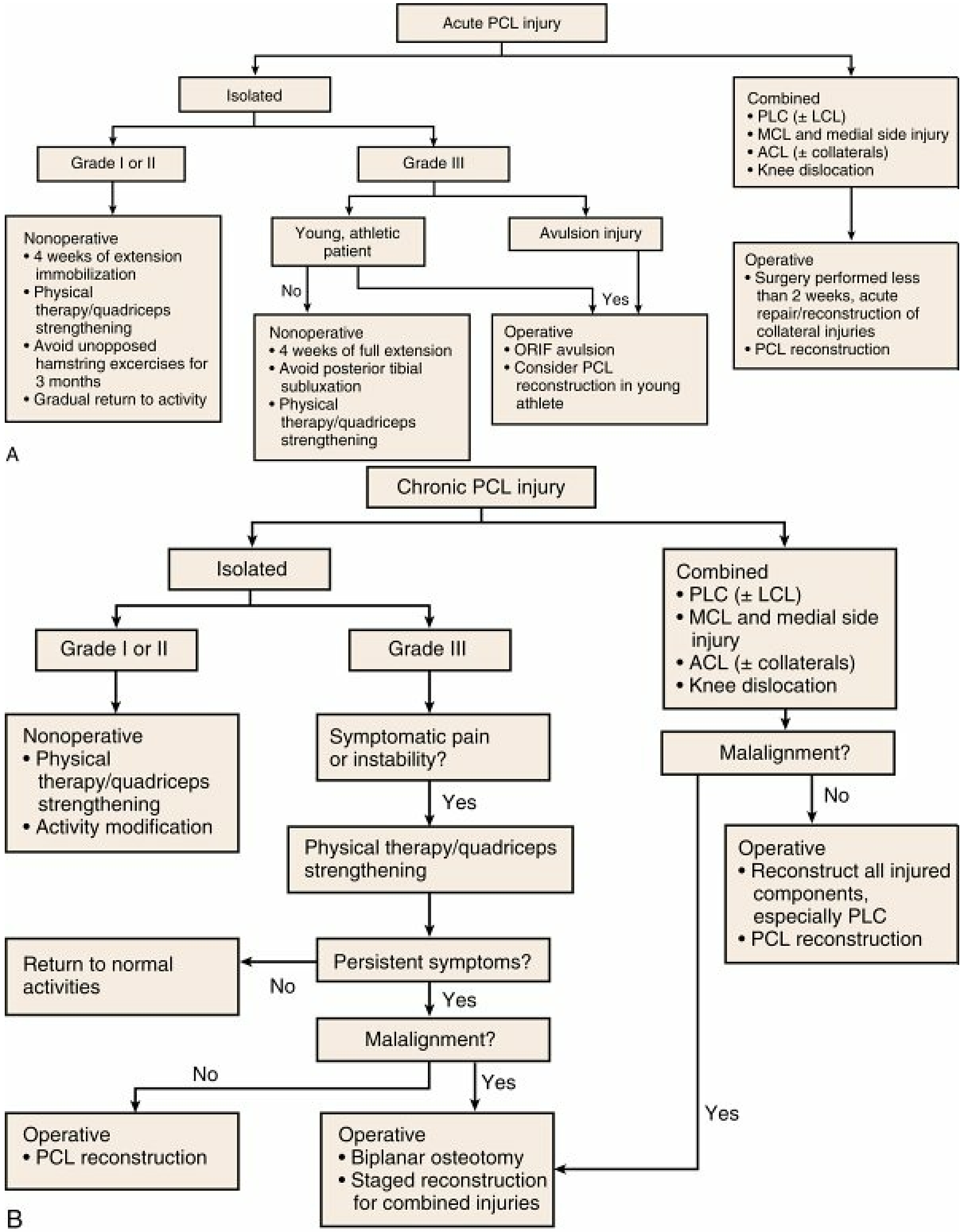


FIG. 4.16 Algorithms for management of acute (A) and chronic (B) PCL injury. *ORIF*, Open reduction and internal fixation.

□ Imaging

- Plain radiographs should be obtained to evaluate for avulsion injuries (acute) and arthrosis of the medial and patellofemoral compartments (chronic).
- Stress radiographs are becoming the standard for evaluation and grading of PCL injuries; side-to-side differences of more than 12 mm on stress radiographs are suggestive of a combined PCL and PLC injury.

- MRI is a confirmatory study.

□ Treatment (Fig. 4.16)

- **Nonoperative treatment is favored for most grades I and II (isolated) PCL injuries.**
    - Rehabilitation should focus on strengthening the knee extensors.
- Grade III injuries are indicative of a combined injury, usually to the PLC.
- Bony avulsion fractures can be repaired primarily with good results, although primary repair of midsubstance PCL injuries has not been successful.
- Chronic PCL deficiency can result in late chondrosis of the patellofemoral and medial compartments due to increased contact pressures.
- PCL reconstruction is recommended for functionally unstable or combined injuries.

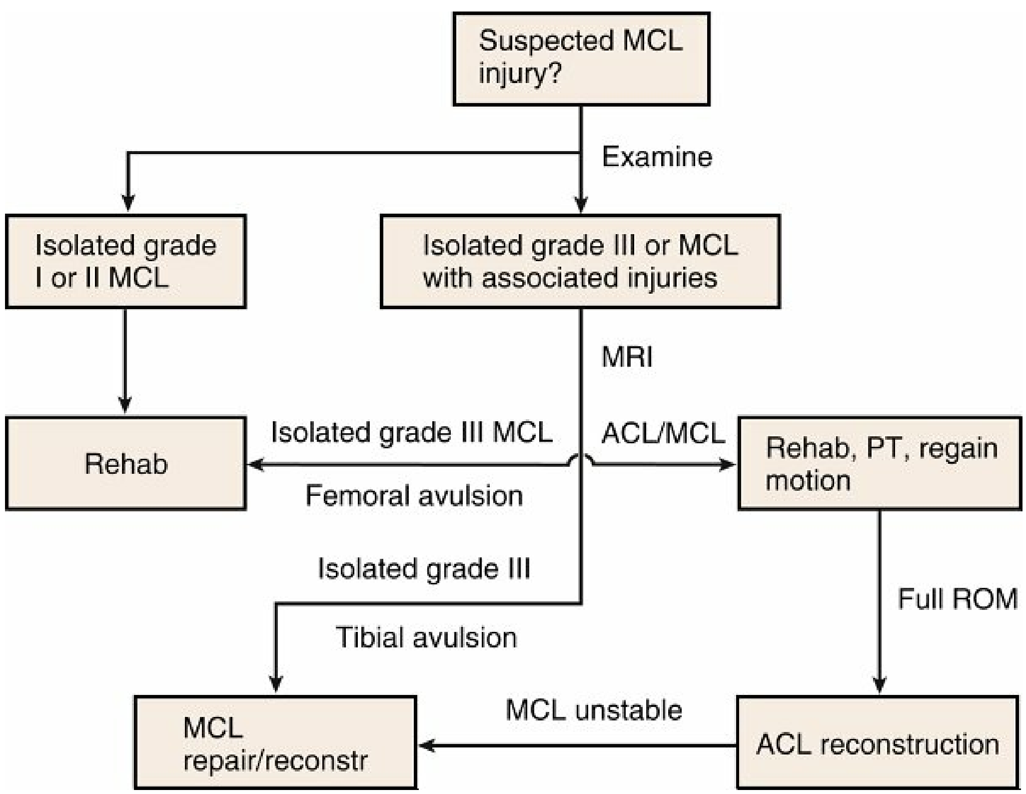


FIG. 4.17 Algorithm for management of MCL injuries. Grade 1: 3–5 mm; grade 2: 6–10 mm; grade 3: >10 mm. *PT,* Physical therapy; *Rehab,* rehabilitation.

- In general, the results of PCL reconstruction are not as good as those of ACL reconstruction, and some residual posterior laxity often remains.
- For successful reconstruction, concomitant ligament injuries must be addressed.
- A biplanar high tibial osteotomy can be used to treat

combined malalignment and PCL insufficiency.
        - Increasing posterior tibial slope results in an anterior shift of the resting position of the tibia and thus minimizes posterior tibial sag.
    - Surgical techniques
        - Many techniques for PCL reconstruction have been published, and they can generally be divided into tibial inlay versus transtibial methods and single-bundle versus double-bundle methods.
        - Single-bundle reconstructions (which focus on reconstructing the anterolateral bundle) should be tensioned in 90 degrees of flexion.
        - Tibial inlay has biomechanical advantages, such as a decrease in the "killer turn" and reduced attenuation of the graft, but is technically more challenging.
        - Double-bundle techniques may improve biomechanical function in both extension and flexion, but a clinical advantage to those techniques has not yet been shown.
            - The anterolateral bundle is the most important for posterior stability at 90 degrees of flexion and should be tensioned in flexion; the posteromedial bundle has a reciprocal function and should be tensioned in extension.
    - Rehabilitation
        - Quadriceps strengthening and open kinetic chain knee extension exercises protect the graft by resulting in anteriorly directed forces.
        - Open kinetic chain knee flexion caused by hamstring contraction should be avoided because it causes posteriorly directed force across the graft.
        - Limited or prone ROM should be considered early to protect the graft.

- **MCL injury**
    - History and physical examination
        - MCL injury occurs as a result of valgus stress to the knee.
        - Pain and instability with valgus stress testing at 30 degrees of flexion (and not in full extension) are diagnostic.

- Opening in full extension usually signifies other concurrent injuries (ACL and PCL).
- **Injuries most commonly occur at the femoral origin.**

- ◻ Treatment (Fig. 4.17)
  - **Nonoperative treatment** (hinged knee brace) is highly successful in alleviating isolated MCL injuries.
  - Clinical work has shown the advantage of nonoperative treatment (bracing) of an associated MCL injury in patients receiving an ACL reconstruction.
  - **Distal (tibia-side) injuries have less healing potential** than proximal (femur-side) injuries.
  - Prophylactic bracing may be helpful for football players, especially interior linemen.
  - Advancement and reinforcement of the ligament are rarely necessary for chronic injuries that do not respond to conservative treatment.
  - In chronic injuries, calcification may be present at the medial femoral condyle insertion (Pellegrini-Stieda sign).
  - Pellegrini-Stieda syndrome, which can occur with chronic MCL injury, usually responds to a brief period of immobilization followed by progressive motion.

- ▪ **LCL injury**
  - ◻ Varus instability in 30 degrees of flexion is diagnostic only for an isolated LCL ligament injury.
  - ◻ **Isolated injuries to the LCL ligament are uncommon** and should be managed nonoperatively if laxity is mild (Fig. 4.18).
- ▪ **PLC injury**
  - ◻ History
    - Rarely isolated and is usually associated with other ligamentous injuries (especially those of the PCL)

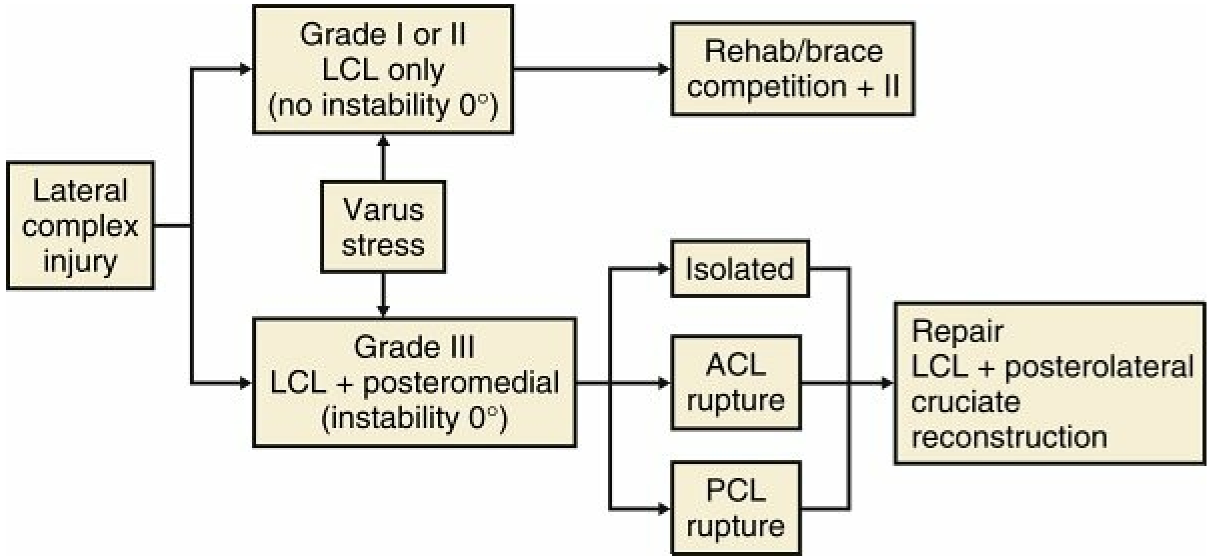


FIG. 4.18 Algorithm for management of lateral complex injuries.
From Spindler KP, Walker RN: General approach to ligament surgery. In Fu FH et al, editors: *Knee surgery*, Baltimore, 1994, Williams & Wilkins.

Table 4.5

Static Shoulder Restraints

Structure	Arm Position	Restraint
Superior GHL	Adduction	Inferior translation External rotation
	Flexion, adduction, and internal rotation	Posterior translation
Middle GHL	Adduction	External rotation
	Adduction and external rotation	Inferior translation
	45 degrees abduction and external rotation	Anterior and posterior translation
Inferior GHL, anterior band	90 degrees abduction and external rotation	Anterior translation Inferior translation
Inferior GHL, posterior band	90 degrees abduction and internal rotation	Posterior translation Inferior translation
Rotator interval (superior GHL and CHL)	Adduction	Inferior translation
Posterior capsule	Flexion, adduction, and internal rotation	Posterior translation

- □ Physical examination
  - **Examination for increased external rotation (dial test) at 30 and 90 degrees of knee flexion**, the external rotation recurvatum test, the posterolateral drawer test, and the reverse pivot shift test are important (Table 4.5).
    - Increased external rotation at 30 degrees of flexion

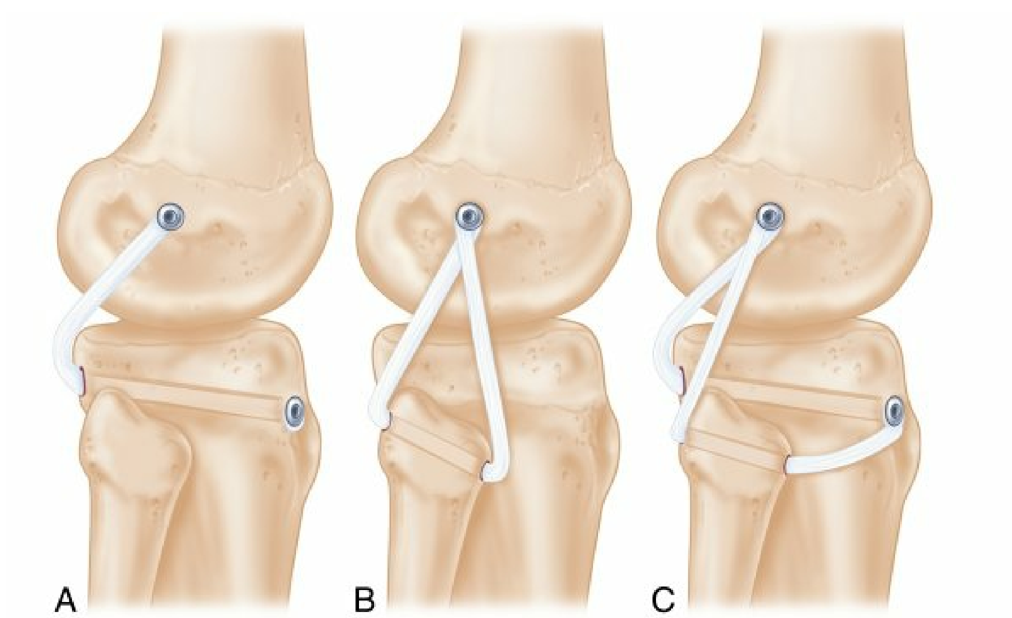
only: isolated PLC injury
        - Increased external rotation at 30 and 90 degrees of flexion: combined PCL and PLC injury
    - Careful evaluation of the peroneal nerve should be performed because approximately 10% of PLC injuries are associated with peroneal nerve palsy.
    - Varus alignment is associated with higher rates of PLC reconstruction failure. Evaluation for triple varus alignment should always be performed.
        - Primary varus alignment: tibiofemoral malalignment
        - Secondary varus alignment: LCL deficiency contributing to increased lateral opening
        - Triple varus alignment: deficiency of the remaining PLC with overall varus recurvatum alignment
        - Long-leg standing radiographs are necessary, especially with chronic injuries, to determine mechanical axis and whether a proximal tibial osteotomy is necessary for varus correction.
- □ Treatment
    - Newer studies have demonstrated up to a 40% failure rate for acute isolated repairs of PLC injuries.
    - A hybrid approach has been recommended, with repair of avulsions and reconstruction of midsubstance injuries.
        - Repair of the LCL, popliteus tendon, or popliteofibular ligament should be performed if the structure can be anatomically reduced to its attachment site with the knee in full extension. This procedure should be combined with a reconstruction.
    - Reconstruction techniques include PLC advancement (only if structures are attenuated but intact), popliteal bypass (not currently favored), two- and three-tailed reconstruction, biceps tenodesis, and (newer) “split” grafts and anatomic reconstructions, which are used to reconstruct both the LCL and the popliteal/posterolateral corner (Fig. 4.19).
    - Treatment of choice for chronic PLC injuries is often a valgus open-wedge osteotomy.

▪ **Multiple-ligament injury (MLI)**
- □ Introduction
    - Combined ligamentous injuries (especially ACL-PCL injuries) can be a result of a knee dislocation.

- Knee dislocations most frequently occur as a result of high-velocity trauma.
- However, “ultra-low-velocity” multiple ligament injury (ULV-MLI) has also been described.
- In the largest series to date, patients with ULV-MLI substantially differ from those with MLI.
    - Morbidly or supermorbidly obese
    - More frequently female
    - Higher rates of neurovascular injury
    - Higher rates of postoperative complications

□ History and physical examination

- Dislocations classified on the basis of direction of tibial displacement
    - Anterior dislocations most common (40%)
    - Vascular injury occurs at 50 degrees of knee hyperextension.



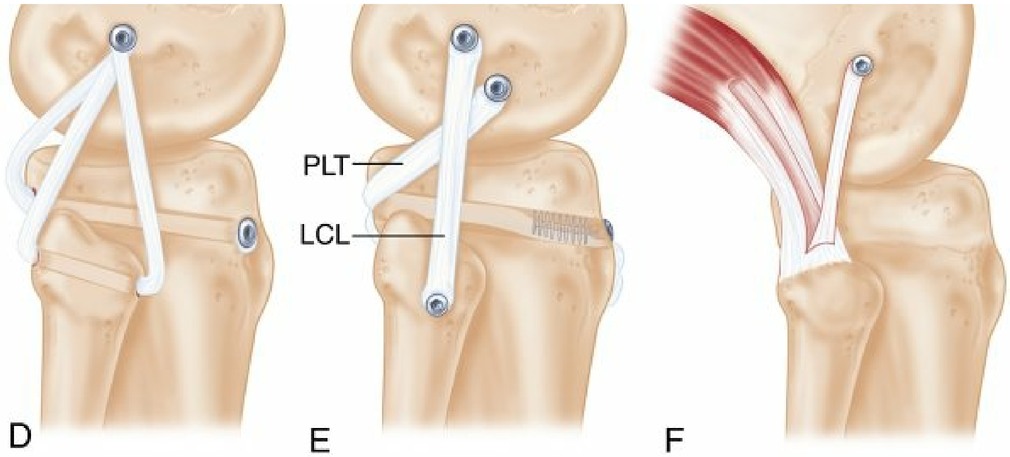


FIG. 4.19 Posterolateral corner reconstruction techniques. (A) Müller popliteal bypass. (B) Larson figure-of-eight. (C) Two-tail. (D) Three-tail. (E) Anatomic. (F) LCL reconstruction using strip of biceps tendon/fascia. *PLT,* Popliteus tendon.
From Gwalthmey FW, Miller, MD: Posterolateral corner repair and reconstruction. In Miller MD et al, editors: *Operative techniques: knee surgery*, ed 2, Philadelphia, 2018, Elsevier, Fig. 24.13.

- The incidence of vascular injury knee dislocation is approximately 20%–30%.
- Initial evaluation should include a neurovascular examination (Fig. 4.20).
- Vascular consultation should be obtained in any patient with absence of pulses or an ankle-brachial index (ABI) less than 0.9.

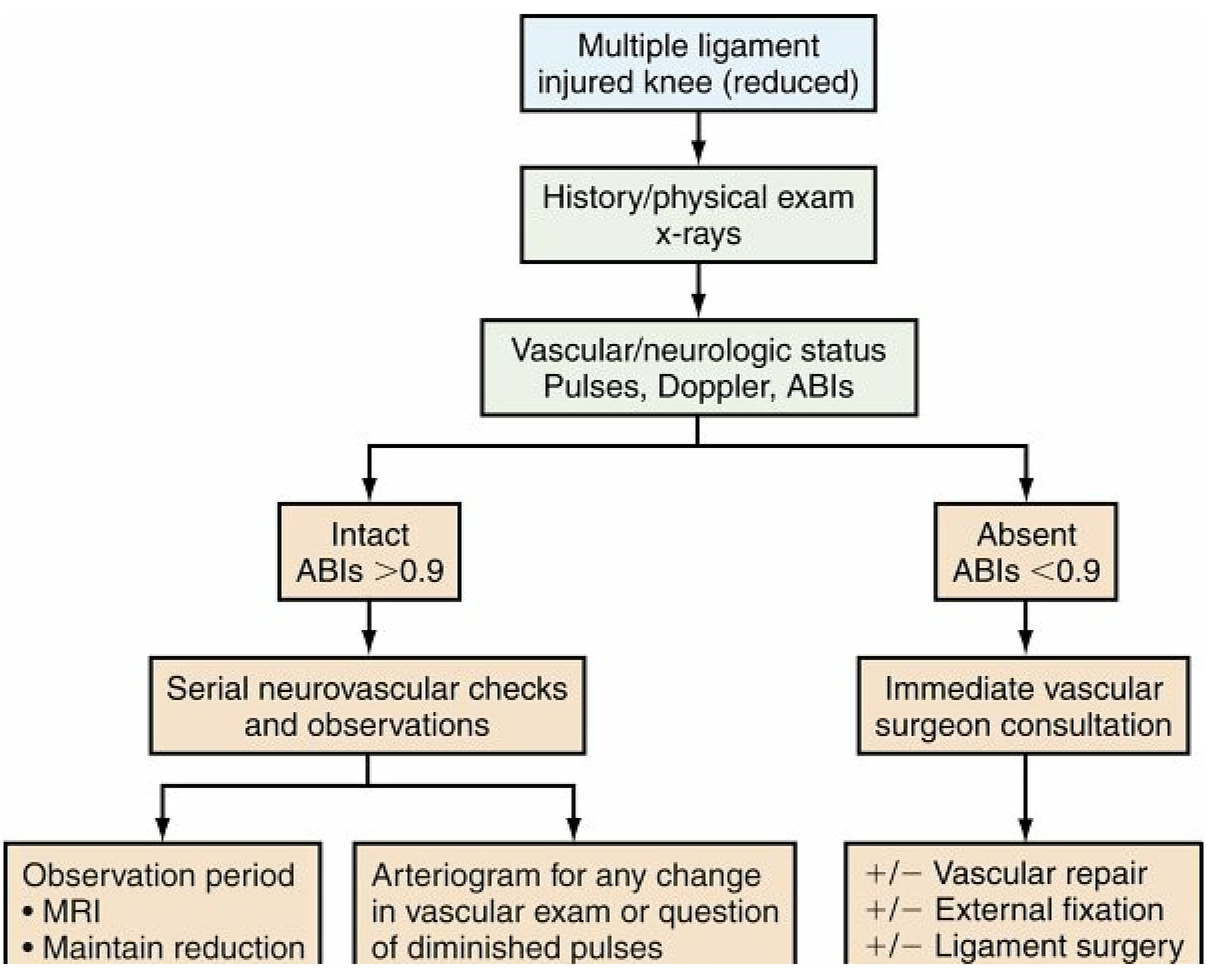
□ Treatment

- Initial management involves immediate reduction and repeat neurovascular examination.
- Definitive treatment is usually operative.
- Emergency surgical indications include popliteal artery injury, compartment syndrome, open dislocations, and irreducible dislocations.
    - Posterolateral rotatory knee dislocations are the most common irreducible knee dislocation.
    - The medial femoral condyle buttonholes through the medial capsule.
- Most surgeons recommend delaying surgery 1–2 weeks to ensure that no vascular injury occurs.
- Use of the arthroscope, especially with a pump, must be limited during these procedures because of the risk of fluid extravasation.
- Incidence of stiff knee after these combined procedures is high; early motion is crucial to avoiding it.
- According to a meta-analysis, staged treatment might have produced better subjective outcomes but, like acute treatment, was associated with additional procedures to treat

joint stiffness. Early mobility acute surgical treatment was associated with better subjective outcomes than immobilization.

Osteochondral Lesions

- **Osteochondritis dissecans (OCD)**
  - Introduction
    - Involves subchondral bone and overlying cartilage separation; etiology unclear but may be related to occult trauma or microvascular problems
    - Most often involves the **lateral aspect of the medial femoral condyle (** Fig. 4.21 **)**
    - The lateral femoral condyle is involved in 15%–20% of cases; the patella is rarely involved.
    - The condition resolves spontaneously in the majority of juvenile cases, in about 50% of adolescent cases, and rarely in adult cases.



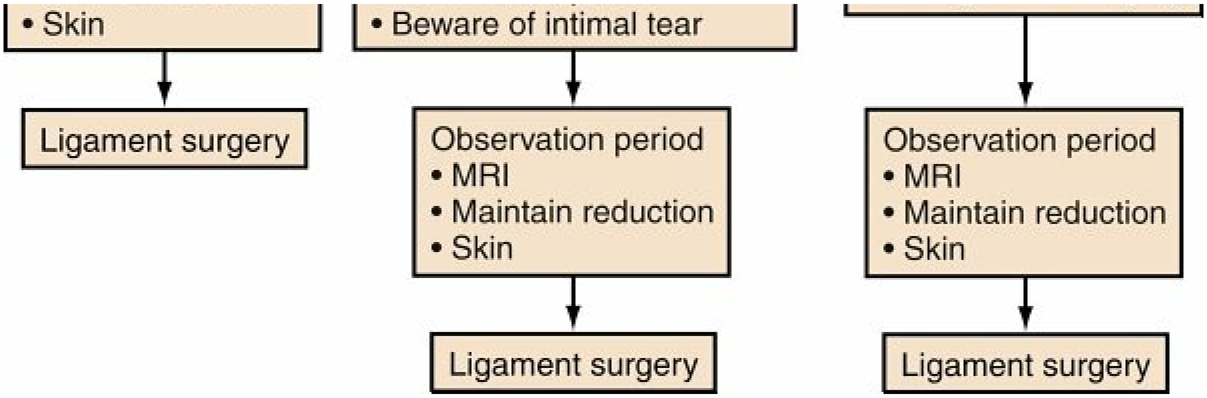


FIG. 4.20 Algorithm for neurovascular examination of multiple ligament injury. *ABI,* Ankle-brachial index.

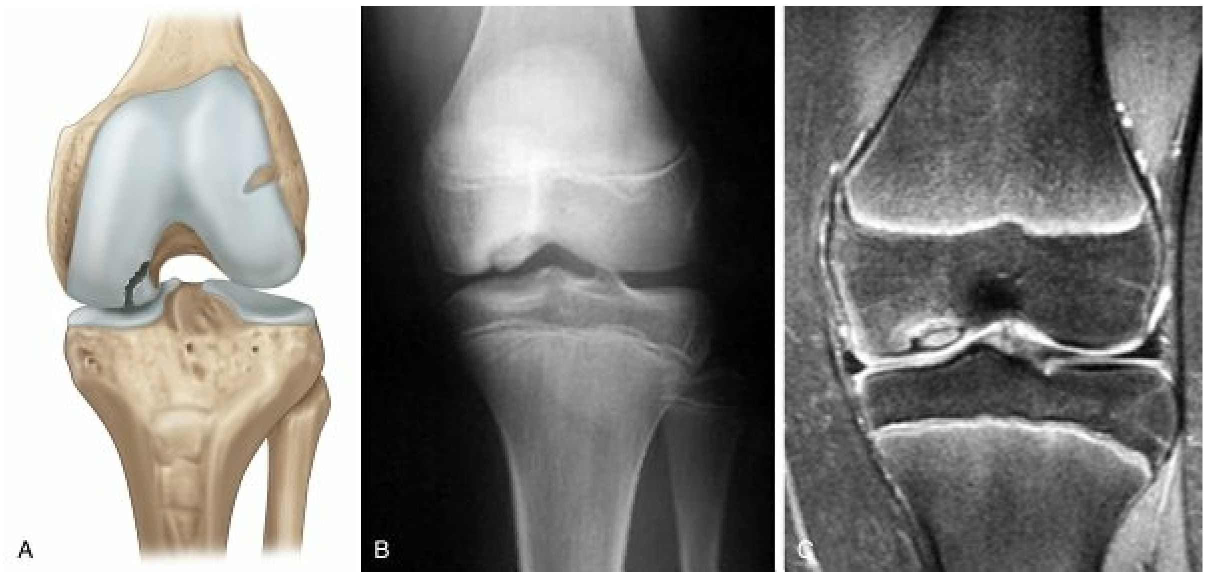


FIG. 4.21 Osteochondritis dissecans of the medial femoral condyle. (A) Illustration. (B) Radiograph. (C) MR image.

A From Tria AJ, Klein KS: *An illustrated guide to the knee,* Edinburgh, Churchill Livingstone, 1992; **B and C** from Miller MD et al, editors: *Essential orthopaedics,* ed 2, Philadelphia, 2019, Saunders, Fig. 224-3.

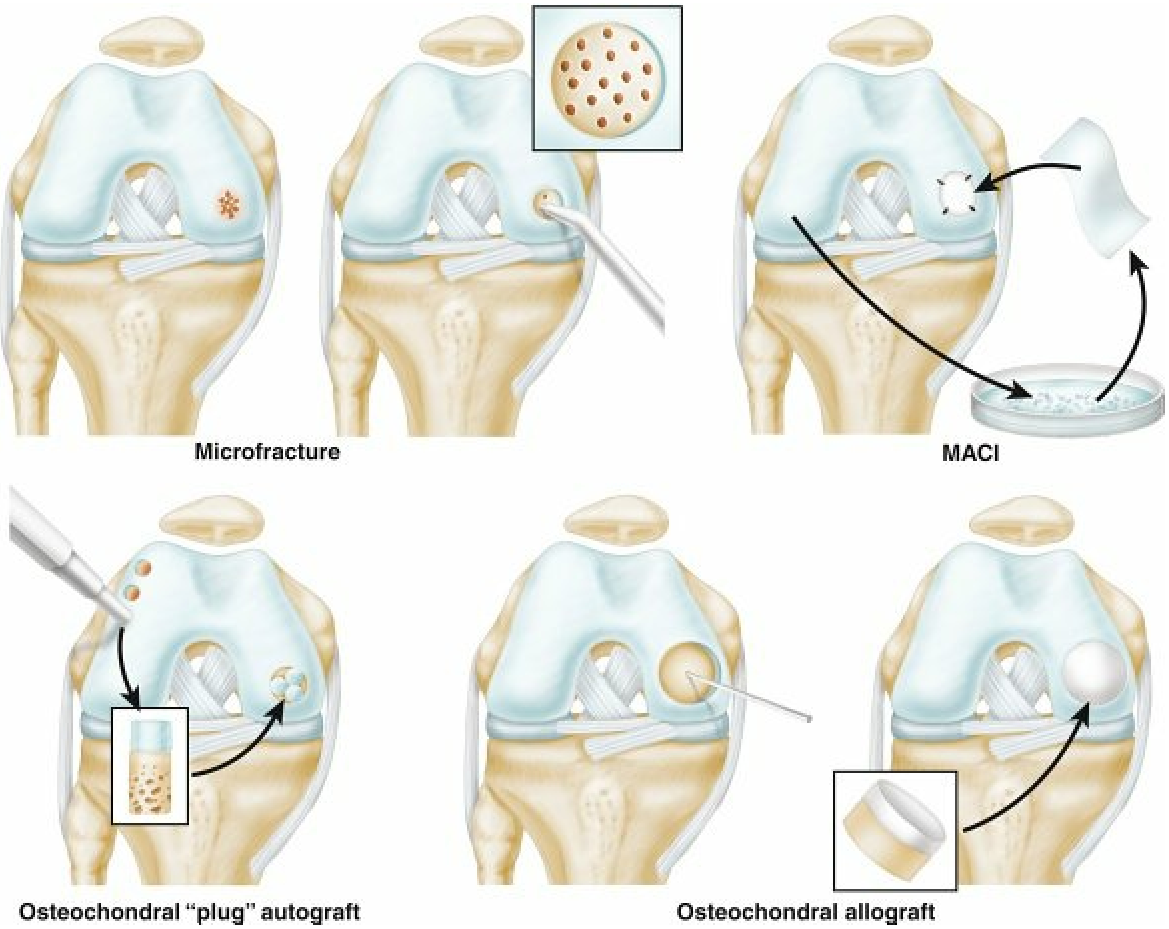


FIG. 4.22 Surgical treatment of chondral injuries. *MACI,* Matrix-assisted chondrocyte implantation (Vericel, Cambridge, MA).
From Miller MD et al, editors: *Essential orthopaedics,* ed 2, Philadelphia, 2019, Saunders.

- Diagnosis
  - Patients usually have poorly localized vague complaints.
  - Radiographs, nuclear imaging, and MRI can be helpful in determining the size, location, and characteristics of the lesion.
- Treatment and prognosis
  - Children with **open physes** have the best prognosis, and often these lesions can be simply **observed.**
  - In situ lesions can be treated with retrograde drilling.
  - Detached lesions may necessitate abrasion chondroplasty or newer, more aggressive techniques.
  - Osteochondritis dissecans in adults is usually symptomatic and leads to arthritis if left untreated.

▪ **Articular cartilage injury**

- Overview
  - The distinction between articular cartilage injury and osteochondritis dissecans is not often clear, but articular cartilage injury occurs as a result of rotational forces in direct trauma.
  - It usually occurs on the medial femoral condyle.
  - MRI has been found to underestimate the size of articular

cartilage defects in approximately 75% of cases.
- The lesions are classified according to their arthroscopic appearance.

□ Treatment

- Débridement and chondroplasty are currently recommended for symptomatic lesions.
- Displaced osteochondral fragments can sometimes be replaced and secured with small recessed screws or absorbable pins.
- For discrete, isolated, full-thickness cartilage injuries, several treatment options are in clinical use: microfracture, chondrocyte implantation, and osteochondral transfer (plugs), including autograft and allograft options (Fig. 4.22).
- Particulated juvenile cartilage allograft remains investigational.
- Diffuse chondral damage is a relative contraindication to these procedures.
- Donor-site problems and creation of true articular cartilage at the recipient site are still challenges.
- Age, lesion size, patient's desired activity level, alignment, meniscal integrity, and ligamentous stability must all be taken into consideration in selection of the appropriate treatment option. An algorithm is presented in Fig. 4.23.
- Surgical techniques (see Fig. 4.22)
    - Marrow-stimulating techniques
        - Include microfracture, drilling, and abrasion arthroplasty
        - Involve perforation of the subchondral bone after removal of the "tidemark" cartilage, with eventual clot formation and fibrocartilaginous repair tissue
        - Type I collagen with inferior wear characteristics
        - Good clinical results in small defects (<4 cm^2) are obtained in 60%–80% of patients.
    - Osteochondral autografts
        - Osteochondral autograft transplantation (OAT) (e.g., Osteochondral Autograft Transplant System [Arthrex, Inc, Naples, FL])

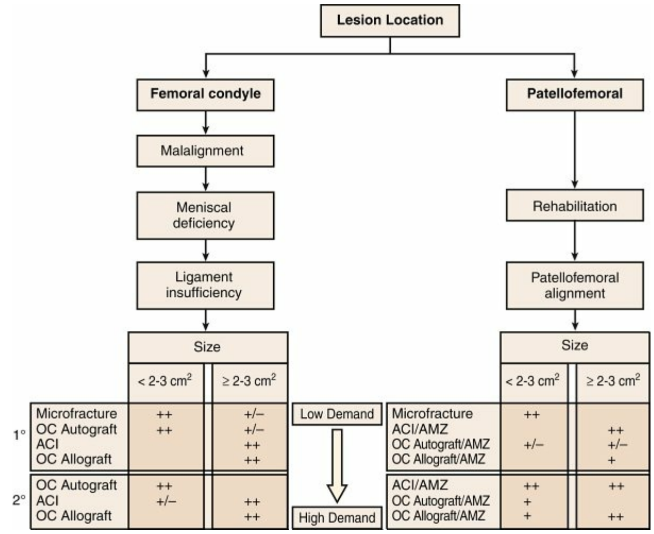


FIG. 4.23 Algorithm for management of focal cartilaginous lesions of the knee. *AMZ,* Anteromedialization; *OC,* osteochondral.
Modified from Miller MD, Thompson SR, editors: *DeLee & Drez's orthopaedic sports medicine*, ed 4, Philadelphia, 2014, Saunders, Fig. 97-5.

- Mosaicplasty
    - Can be used to address medium-sized lesions (3 cm^2) that include subchondral bone loss
    - Lateral trochlea and medial trochlea are acceptable harvest locations.
    - Complications include donor site morbidity.
- Osteochondral allografts
    - Can be used for larger lesions, especially with bone loss. Main concerns include the small risk of disease transmission and chondrocyte viability, which has improved with graft preservation techniques (storage at 4°C). These grafts are still ideally used within the first 30 days of donor death.
- Autologous chondrocyte implantation (ACI)
    - Allows for creation of type II collagen–rich hyaline-like cartilage
    - Indicated for medium-sized to larger chondral lesions without bony defects; multiple surgical procedures are required for biopsy/harvest and then definitive repair.

            - Complications related to autologous chondrocyte implantation include chondrocyte overgrowth and periosteal flap hypertrophy, along with the morbidity of the second surgical procedure.
            - The periosteal flap has largely been abandoned as a result, and type I/III bilayer collagen membrane, which is now approved in the United States, used instead. This change has reduced the need for reoperation by 80%.
        - Results
            - At present, no definitive research has demonstrated superiority of any cartilage restoration procedure.
            - Current best available research suggests that for smaller lesions, microfracture, OAT, and ACI have similar recovery periods and functional results.

- **Osteonecrosis**
    - Atraumatic osteonecrosis of the knee is similar to idiopathic osteonecrosis of the hip. Risk factors are similar to those of the hip and are common in elderly women.
    - Spontaneous osteonecrosis of the knee (SONK) is thought to represent a subchondral insufficiency fracture and is typically a self-limiting condition. It can follow knee arthroscopy in middle-aged women and should be treated with limited weight bearing until it resolves.
    - One hypothesis for the cause of SONK involves a meniscal root tear.

Synovial Lesions

- **Pigmented villonodular synovitis and synovial chondromatosis**
    - Please refer to Chapter 9, Orthopaedic Pathology.
- **Plicae**
    - Synovial folds that are embryologic remnants
    - They are occasionally pathologic, particularly the medial patellar plica, which can cause abrasion of the medial femoral condyle and sometimes responds to arthroscopic excision.
    - Other synovial lesions that respond to synovectomy include

chondromatosis, osteochondromatosis, pauciarticular juvenile rheumatoid arthritis, and hemophilia.

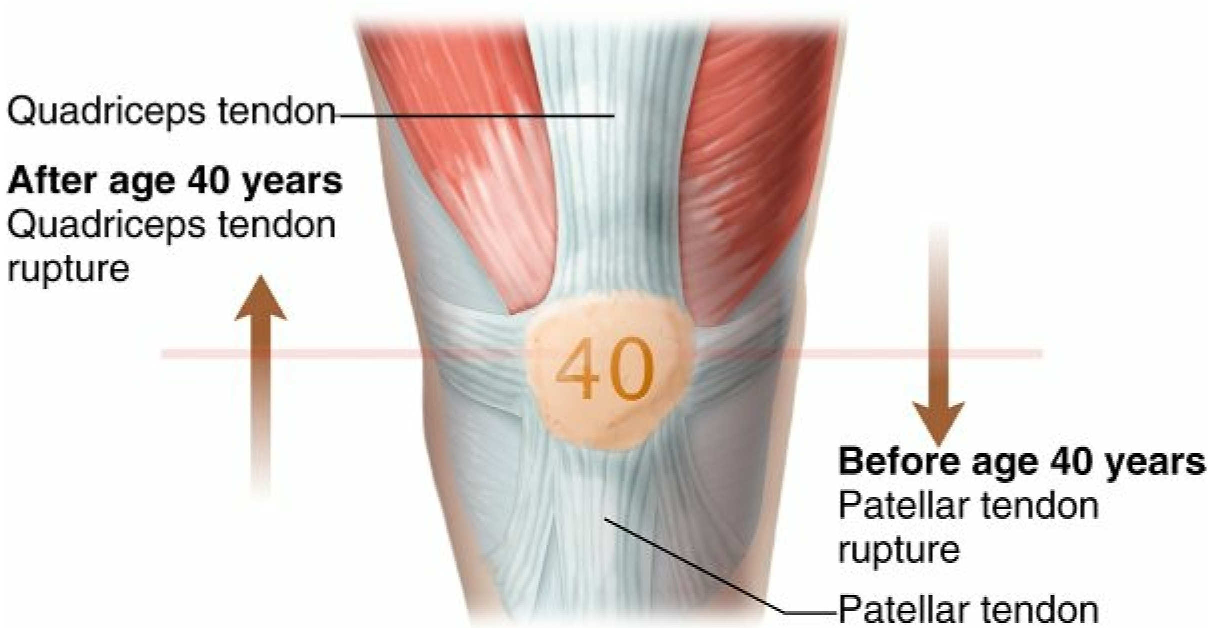


FIG. 4.24 Patellar tendon ruptures are more common before age 40 years, and quadriceps tendon ruptures more common after age 40 years.

Patellofemoral Disorders

- **Introduction**
  - Anterior knee pain is classified on the basis of etiologic factors. The term *chondromalacia* should be replaced with a specific diagnosis.
  - Abnormalities of patellar height
    - Patella alta (high-riding patella) and patella baja (low-riding patella) are determined from various measurements made on lateral radiographs of the knee (see Fig. 4.7).
    - Patella alta can be associated with patellar instability, because the patella may not articulate with the sulcus until higher degrees of knee flexion are reached. Consequently, there is reduced contact and stability in knee extension and early flexion.
    - Patella baja is often the result of fat pad and tendon fibrosis, and proximal transfer of the tubercle may be required in refractory cases.
- **Trauma**
  - Includes fractures of the patella (discussed in Chapter 11, Trauma) and tendon injuries
  - Tendon ruptures
    - Quadriceps tendon ruptures, which are more common than

patellar tendon ruptures, occur most often with indirect trauma in patients **older than 40 years.** In younger patients, patellar tendon ruptures occur with direct or indirect trauma (Fig. 4.24).

- Both types of tendon rupture are more common in patients with underlying disorders of the tendon (i.e., diabetes mellitus, hyperparathyroidism, chronic renal failure, steroid use).
- A palpable defect and the inability to extend the knee are diagnostic signs. The patient can often maintain extension owing to an intact retinaculum, but active extension is difficult.
- Patella alta is a consistent finding with patella tendon rupture.
- Primary repair with temporary stabilization (McLaughlin wire or suture) may be indicated.

□ Repetitive trauma: overuse injuries

- Patellar tendinosis (jumper's knee)
    - This condition is perhaps better termed *tendinosis.*
    - Most common in athletes who participate in jumping sports such as basketball and volleyball
    - Associated with pain and tenderness near the inferior border of the patella (worse in extension than in flexion)
    - Treatment includes NSAIDs, physical therapy (strengthening including eccentric exercise and ultrasonography), and orthoses (patella tendon strap).
    - Surgery involving excision of necrotic tendon fibers is rarely indicated.
- Quadriceps tendinosis
    - Less common than patella tendinosis but equally as painful
    - Patients may note painful clicking and localized pain at the superior border of the patella.
    - Operative treatment is occasionally necessary.
- Prepatellar bursitis (housemaid's knee)
    - The most common form of bursitis of the knee and associated with a history of prolonged kneeling
    - Supportive treatment (knee pads, occasional steroid injections) and, in rare cases, bursal excision are recommended.

- Aspiration is advocated in wrestlers to rule out infection (particularly MRSA) because wrestling requires kneeling on the flexed knee.
- Iliotibial band friction syndrome
  - Can occur in runners (especially those running hills) and cyclists
  - Result of abrasion between the iliotibial band and the lateral femoral condyle
  - Localized tenderness at the lateral femoral condyle, worse with the knee flexed 30 degrees, is common.
  - The **Ober test** (patient lies in lateral decubitus position with hyperextension of ipsilateral hip; examiner is able to bring the leg from abduction to adduction to demonstrate tightness of the iliotibial band) is helpful in making the diagnosis.
  - Rehabilitation is usually successful.
  - Surgical excision of an ellipse of the iliotibial band is occasionally necessary.
- Semimembranosus tendinitis
  - Most common in male athletes in their early 30s
  - Can be diagnosed with MRI or nuclear imaging and often responds to stretching and strengthening exercises
  - A steroid injection may be added if no improvement occurs.
- Pes anserinus bursitis
  - Characterized by localized pain, tenderness, and swelling over the proximal anteromedial tibia at the insertion site of the sartorius, gracilis, and semitendinosus muscles (≈6 cm inferior to joint line)
  - Treated conservatively with oral antiinflammatory medication, localized corticosteroid injections, and activity modification

▪ **Patellar instability**

□ Introduction

- See Knee Anatomy section for important information on MPFL anatomy.
- Patellar instability, like glenohumeral instability, exists on a spectrum from frank dislocation to subtle subluxation.
- Etiology can be multifactorial

- Traumatic MPFL rupture
- Patellar and trochlear dysplasia
- Patella alta
- Ligamentous laxity
- Muscular imbalance (VMO weakness)

• Dislocation is typically lateral

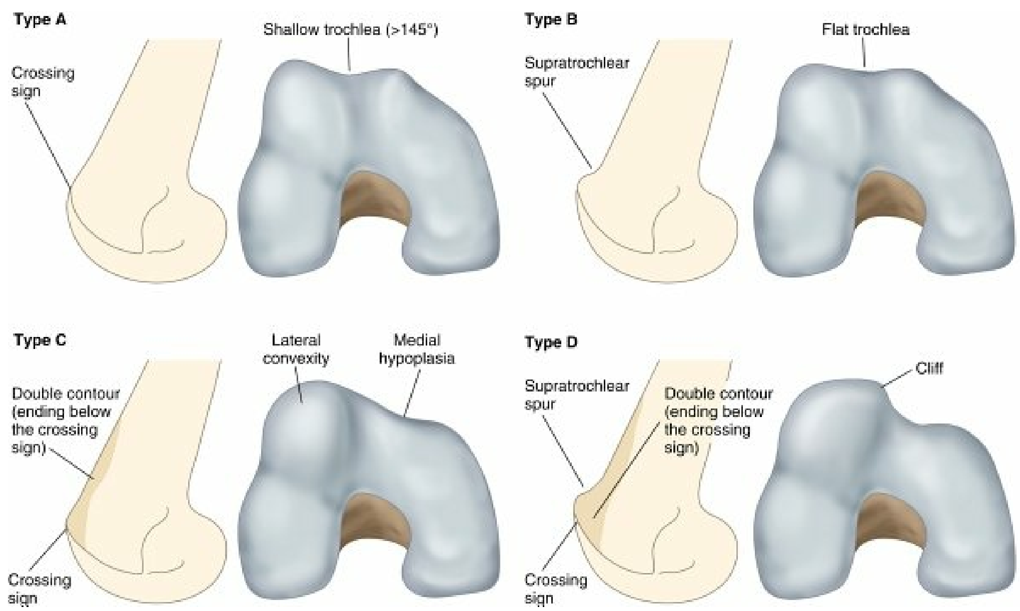


FIG. 4.25 DeJour classification of trochlear dysplasia.

• Frequent cause of hemarthrosis

• Recurrence rate following first-time dislocation between 15% and 60%

Younger age, patella alta, and trochlear dysplasia increase risk for recurrence.

• Articular cartilage on the medial facet of the patella is most commonly injured during reduction of the patella.

• If this injury is associated with femoral anteversion, genu valgum, and pronated feet, the symptoms can be exacerbated, especially in adolescents ("miserable malalignment syndrome").

□ History and physical examination

• Instability may be due to external tibial rotation with a planted foot or a direct blow to the medial aspect of the knee

• Often a pop is felt; should not be confuse with an ACL tear

• Examination may reveal a positive patellar apprehension test result, the presence of the J sign, and three to four quadrants of lateral patellar glide.

□ Imaging

• Radiographs are necessary to identify fracture, loose bodies, arthritis, malalignment, and abnormal anatomy.

- Trochlea dysplasia can be identified on a lateral radiograph from the presence of a crossing sign or a supratrochlear spur.
    - Classified by the Dejour system (Fig. 4.25)
    - Trochlear groove line normally intersects the anterior femoral cortex.
    - A crossing sign is present when the trochlear groove line intersects the anterior femoral condyle.
        - Crossing sign has been associated with patellar instability.
- A variety of additional quantitative measurements can be obtained to quantify bony abnormalities.

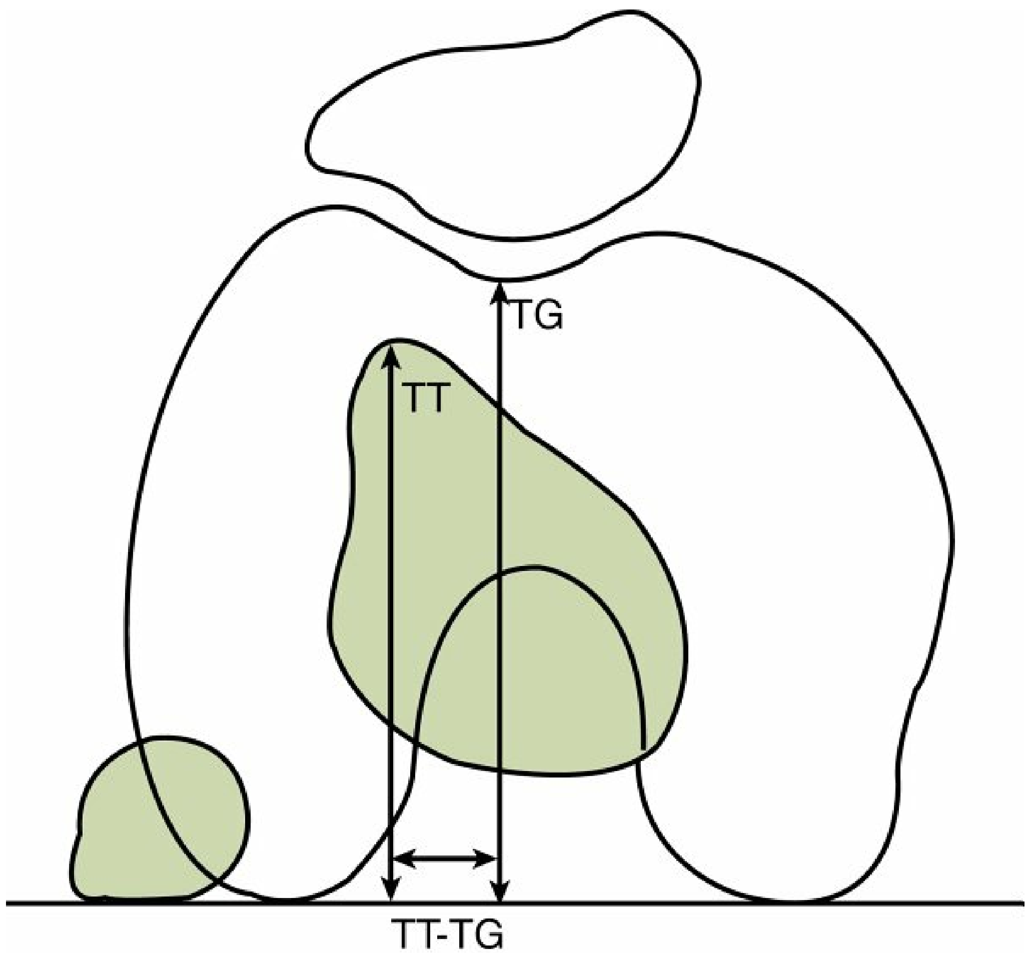


FIG. 4.26 Tibial tuberosity–trochlear groove (TT-TG) distance.

- CT
    - Most frequently used to measure the **tibial tubercle–trochlear groove (TT-TG) distance** (Fig. 4.26)
        - A measurement of the lateralization

of the tibial tubercle
            - Normal values between 9 and 13 mm
            - TT-TG distance 15–20 mm questionably abnormal
            - TT-TG distance over 20 mm highly associated with patellar instability
        - Utility of dynamic CT continues to be examined.
    - MRI
        - In complete dislocation, a bone bruise pattern involving the lateral femoral condyle and medial patella is often observed.

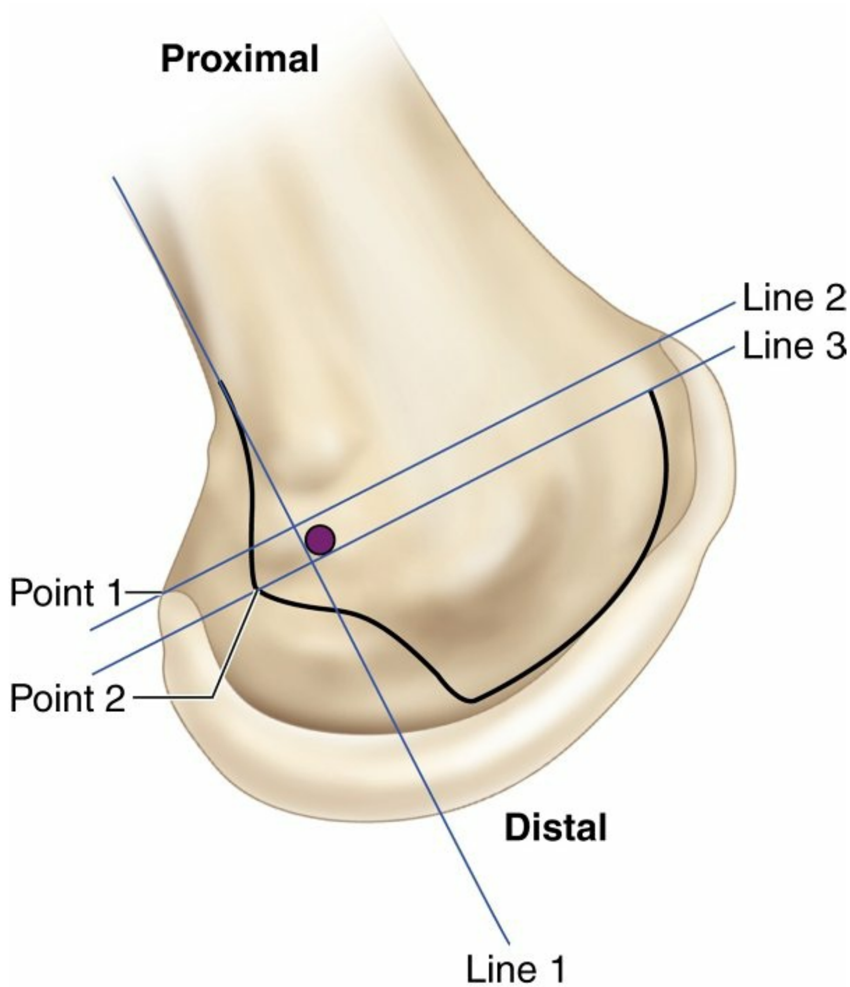


FIG. 4.27 Schottle point for radiographically identifying the femoral attachment of the MPFL. This point occurs 1 mm anterior to the posterior cortex extension line *(Line 1)*, 2.5 mm distal to the posterior origin of the medial femoral condyle and proximal to the level of the posterior point of the Blumensaat line on a lateral radiograph with both posterior condyles projected in the same plane. For radiographic identification of this point, two perpendiculars to *Line 1* are drawn, one *(Line 2)* intersecting the contact point of the medial condyle (*Point 1)* and the posterior cortex and the other *(Line 3)* intersecting the most posterior point of the Blumensaat line *(Point 2)*.

- The MPFL is often disrupted, most frequently at its patellar insertion.
- MRI is useful to diagnose articular cartilage damage.
  - Articular cartilage of medial patellar facet is most common donor site.
- May be used to calculate TT-TG distance; often underestimates true TT-TG distance as calculated on CT

□ Management

- Acute first-time patellar dislocations have traditionally been treated nonoperatively.

- However, some surgeons advocate early surgical treatment with arthroscopic evaluation or débridement and acute repair of the medial patellofemoral ligament (usually at the medial epicondyle). This protocol is still somewhat controversial.

- Occasionally surgery on a first-time patellar dislocation is performed if there is a loose body.
- Surgical procedures include proximal and distal realignment.
- Surgical techniques
    - Proximal realignment typically involves MPFL reconstruction.
        - Precise technique is variable but involves use of a gracilis or semitendinous tendon (autograft or allograft) with incorporation into patella and femur.
        - Femoral attachment should be performed at the anatomic origin (Schottle point) (Fig. 4.27).
        - Several techniques have fallen out of favor:
            - VMO advancement (Green procedure)
            - Medial retinacular plication
            - Isolated lateral release should not be performed for patellar instability.
        - Distal realignment is typically tibial tubercle anterior medialization.
            - Indicated for patients with an increased Q angle or a **TT-TG distance exceeding 20 mm.**
            - Proximal arthrosis of the medial patellar facet is a contraindication to this procedure.
- Complications
    - Medial patellar instability or medial patellar

osteoarthritis from overtightening of the MPFL reconstruction

- **Chronic conditions**
  - Patellofemoral pain syndrome (idiopathic anterior knee pain)
    - Extremely common cause of anterior knee pain, particularly in the adolescent
    - Typically manifests as anterior knee pain made worse by activities that increase compressive loads on the patellofemoral joint
      - Insidious onset; occasionally described as sensation of instability
    - Etiology multifactorial
      - Muscular weakness often present, with weak quadriceps, hip abductors, and core musculature
    - Management is focused on prolonged rehabilitation.
  - Lateral patellar facet compression syndrome
    - Problem associated with a tight lateral retinaculum and excessive lateral tilt without excessive patellar mobility
    - Lateral tilt is best evaluated by measurement of the lateral patellofemoral angle (Fig. 4.28).
    - Treatment includes activity modification, NSAIDs, and strengthening of the VMO muscle.
    - Arthroscopy and lateral release are occasionally required but are indicated only in the setting of objective evidence of lateral tilt that has not responded to extensive nonoperative management.
      - The best candidates for arthroscopy and lateral release have a neutral or negative tilt with a medial patellar glide of less than one quadrant and a lateral patellar glide of less than three quadrants. Arthroscopic visualization through a superior portal demonstrates that the patella does not articulate medially with 40 degrees of knee flexion.
  - Bipartite patella (Fig. 4.29)
    - Failure of an ossification center of the patella to coalesce
      - Can result in a bipartite or tripartite patella
    - Most commonly located at the superolateral pole
      - Typically has smooth edges, differentiating it from a patellar fracture
    - Typically asymptomatic and found incidentally on radiographs; present bilaterally in up to half of patients
    - If symptomatic, manifests as anterior knee pain

- Associated with nail-patella syndrome
- Conservative management is the mainstay of symptomatic bipartite patella.
- Rarely, surgical excision or arthroscopic lateral release may be performed.

□ Patellofemoral arthritis

- Injury and malalignment can contribute to patellar degenerative joint disease.
- Other procedures for advanced patellar arthritis include anterior (Maquet) or anteromedial (Fulkerson) transfer of the tibial tubercle, or patellectomy for severe cases. Patellofemoral arthroplasty has been introduced as another treatment option but remains controversial.

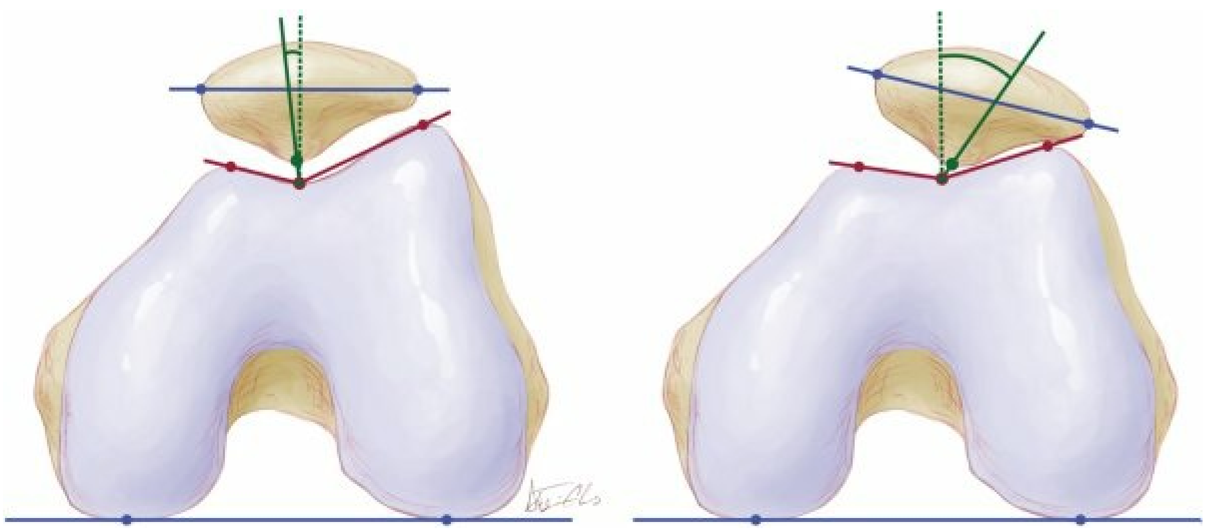
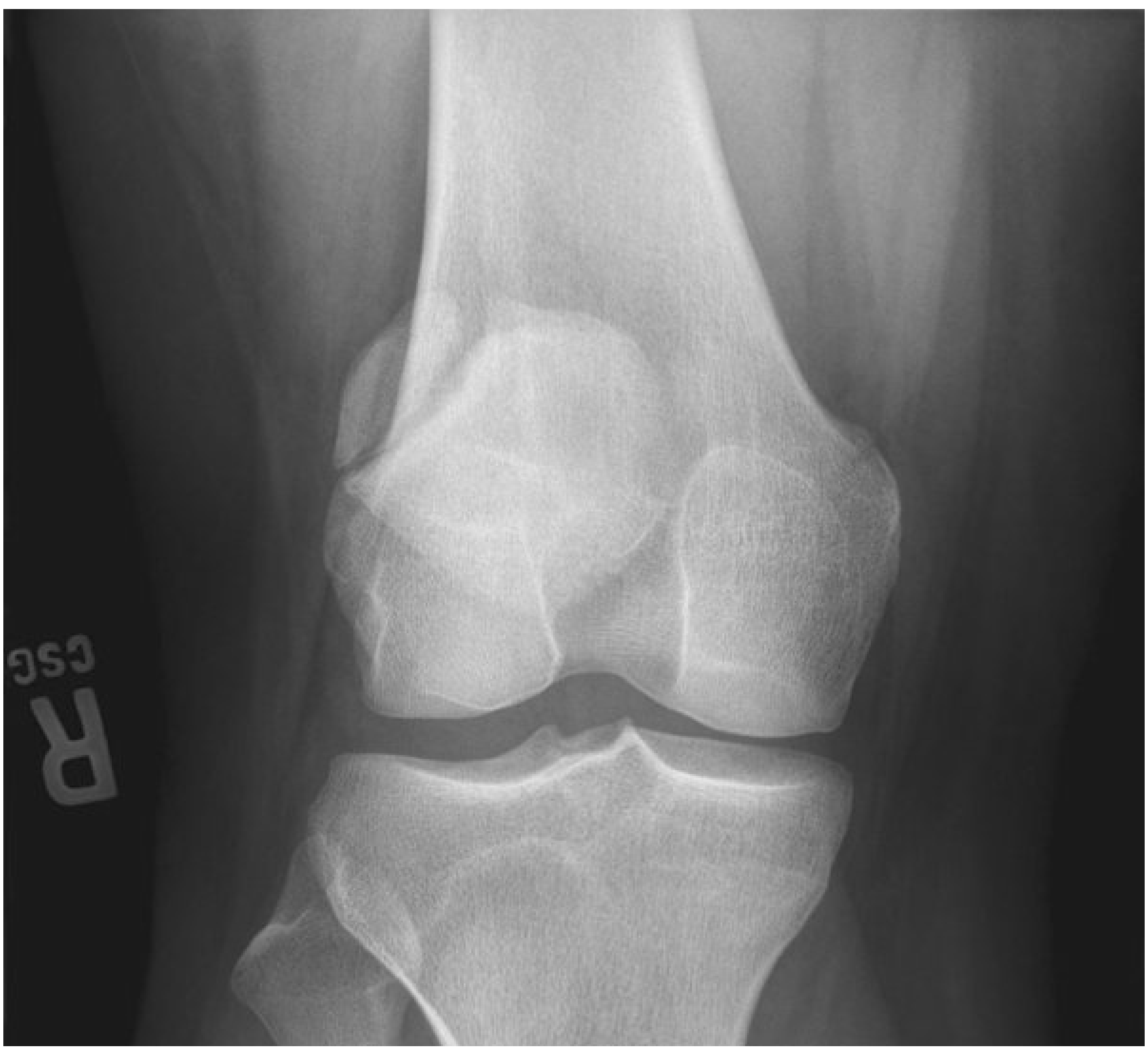


FIG. 4.28 The sulcus angle *(red lines)* is the angle formed in the axial plane from the highest point on the lateral facet, to the trochlear groove, to the highest point on the medial facet. An angle of 138 degrees represents normal anatomy, with an angle of 150 degrees or greater representing an abnormally shallow groove. The congruence angle *(green lines)* is formed by a line drawn through the apex of the trochlear groove that bisects the sulcus angle with a line through the lowest point on the articular ridge of the patella. A value of −6 degrees represents normal anatomy *(left)*, whereas a value greater than 16 degrees represents an abnormal patellofemoral articulation *(right)*. Patellar tilt *(blue lines)* is the angle formed by a line drawn parallel to the posterior femoral condyles and a line drawn through the transverse axis of the patella.

Modified from Sherman SL et al: Patellofemoral anatomy and biomechanics, *Clin Sports Med* 33:389–401, 2014.



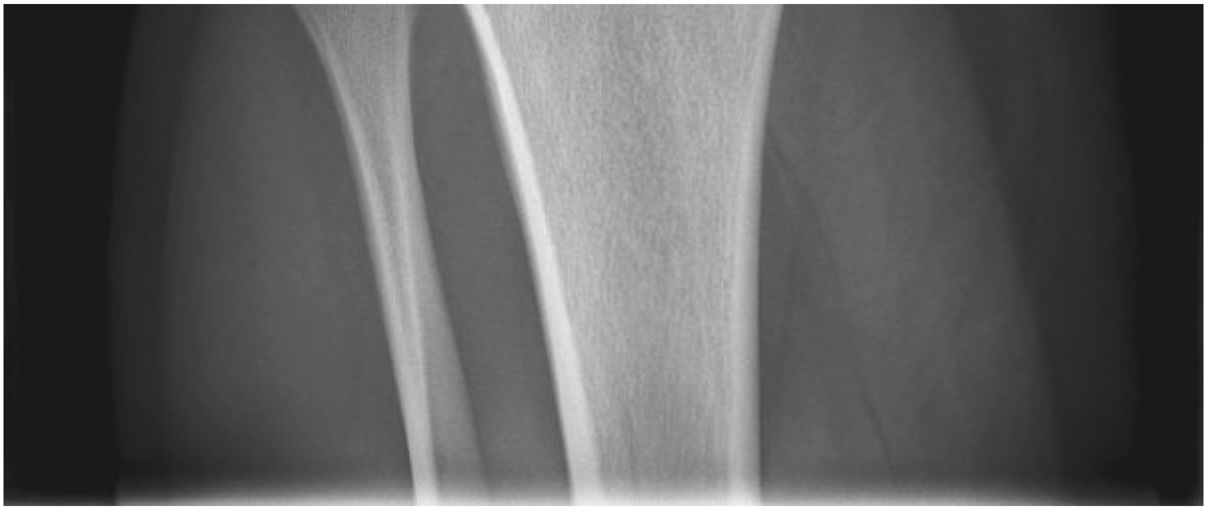


FIG. 4.29 Radiographic appearance of a bipartite patella.

- Anterior fat pad syndrome (Hoffa disease)
  - Trauma to the anterior fat pad can lead to fibrous changes and pinching of the fat pad, especially in patients with genu recurvatum.
  - Activity modification, ice, knee padding, and injection can be helpful.
  - Arthroscopic excision is occasionally beneficial.
- Complex regional pain syndrome (formerly known as *reflex sympathetic dystrophy*)
  - Characterized by **pain out of proportion** to physical findings, this condition is an exaggerated response to injury.
  - Three stages are typical: (1) swelling, warmth, and hyperhidrosis; (2) brawny edema and trophic changes; and (3) glossy, cool, dry skin and stiffness.
  - Patellar osteopenia and a "flamingo gait" are also common.
  - Treatment includes nerve stimulation, NSAIDs, and sympathetic or epidural blocks—response to which can be diagnostic.
- Idiopathic chondromalacia patellae
  - Articular damage and changes to the patella have traditionally been referred to as *idiopathic chondromalacia patellae;* however, this term has fallen into disfavor.
  - Treatment is usually symptomatic, and physical therapy is heavily emphasized.
  - Débridement procedures are of questionable benefit.
  - The Outerbridge classification system of articular cartilage lesions is still in common use today.

Pediatric Knee Injuries

- **ACL injury**
  - Historically, tibial spine fractures were thought to be more common than ACL tears in children. However, later data suggest that ACL rupture may be more common.
  - History and physical examination similar to those in adult ACL injury
  - Management remains controversial
    - Proponents of operative management cite an increased risk of meniscal damage, chondral damage, and inability to return to activities with an ACL-deficient knee.
    - Detractors of operative management cite the risk of growth disturbances and angular deformities; the latest meta-analysis suggests a 2% risk of disturbance following ACL reconstruction.
      - BPTB autografts associated with higher risk of physeal disruption
  - A variety of surgical techniques have been described. All-epiphyseal, combined intraarticular/extraarticular, hybrid, and traditional transphyseal techniques can be employed.
    - Genu recurvatum has been associated with physis-sparing techniques.
- **Meniscal injuries**
  - By 10 years of age, the meniscus has developed its adult microvascular structure.
  - MRI has lower sensitivity and specificity in children than in adults for detecting meniscal tears; this difference is due to the greater meniscal vascularity in children.
  - Because of the greater vascularity, meniscal repairs may have better results in children.
  - The examiner must be vigilant for discoid lateral meniscus in this population
- **Osteochondroses**
  - Also known as a *traction apophysitis,* osteochondroses are due to disordered enchondral ossification of a previous epiphysis.
  - Osgood-Schlatter disease
    - Due to repetitive loading of the patellar tendon insertion onto the tibial tubercle
    - Pain is isolated to tibial tubercle
    - Responds to nonoperative management, including a period of immobilization
    - Surgical excision of the ossicle is rarely performed.
  - Sinding-Larson-Johansson disease
    - Due to repetitive loading of the patellar tendon's origin at the inferior pole of the patella

- Typically occurs in boys who are slightly younger than those with Osgood-Schlatter disease
  - The ossification center at the inferior pole of patella closes prior to that at the tibial tubercle.
- Rehabilitation should focus on eccentric quadriceps strengthening.

- **Physeal injuries**
  - Most often involve Salter-Harris II fractures of the distal femoral physis
  - Pain, swelling, and an inability to ambulate are common.
  - **Stress radiographs and/or MRI** may be necessary to make the diagnosis.
  - Open reduction and internal fixation are indicated for displaced Salter-Harris II, III, and IV fractures and for Salter-Harris I fractures that cannot be adequately reduced.
  - It is important to counsel the parents that knee physeal injuries, particularly distal femoral physeal injuries, may have a worse prognosis than other physeal fractures owing to premature physeal closure.
- **Tibial spine fractures and tibial tubercle fractures are discussed in** Chapter 11, Trauma.

Section 2 Pelvis, HIP, and Thigh

Contusions

- **Iliac crest contusion ("hip pointer")**
  - □ Direct trauma to the iliac crest area can occur in contact sports.
  - □ An avulsion of the iliac apophysis should be confirmed or ruled out in adolescent athletes.
  - □ Treatment consists of ice, compression, pain control, and placing the affected leg on maximal stretch.
  - □ Corticosteroid injections have occasionally been advocated.
  - □ Additional padding is indicated after the acute phase.
- **Groin contusion**
  - □ An avulsion fracture of the lesser trochanter, traumatic phlebitis, thrombosis, athletic pubalgia, or femoral neuropathy must be confirmed or ruled out before supportive treatment of a groin contusion is initiated.
- **Quadriceps contusion**
  - □ Can result in hemorrhage and late myositis ossificans
  - □ Acute management includes cold compression and **overnight immobilization in 120 degrees of flexion.**
  - □ Close monitoring for compartment syndrome is indicated in the acute phase.

Muscle Injuries

- **Hamstring strain/rupture**
  - □ Hamstring strain is a common injury, often the result of sudden stretch on the musculotendinous junction during sprinting.
    - Can occur anywhere in the posterior thigh but myotendinous junction most common
    - Initial treatment is supportive, followed by stretching and strengthening.
    - To prevent recurrence, return to play/sport should be delayed until strength is approximately 90% that of the opposite side.
  - □ Complete rupture much less common
    - Radiographs may demonstrate avulsion from the ischial tuberosity; MRI is important in determining the extent of injury.
    - Nonoperative management is recommended for single tendon ruptures and multiple tendon ruptures with

retraction less than 2 cm.
        - Operative management of three tendon ruptures entails direct repair to bone.
- **Athletic pubalgia (sports hernia or core muscle injury)**
    - Common in ice hockey, soccer, and rugby; these injuries must be differentiated from subtle hernias.
    - Injury to the muscles of the abdominal wall or adductor longus produce anterior pelvis or groin pain (or both) without the classic physical findings of a true inguinal hernia.
    - Can result from acute trauma or microtrauma associated with overuse of the affected muscle
    - Combination of abdominal hyperextension and thigh hyperabduction
    - Treated nonoperatively for 6–8 weeks, with rest and therapy.
    - Active strengthening of the core, abductors, and adductors is critical.
    - Repair or reinforcement of the anterior abdominal wall is indicated after conservative measures have failed and other causes have been excluded.
    - Decompression of the genital branch of the genitofemoral nerve is also favored by some writers in patients presenting with athletic pubalgia.
- **Rectus femoris strain**
    - Acute injuries are usually located more distally on the thigh, but chronic injuries are usually nearer the muscle origin.
        - Pain is elicited with resisted hip flexion or extension.
        - Treatment includes ice and stretching/strengthening exercises.

Bursitis

- **Trochanteric bursitis**
    - Occurs frequently in female runners and is associated with training on banked surfaces
    - Treatment includes oral antiinflammatory drugs, stretching, and rest.
    - Corticosteroid injections are occasionally advocated.
- **Iliopsoas bursitis**
    - A cause of anterior hip pain in athletes and often associated with mechanical irritation of the iliopsoas tendon
    - Also a cause of “snapping” or “clicking” symptoms associated with hip pain

Nerve Entrapment Syndromes

- **Ilioinguinal nerve entrapment**

- The ilioinguinal nerve can be constricted by hypertrophied abdominal muscles as a result of intensive training.
- Hyperextension of the hip may exacerbate the pain that patients experience, and hyperesthesia symptoms are common. Surgical release is occasionally necessary.

- **Obturator nerve entrapment**
  - Can lead to chronic medial thigh pain, especially in athletes with well-developed hip adductor muscles (e.g., skaters)
  - Nerve conduction studies are helpful for establishing the diagnosis.
  - Treatment is usually supportive.
- **Lateral femoral cutaneous nerve entrapment**
  - Can lead to meralgia paresthetica, a painful condition
  - Tight belts, excessive pannus, and prolonged hip flexion may exacerbate symptoms.
  - Release of compressive devices, postural exercises, and NSAIDs are usually curative.
- **Sciatic nerve entrapment**
  - Can occur anywhere along the course of the nerve, but the two most common locations are at the level of the ischial tuberosity and by the piriformis muscle (this condition known as *piriformis syndrome*)

Bone Disorders

- **Stress fractures**
  - A history of overuse, an insidious onset of pain, and localized tenderness and swelling are typical.
  - Bone scan can be diagnostic, even with normal findings on plain radiographs.
  - **MRI is the most specific method** for detecting stress fractures.
  - Treatment includes protected weight bearing, rest, cross-training, analgesics, and therapeutic modalities.
  - There are several especially **problematic stress fractures**
    - **Femoral neck stress fracture**
      - Can occur on tension side (superior surface) or compression side (inferior surface)
      - Compression-side fractures are more common and can be treated nonoperatively with rest and protected weight bearing.
      - **Tension-side** fractures are much more serious and may require operative stabilization.
    - Femoral shaft stress fracture
      - Usually responds to protected weight bearing but

can progress to complete fracture if unrecognized

- The fulcrum test may be helpful in making this diagnosis.

- **Avascular necrosis**
  - Traumatic hip subluxation can disrupt the arterial blood supply to the hip and result in avascular necrosis.
  - Early recognition of these injuries, which are seen in football players, is essential.
  - With posterior subluxation or dislocation, one study found a 25% incidence of avascular necrosis.
  - Obturator oblique radiographs (to determine the presence of an avulsion injury) and MRI are recommended.
  - Such imaging should be followed by aspiration of the hip if a large hemarthrosis is present, 6 weeks of minimal weight bearing, and repeat MRI.
  - With atraumatic injuries, other causative factors (alcohol, catabolic steroids, and decompression sickness) should be sought.
- **Osteitis pubis**
  - Repetitive trauma can cause an inflammation of the symphysis.
  - Occurs frequently in soccer players, hockey players, and runners
  - Conservative management is usually curative.
- **Tumors**
  - Because more than 10% of all musculoskeletal tumors occur in the hip and pelvis, they must be suspected in cases of unexplained pain.

Intraarticular Disorders

- **Later studies have demonstrated a high rate of abnormal MRI findings in asymptomatic patients with intraarticular disorders, as follows:**
  - 60%–80% prevalence of labral tears
  - 25% prevalence of chondral defects
  - 20% prevalence of acetabular paralabral cysts
- **Loose bodies**
  - Often result from trauma or diseases such as synovial chondromatosis
  - Should be removed, typically arthroscopically, to prevent wear
- **Labral tears**
  - Often a cause of mechanical hip pain manifesting with vague symptoms
  - MR arthrography is the most sensitive and specific test.
  - Incidence of labral tears is highest in patients with acetabular dysplasia.
  - Commonly associated with underlying structural disease.

- ◻ **Labral tears associated with femoroacetabular impingement (FAI) are usually located anteriorly** and result from crushing of the labrum between bony surfaces. Tears from dysplasia are usually more lateral and result from shear forces.
- ◻ Labral hypertrophy may be seen in dysplasia.
- ◻ For the best results, underlying hip disease should be addressed in addition to the labral tear.
- ◻ Arthroscopic labral repair is now preferred over labral débridement for most patients.

- ▪ **Chondral injuries**
  - ◻ Articular surface injury is often a cause of mechanical hip pain.
  - ◻ Chondral delamination is associated with cam-type FAI.
  - ◻ Microfracture is effective in the treatment of focal lesions.
- ▪ **Ruptured ligamentum teres**
  - ◻ Associated with mechanical hip pain because the ruptured ligament catches within the joint after a hip dislocation.
  - ◻ Débridement is often necessary.
  - ◻ The viability of the femoral head is not in jeopardy with a ruptured ligamentum teres.

Femoroacetabular Impingement

- ▪ **Definition**
  - ◻ Abnormal contact between proximal femur and acetabulum that leads to chondral damage and symptoms
- ▪ **Types (** Fig. 4.30)
  - ◻ Cam, pincer, and a combination of cam and pincer; combined type most common
    - **Cam impingement**
      - Most common in young males
      - Caused by aspherical femoral head and decreased head-neck offset; typically located anterolateral on femoral neck
      - In hip flexion, the aspherical head creates a shearing force along the acetabular cartilage, resulting in delamination. Avulsion of the labrum may also occur.
    - **Pincer impingement**
      - Most common in middle-aged females
      - Caused by acetabular overcoverage that results in abnormal contact between the acetabular rim and femoral head-neck junction

- Overcoverage may be due to protrusio acetabuli, coxa profunda, or acetabular retroversion.
- Results in intrasubstance tears of the labrum, typically in the anterosuperior quadrant; the anterosuperior femoral head is levered against the acetabular rim, and a contrecoup cartilage lesion may occur in the posteroinferior acetabulum.

- **Evaluation**
  - Groin or hip pain in association with limitation in ROM, especially flexion and internal rotation, can be a symptom.
  - Patients generally have more passive external rotation than internal rotation.
  - A positive result of an anterior impingement test is reproduction of symptoms with passive flexion, adduction, and internal rotation.
- **Imaging**
  - Plain radiographs should include an AP pelvis view (Fig. 4.31) and a lateral view; most hip arthroscopy surgeons now prefer a 45-degree Dunn lateral view. A false profile view is useful for evaluating anterior coverage, subspine deformities, and joint space narrowing
    - A "pistol-grip deformity," demonstrating a nonspherical femoral head, is seen in cam impingement.
    - A crossover sign is classically seen with acetabular retroversion that causes pincer impingement.
      - Anterior wall crosses lateral to posterior wall.
  - Later studies have demonstrated a high rate of false-positive radiographic findings.
    - Prevalence of coxa profunda has been demonstrated to be the same in asymptomatic patients as in those with diagnosed FAI.
    - More than 90% of asymptomatic adolescents have at least one radiographic parameter suggesting FAI, and 50% have two.
    - CT can give additional information about femur-acetabulum mismatch.
  - MR arthrogram can be used to provide information about cartilaginous and labral injuries (Fig. 4.32).

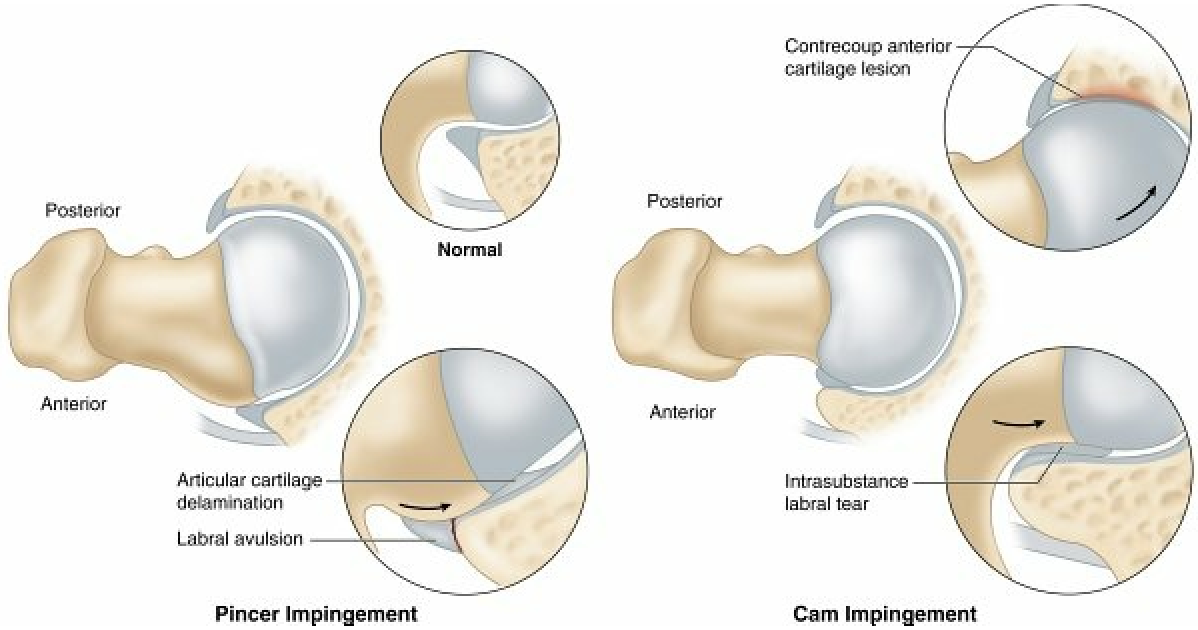


FIG. 4.30 Pathophysiology of femoroacetabular impingement.

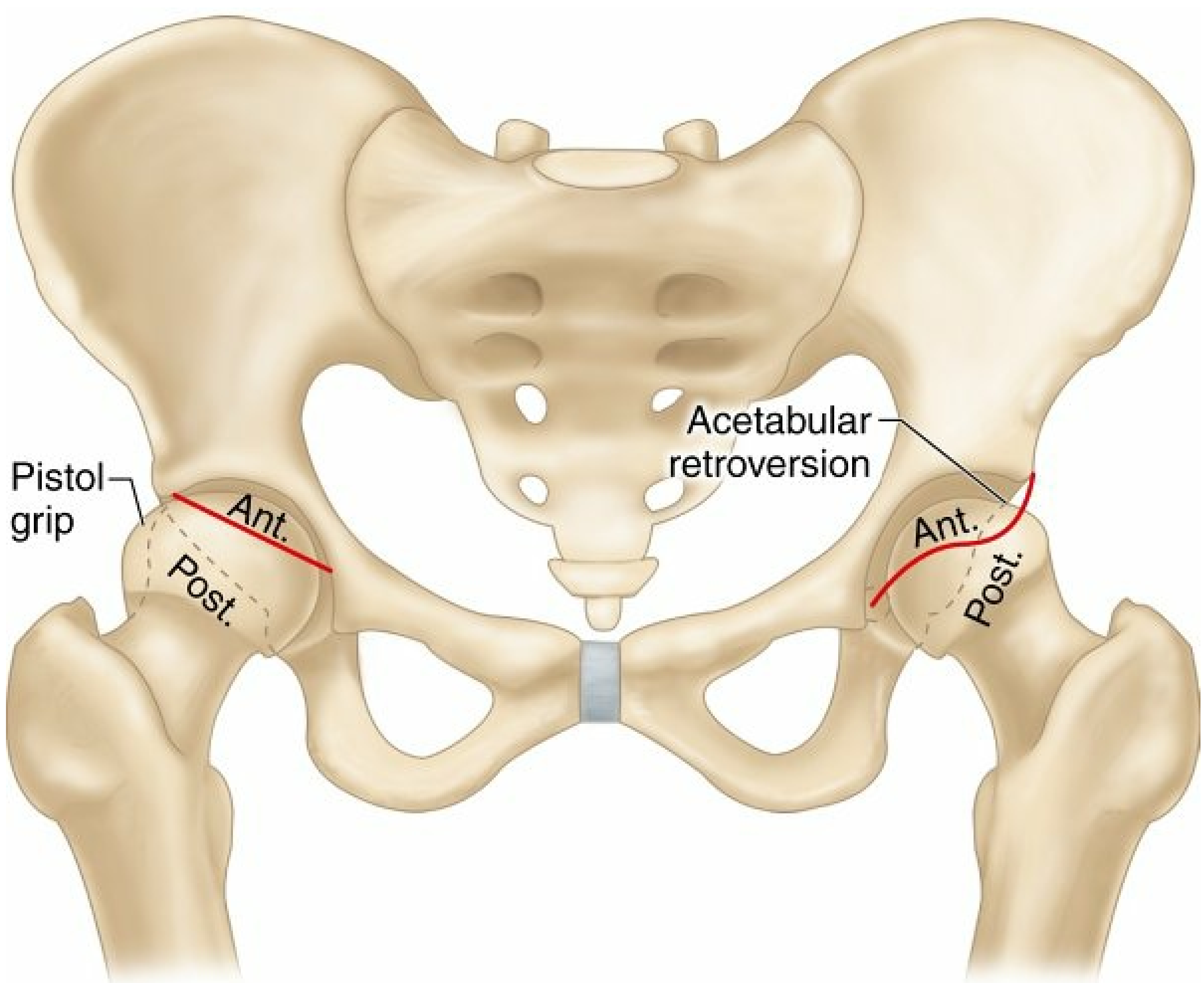


FIG. 4.31 Abnormalities visualized in FAI. The right hip has a normal acetabulum (the *anterior line* does not cross the *posterior line*) but a nonspherical femoral head. The left hip has a normal femoral head but retroverted acetabulum (the *anterior line* crosses the *posterior line*).

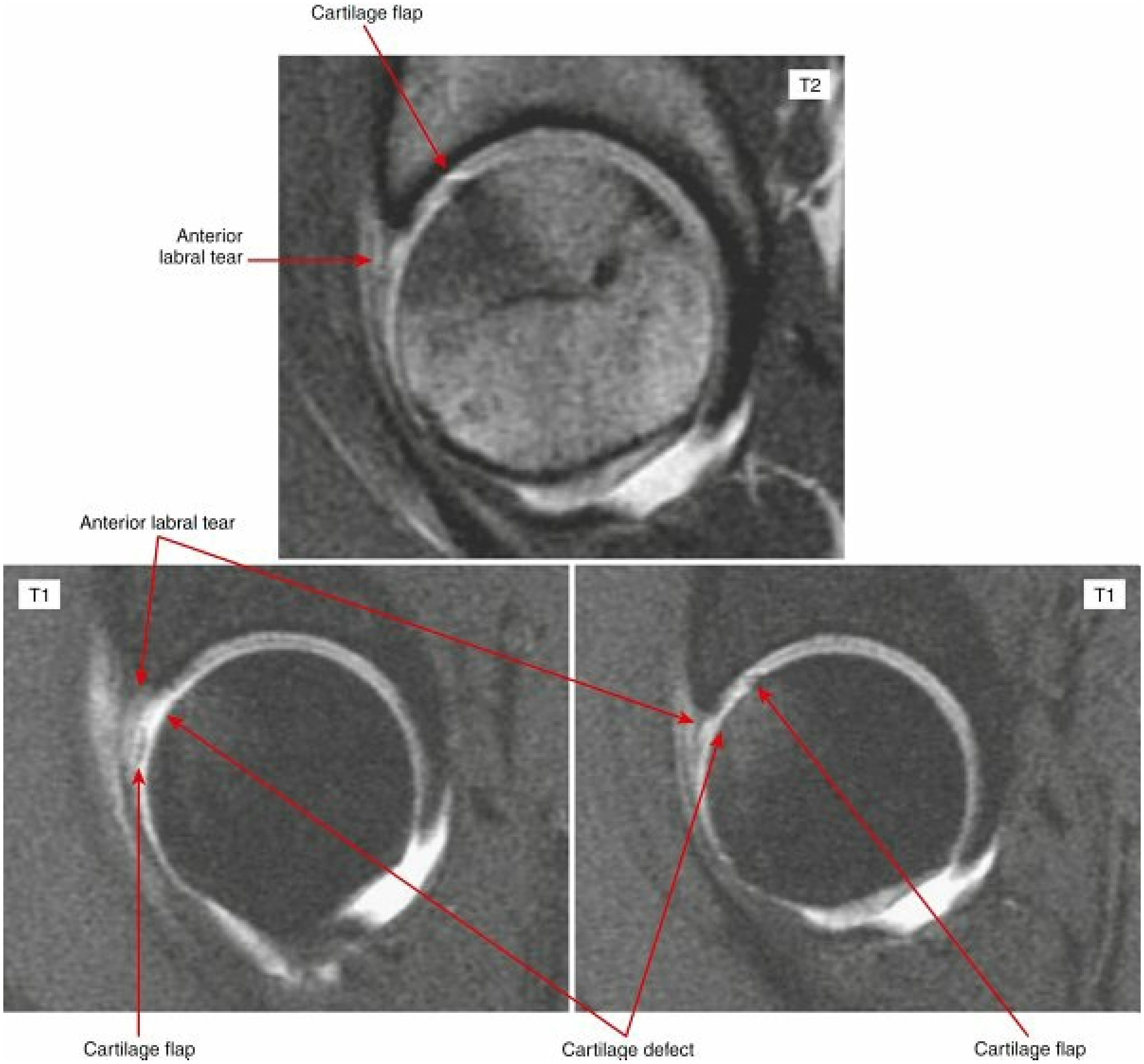


FIG. 4.32 MR arthrogram of the hip (T1-weighted and T2-weighted images as indicated) showing anterior labral tear and cartilage flap.
From Morrison W: *Problem solving in musculoskeletal imaging*, Philadelphia, Mosby, 2008, Fig. 11-56.

- **Treatment**
  - Initial management is typically conservative, including diagnostic/therapeutic injections.
  - Operative options include open or arthroscopic procedures to shave the femoral head and neck or acetabular rim, periacetabular osteotomy, femoral osteotomy, or combinations of these procedures with labral repair or, less often, débridement.
    - Tönnis grade 2 or higher arthritic changes are associated with poor outcomes. Joint space narrowed to <2 mm is associated with increased risk of conversion to total hip arthroplasty (THA) after arthroscopic treatment.
    - THA is reserved for patients with significant arthritic changes.

Other HIP Disorders

- **Snapping hip (coxa saltans): two types—external and internal**
  - External
    - A thickened posterior band within the iliotibial band abruptly catches on the greater trochanter.
    - More common in women with wide pelvises and prominent trochanters and can be exacerbated by running on banked surfaces
    - Snapping may be reproduced with passive hip flexion from an adducted position.
    - Patients may report and be able to demonstrate voluntary hip subluxation (**can be seen from across the room**), which is actually the IT band snapping.
    - Stretching and strengthening exercises, modalities such as ultrasonography, and occasionally surgical iliotibial lengthening may relieve the snapping.
  - Internal
    - Iliopsoas tendon either catches on underlying bony prominences or anterior hip capsule or rolls over itself.
    - **Audible pop** with extension and internal rotation of the hip from a flexed and externally rotated position (can be heard from across the room)
    - Diagnosed with extension and internal rotation of the hip from a flexed and externally rotated position
    - Present in up to 10% of the population
    - Dynamic ultrasonography or arthrography may also be helpful in determining the diagnosis.
    - Surgical release indicated for refractory painful internal snapping

HIP Arthroscopy

- **Indications (** Fig. 4.33)
  - **FAI, labral tears, loose bodies, ligamentum teres disorders, snapping hip, synovial conditions.**

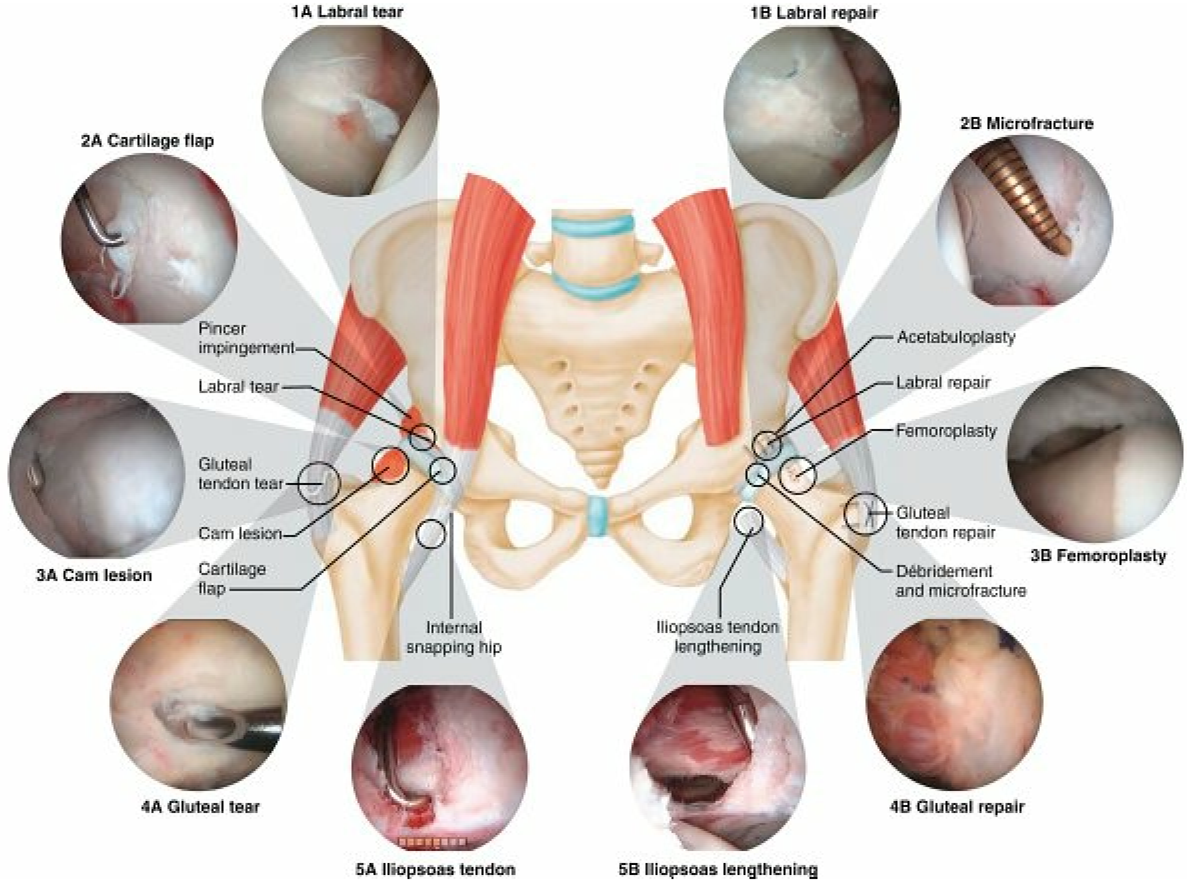


FIG. 4.33 Sports-related hip pathology.

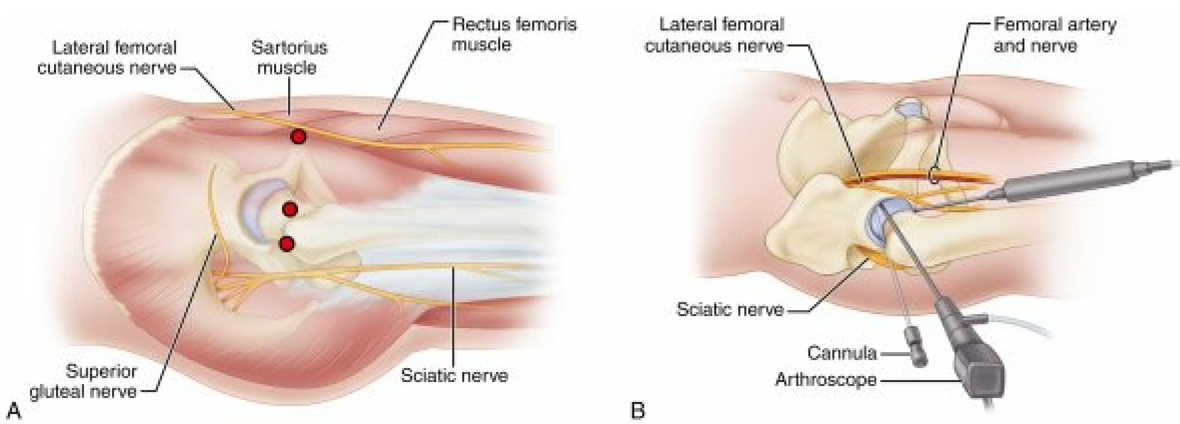


FIG. 4.34 Portals *(red dots)* for hip arthroscopy are the anterior portal and two portals on either side of the greater trochanter. Superficial (A) and deep (B) structures are shown.
From Canale ST, Beaty JH, editors: *Campbell's operative orthopaedics*, ed 12, Philadelphia, Mosby, 2013, Fig. 51-59.

- Expanding indications for gluteal tendon tears, hamstring tears, ischiofemoral impingement, deep gluteal space disorders

- **Contraindications**
  - Dysplasia, avascular necrosis, arthritis, global acetabular or femoral deformities, rotational deformities of the hip
- **Setup**
  - Hip arthroscopy is typically performed with the patient in the supine or lateral position with approximately 50 lb (22.7 kg) of traction and a

well-padded perineal post.

- **Portals**
  - Three portals are commonly used for instrumentation: one on each side of the greater trochanter and an additional anterior portal (Fig. 4.34).
- **Compartments**
  - Three compartments are described
    - The *central compartment* refers to the intraarticular portion of the hip joint between the cartilaginous portions of the proximal femur and the acetabulum.
    - The *peripheral compartment* refers to the intraarticular portion of the hip joint along the neck of the femur and the edge of the acetabulum.
    - The *lateral compartment* refers to the extraarticular portion in the peritrochanteric region and trochanteric bursa.
  - Complications
    - Complications, which are rare, are associated with traction injuries, iatrogenic chondral injuries, iatrogenic labral injury, and neurovascular injury caused by aberrant portal placement.
      - The sciatic and pudendal nerves are most frequently injured by traction.
      - The maximum traction weight, not the duration of traction, has been associated with sciatic nerve injury.
    - The anterior portal puts the lateral femoral cutaneous nerve at risk.
      - Also at risk are the ascending branch of the lateral femoral circumflex artery and the femoral neurovascular bundle.
    - The anterolateral portal is associated with injury to the superior gluteal nerve.
    - The posterolateral portal places the sciatic nerve at risk, particularly when the hip is externally rotated.
    - Heterotopic ossification has been reported to occur following hip arthroscopy. NSAIDs have been shown to reduce the incidence.

Section 3 Shoulder

Anatomy (Figs. 4.35 and 4.36; Table 4.6)

- **See** Chapter 2, Anatomy, for a thorough discussion of shoulder anatomy.

Biomechanics

- **The shoulder is stabilized by both static and dynamic restraints.**
  - Static restraints (Fig. 4.37; see Table 4.5)
    - Structures that provide unidirectional limitations to translation
    - Include the glenoid labrum, articular version, articular conformity, negative intraarticular pressure, capsule (posterior capsule and rotator interval), and glenohumeral ligaments (GHLs)
    - Glenoid labrum increases depth of glenoid concavity.
      - Serves to anchor the glenohumeral ligaments
    - The superior GHL (SGHL) and coracohumeral ligament (CHL) are reinforcing structures of the rotator interval; they limit inferior translation and external rotation when the arm is adducted and posterior translation when the arm is flexed forward, adducted, and internally rotated.
      - Imbrication of the rotator interval decreases inferior and posterior translation, whereas its release produces greater forward flexion (FF) and external rotation (ER).
    - The middle GHL (MGHL) limits external rotation of the adducted humerus, inferior translation of the adducted and externally rotated humerus, and anterior and posterior translation of the partly abducted (at 45 degrees) and externally rotated arm.

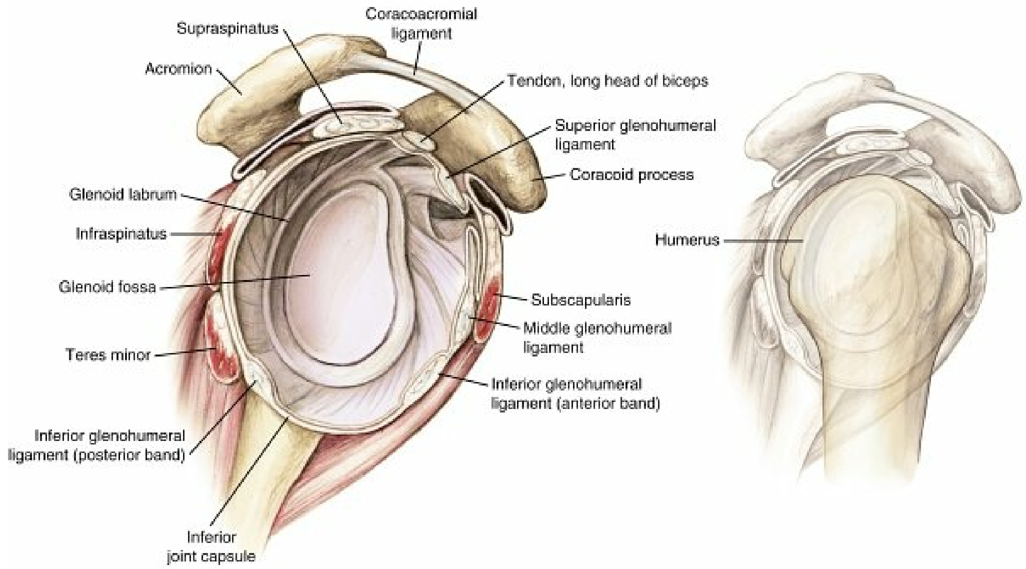


FIG. 4.35 Important ligaments of the shoulder.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders.

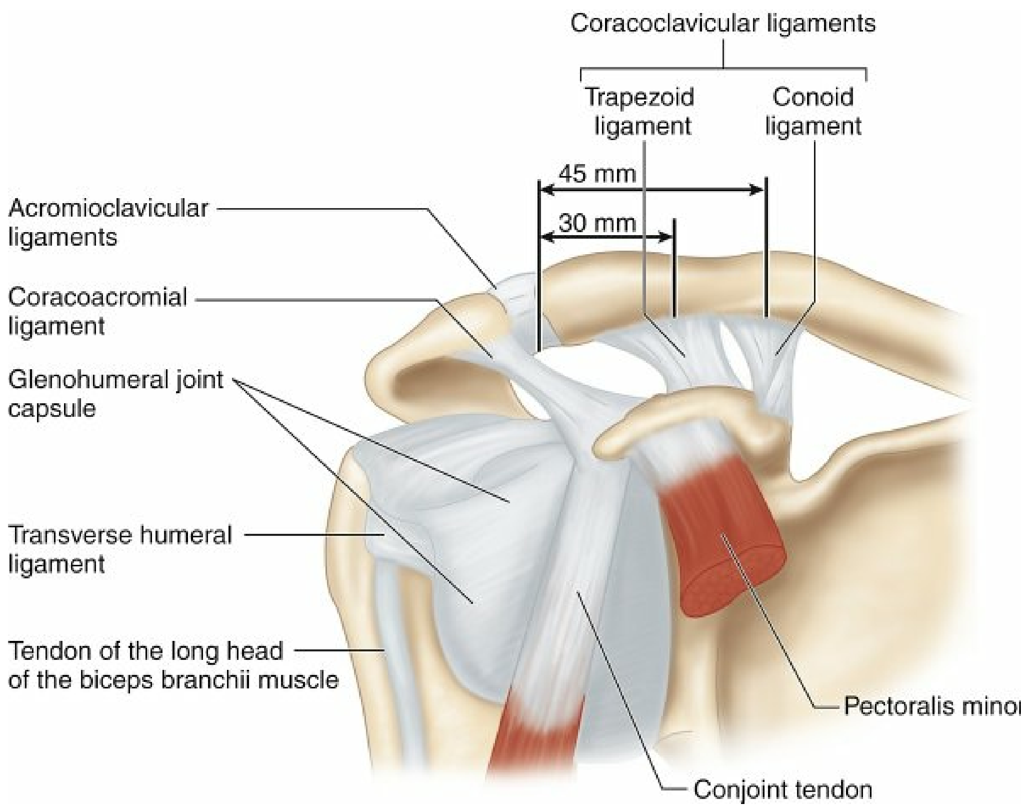


FIG. 4.36 Anatomy of the superior shoulder suspensory complex and adjacent structures.

Table 4.6

Shoulder Injuries: Radiographic Findings

View/Sign	Findings	Significance
View of supraspinatus outlet	Acromial structure (types I to III)	Type III acromion associated with impingement
View of 30-degree caudal tilt	Subacromial spurring	Area below level of clavicle is impingement area
Zanca 10-degree cephalic tilt	AC joint disease	AC DJD, distal clavicle osteolysis
West Point view	Anterior-inferior glenoid evaluation	Bony Bankart lesion seen with instability
Apical oblique (Garth) view	Anterior-inferior glenoid evaluation; humeral head evaluation	Bony Bankart lesion seen with instability; Hill-Sachs defect
Stryker notch	Humeral head evaluation	Hill-Sachs impression fracture
AP internal rotation	Humeral head evaluation	Hill-Sachs defect
Hobbs view	Sternoclavicular injury	Anteroposterior dislocations
Serendipity view	Sternoclavicular injury	Anteroposterior dislocations
45-degree abduction, true AP view	Glenohumeral space	Subtle DJD
Arthrography	Rotator cuff injuries	Dye above cuff indicates tear
CT	Fractures	Classification is easier
MRI ± arthrography	Soft tissue evaluation	Labral, cuff, muscle tears

- **The inferior GHL (IGHL) complex** serves as the primary restraint to anterior, posterior, and inferior glenohumeral translation at 45 to 90 degrees of glenohumeral elevation. The anterior IGHL is important in external rotation, and the posterior IGHL important in internal rotation (IR).

□ Dynamic restraints

- These include joint concavity compression produced by synchronized contraction of the rotator cuff, which acts to stabilize the humeral head within the glenoid; increased capsular tension produced by direct attachments of the rotator cuff to the capsule; the scapular stabilizers that act to maintain a stable glenoid platform ("ball on a seal's nose"); and proprioception.

- **Throwing**
    - Significant forces are generated during throwing and can result in anatomic variation and injury.
    - Typically there is greater external rotation and a loss of internal rotation of the dominant shoulder in comparison with the nondominant shoulder; this condition is referred to as *glenohumeral internal rotation deficit* (GIRD).
    - The anterior capsule is selectively stretched, whereas the posterior capsule is tightened. These developments can predispose to both instability and internal impingement.
    - Bony changes have also been observed in the dominant shoulder, including increased humeral head retroversion and glenoid retroversion.
    - The five phases of throwing are shown in Fig. 4.38.
    - Maximal torque is generated during two actions: maximal external rotation (late cocking) and just after ball release (deceleration).
        - The **late cocking phase is associated with SLAP** (superior labrum from anterior to posterior) tears and internal impingement.
        - The deceleration phase is associated with tensile failure of the posterior aspect of the supraspinatus and anterior half of the infraspinatus.
            - The rotator cuff must offset the high-energy forces during deceleration.
        - The scapula must rotate during throwing. It retracts during the late cocking phase and then protracts during the acceleration phase.
        - Scapular dyskinesis is extremely common in the patient with a disabled throwing shoulder.
            - Control of scapular retraction and posterior tilt is lost.
            - Results in scapular protraction, anterior tilt, and excessive internal rotation
                - Anterior tilt results in external impingement.
                - Internal rotation results in internal impingement.
                - Loss of control causes decreased rotator cuff strength and increased anterior capsular strain.

Diagnostic Techniques

- **History**
  - Age and chief complaint are two important considerations.
  - **Instability, acromioclavicular (AC) injuries, and distal clavicle osteolysis are more common in young patients.**
  - Rotator cuff tears, arthritis, and proximal humeral fractures are more common in older patients.
  - Direct blows are usually responsible for acromioclavicular separations.
  - Instability occurs with injury to the abducted externally rotated arm.
  - Chronic pain with overhead activity and night pain are associated with rotator cuff tears.
- **Physical examination**
  - Key physical examination points for the shoulder are listed in Table 4.7.
  - For evaluation of true ROM of the glenohumeral joint, the scapula must be stabilized.
- **Imaging of the shoulder**
  - Standard radiographic views:
    - AP view
    - Glenohumeral "true" AP (Grashey) view
    - Axillary lateral view
      - Crucial view to evaluate glenohumeral dislocation and arthritis
    - Scapular Y view
    - Acromioclavicular AP (Zanca) view
      - Taken with a 10-degree cephalic tilt and 50% penetrance
  - Rotational views, supine and prone views, and tilted views may also be obtained.
  - MRI is important for evaluating soft tissue structures, including the rotator cuff and glenoid labrum as well as articular cartilage. An MR arthrogram can improve visualization of pathology.

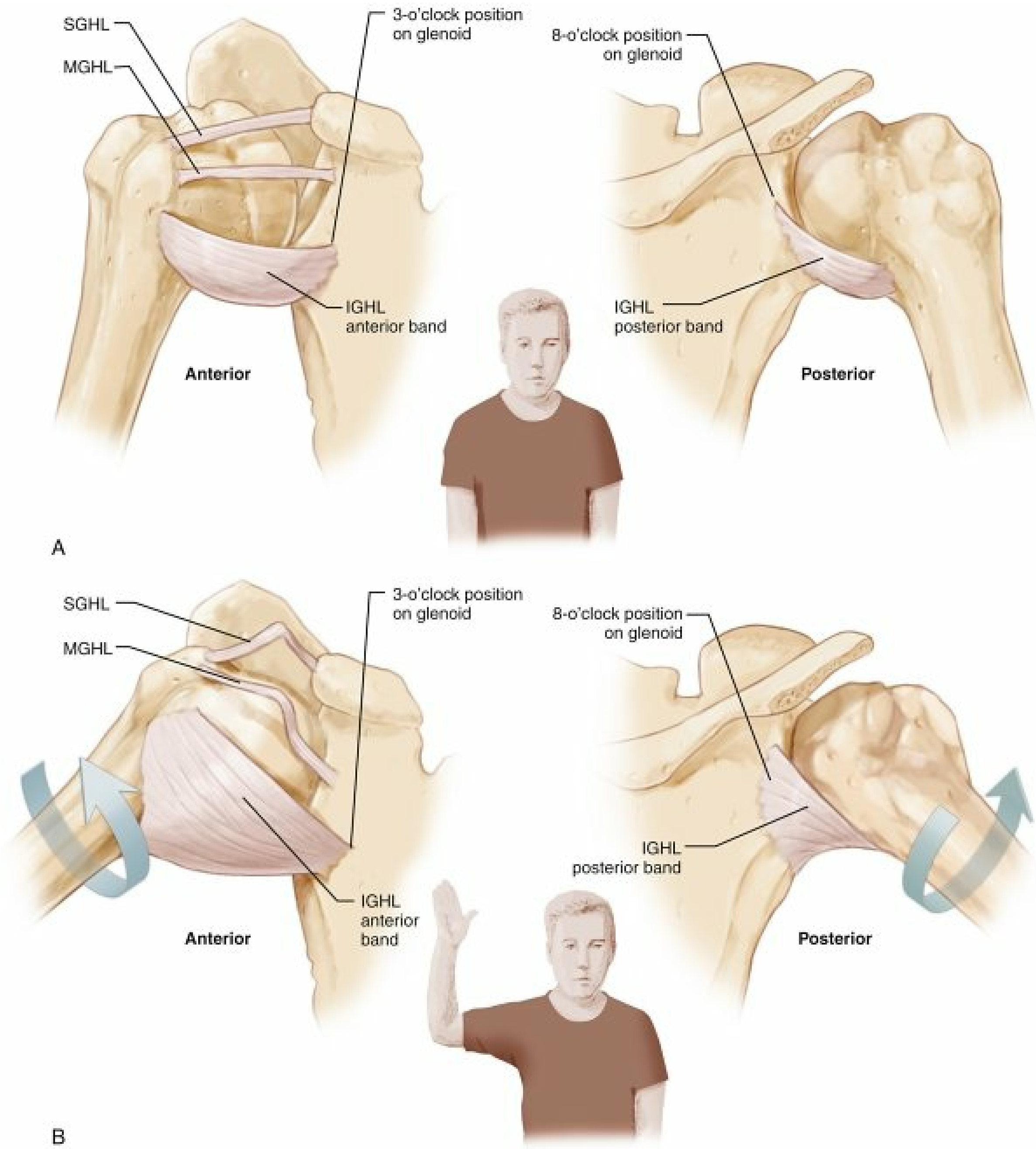


FIG. 4.37 Dynamic relationship of the glenohumeral ligaments, which provide static restraint to the shoulder. (A) In 0 degrees of abduction, the SGHL is taut. (B) As the arm is brought into the "apprehension position" of abduction and external rotation, the anterior band of the IGHL is pulled superiorly and anteriorly to span the midportion of the glenohumeral joint, thus providing anterior stability.

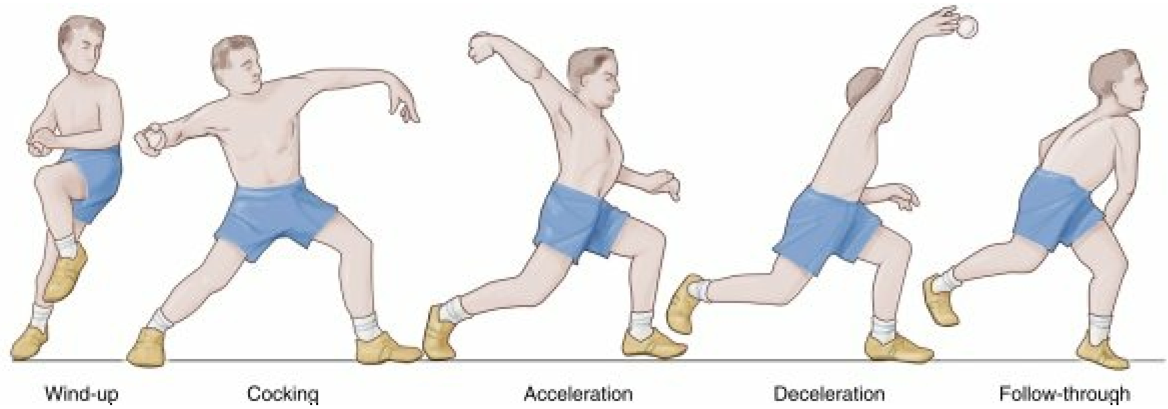


FIG. 4.38 Phases of the throwing motion.

Table 4.7

Shoulder: Key Examination Points

Examination/Sign	Technique	Significance
IMPINGEMENT/ROTATOR CUFF		
Impingement sign	Passive FF >90 degrees	Pain indicates impingement syndrome
Impingement test	Passive FF >90 degrees continues after subacromial injection	Relief of pain indicates impingement syndrome
Hawkins test	Passive FF of 90 degrees and IR	Pain indicates impingement syndrome
Jobe test	Resisted pronation/FF of 90 degrees	Pain indicates supraspinatus lesion
Drop-arm test	Examiner places arm in FF in plane of scapula and then releases it	Inability to maintain FF indicates supraspinatus lesion
Hornblower sign	Resisted maximal ER/abduction of 90 degrees	Pain indicates infraspinatus, supraspinatus, or post-supraspinatus lesion
Rubber band sign	Resisted maximal ER/slight abduction	Pain indicates infraspinatus lesion
Liftoff test	Arm in IR behind back	Inability to elevate arm from back indicates subscapularis lesion
Modified liftoff test	Resisted arm held off back	Inability to keep arm elevated when off back indicates subscapularis lesion
Belly-push test	Elbow held anterior with abduction pressure	Inability to hold elbow forward indicates subscapularis lesion
Bear-hug test	Patient's hand is placed on opposite shoulder and examiner attempts to lift hand from shoulder	Inability to maintain contact with shoulder indicates subscapularis lesion
INSTABILITY		
Apprehension test	Supine abduction in 90 degrees and ER	Apprehension indicates anterior instability
Relocation test	Apprehension with posterior force	Relief of apprehension indicates anterior

		instability
Load-and-shift test	Anterior/posterior force on humeral head	Degree of translation reflects laxity or instability
Modified load-and-shift test	Supine load/shift with elbow bending	Degree of translation reflects laxity or instability
Jerk test	Posterior force applied with arm adduction and FF	A "clunk" sound indicates posterior subluxation
Sulcus sign	Inferior force applied with arm at side	Increased acromiohumeral interval reflects inferior laxity or instability (see Table 4.11 for sulcus grading)
LABRUM/BICEPS		
O'Brien (active compression) test	10 degrees adduction, 90 degrees FF, maximal pronation	Pain with resistance indicates SLAP lesion
Anterior slide test	Hand on hip, joint loading	Pain with resistance indicates SLAP lesion
Crank test	Full abduction, humeral loading, rotation	Pain indicates SLAP lesion
Speed test	Resisted FF in scapular plane	Pain indicates bicipital tendinitis
Yergason test	Resisted supination	Pain indicates bicipital tendinitis
MISCELLANEOUS		
Spurling maneuver	Lateral flexion, rotation, cervical loading	Cervical spine disease or injury
Wright test	Extension-abduction-ER of arm with neck rotated away	Loss of pulse and reproduction of symptoms indicate thoracic outlet syndrome

- ▫ CT can be a helpful adjunct for bony abnormalities around the shoulder and is most typically obtained to characterize glenoid bone loss and for preoperative planning for shoulder arthroplasty
- ▫ Table 4.6 lists several radiographic findings in the shoulder and their significance.

Shoulder Arthroscopy

- **Portals (** Fig. 4.39)
  - ▫ Standard portals
    - Posterior portal (2 cm distal and medial to the posterolateral border of the acromion, used primarily for viewing)

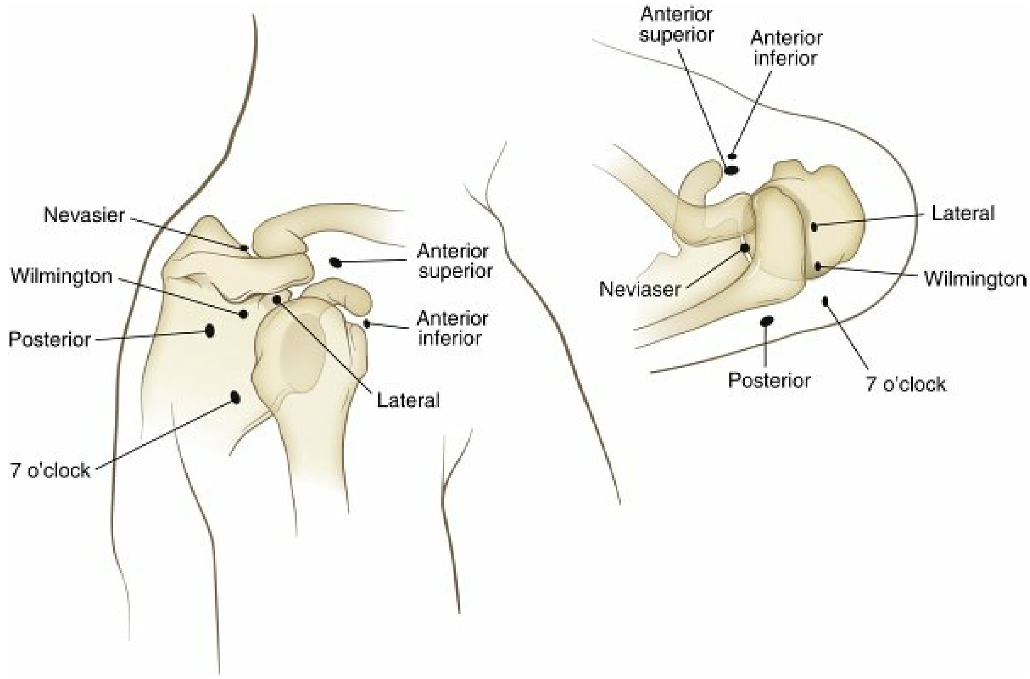


FIG. 4.39 Shoulder arthroscopy portals, viewed from the side *(left)* and from above *(right)*. (From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, 2014, Philadelphia, Saunders.)

  - Anterior portal (just anterior to AC joint)
  - Lateral portal (1–2 cm distal to lateral acromial edge)
- □ Additional portals
  - Supraspinatus (Neviaser) portal for anterior glenoid visualization and SLAP repair (through supraspinatus fossa)
  - Anterolateral and posterolateral portals (portal of Wilmington, just anterior to posterolateral corner of acromion) are useful for labral or SLAP tears and rotator cuff repair.
  - Anteroinferior (5-o'clock position) portal for Bankart repair and stabilization procedures
  - Posteroinferior (7-o'clock position) portal for posterior stabilization procedures

▪ **Hazards**

- □ Posterior portal: axillary nerve, suprascapular nerve, suprascapular artery
- □ Anterior portals: cephalic vein, axillary artery, axillary nerve
- □ Superior portals: suprascapular artery, suprascapular nerve

▪ **Technique**

- □ Intraarticular structures should be systematically evaluated (Fig. 4.40).
- □ As the number and variety of arthroscopic procedures increase, so does the opportunity for iatrogenic injury.
- □ Risk can be minimized by maintaining adequate visualization through hemostasis, avoiding chondral abrasion, maintaining adequate flow with thermal devices, and preventing fluid extravasation by preserving muscle fascial layers.

- The axillary nerve is approximately 12 mm distal to the 6-o'clock position.
- The **axillary nerve** has often branched into its four divisions at this position.
  - From proximal to distal: branch to teres minor, branch supplying lateral cutaneous innervation (superior lateral brachial cutaneous nerve), branch to posterior deltoid, branch to anterior deltoid
  - This explains why the majority of postoperative axillary neurapraxias are reported as typically isolated sensory abnormalities. The branch to teres minor is very difficult to evaluate clinically.

Shoulder Instability

- **Instability is a pathologic condition manifesting as pain that is caused by excessive translation of the humeral head on the glenoid during active shoulder motion; it represents a spectrum of injury to the shoulder stabilizers.**
- **Can be divided into unidirectional and multidirectional types. Matsen coined the acronyms TUBS and AMBRI as mnemonics.**
  - TUBS: *T*raumatic *u*nilateral dislocations with a *B*ankart lesion often necessitate *s*urgery because they typically occur in young patients and have recurrence rates of up to 90% with nonoperative management. Anterior instability is much more common than posterior instability.
  - AMBRI: *A*traumatic *m*ultidirectional *b*ilateral shoulder dislocation/subluxation often responds to *r*ehabilitation, and sometimes an *i*nferior capsular shift or plication is required.
- **Anterior instability**
  - Introduction
    - Most common type of shoulder instability
    - Typically the result of trauma to the arm when in the **abducted and externally rotated position**
    - Fundamentally the pathoanatomy can be capsulolabral, osseous, or both.
    - Capsulolabral pathoanatomy (Fig. 4.41)
      - A Bankart lesion, which was originally described by Bankart as the essential lesion of anterior shoulder instability, has been defined as an avulsion of the anterior-inferior capsulolabral complex with extension into the scapular periosteum and rupture of the periosteal tissue.

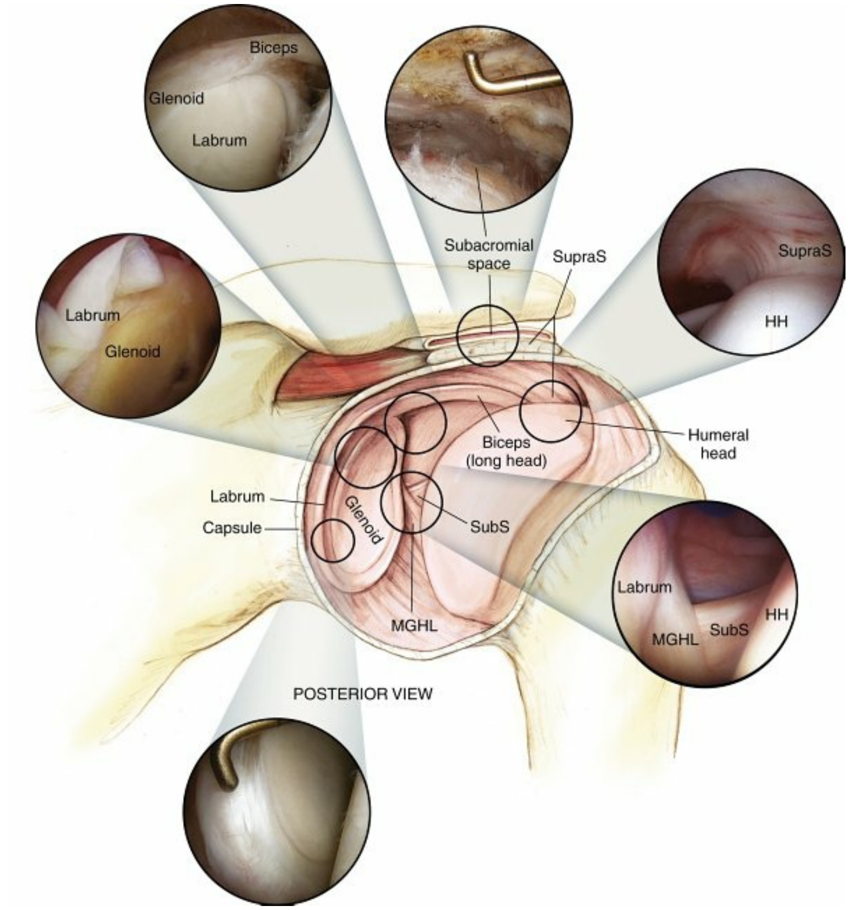


FIG. 4.40 Normal arthroscopic anatomy of the shoulder. *HH,* Humeral head; *MGHL,* middle glenohumeral ligament; *SubS,* subscapularis; *SupraS,* supraspinatus.

From Miller MD et al: *Orthopaedic surgical approaches,* ed 2, 2014, Philadelphia, Saunders.

- Found to occur in 90% of patients with recurrent anterior shoulder instability
- A variety of other capsulolabral lesions have been described: Perthes lesion, anterior labroligamentous periosteal sleeve avulsion (ALPSA) lesion, and humeral avulsion of the glenohumeral ligaments (HAGL) lesion (Table 4.8).
    - A HAGL lesion has an incidence between 1% and 9% and has typically necessitated open repair in the past because of its inferior location. However, newer arthroscopic techniques are being developed.
- Osseous pathoanatomy
    - A degree of bony injury to either the glenoid or the humeral head is thought to occur in almost every patient with anterior shoulder instability.

- Glenoid bone loss may occur either as an identifiable fragment with its attached capsulolabral structures (bony [osseous] Bankart lesion) or as a result of impaction and erosion.
- Some glenoid bone loss is present in 40% of patients with first dislocations and in 85% of those with recurrent dislocations.
- Preoperative recognition of glenoid bone loss is important; **significant bone loss (20%–25% of the width of the glenoid) has been associated with an increased rate of recurrence following Bankart repair.** This percentage corresponds to approximately 6–8 mm of bone loss.
- The bone fragment in a bony Bankart lesion has been shown to undergo rapid absorption within 1 year of the primary injury.
- Humerus-side bone injury typically occurs to the posterior-superior humeral head and has been termed a *Hill-Sachs lesion* after the two radiologists who described it.
    - A Hill-Sachs lesion can be found in 40% of patients with recurrent subluxations but no dislocations, 90% of those with first dislocations, and almost 100% of those with recurrent dislocations.

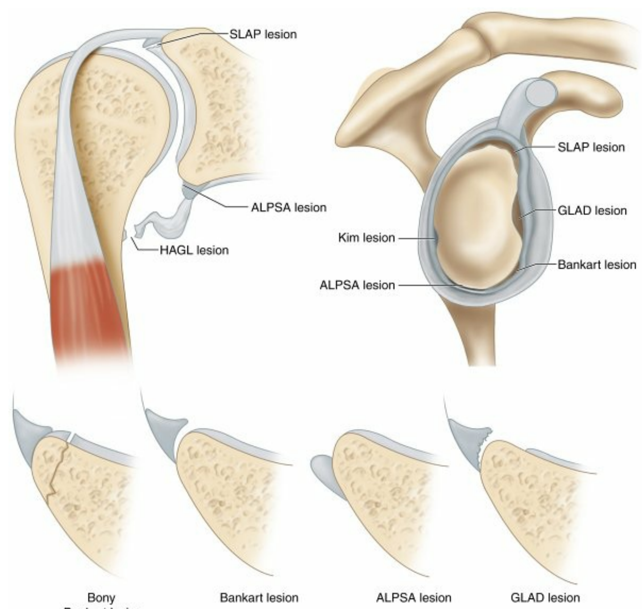


FIG. 4.41 Capsulolabral lesions. *GLAD*, Glenolabral articular disruption.

Table 4.8

Capsulolabral Lesions

Lesion	Description
ASSOCIATED WITH ANTERIOR INSTABILITY	
Perthes	Avulsion of anterior-inferior glenolabral complex with preservation of medial scapular neck periosteum
Bankart	Complete avulsion of anterior-inferior glenolabral complex along with a piece of scapular neck periosteum
Bony Bankart	Osseous avulsion fracture of anterior-inferior glenolabral complex
ALPSA	Avulsion of anterior-inferior glenolabral complex with stripping of medial scapular neck periosteum but preservation of a medial hinge; loose fragment subsequently scars medially down scapular neck
HAGL	Avulsion of glenohumeral ligaments from their humerus-side attachment
NOT ASSOCIATED WITH INSTABILITY	
Glenolabral articular disruption (GLAD)	Superficial tear of anterior-inferior labrum with associated cartilage injury but preservation of anterior-inferior glenolabral complex; manifests as painful shoulder but is not a cause of shoulder instability
SLAP	Disruption of superior labrum, originally described to stop at midglenoid notch [a]

[a] Newer descriptions have associated SLAP tears with Bankart lesions, but SLAP lesion alone is not a cause of shoulder instability.

- An **"engaging" Hill-Sachs lesion** is oriented in such a manner that when the shoulder is placed in abduction and external rotation, the humeral head loses contact with the glenoid, and subluxation or dislocation of the glenohumeral joint follows.
- Newer studies have introduced the concept of "on-track" versus "off-track" shoulders. This concept

evaluates the combined effect of glenoid and humeral bone loss. An on-track shoulder does not have a high risk of failure with arthroscopic labral repair, whereas an off-track shoulder has a high risk of recurrence without either remplissage or Latarjet procedure.

- Age at first dislocation is the most important factor in predicting recurrence. Rates of redislocation:
  - Almost 100% in persons with open physes
  - 70%–95% of persons younger than 20 years
  - 60%–80% in persons aged 20–30 years
  - 15%–20% in persons older than 40 years
- Associated injuries
  - Typically occur in older patients; up to 40% of patients have an associated injury.
  - Dislocation with greater tuberosity fracture is the most common scenario, occurring in 15% of older patients.
  - Rotator cuff tears, axillary nerve palsy, brachial plexus palsy, and axillary artery injury can also occur. The axillary nerve is susceptible to injury after anterior dislocation because of its relatively fixed position.

□ History and physical examination

- Patient typically presents with a history of trauma
- Note should be made of age at first dislocation, increasing ease of dislocation, frequency of recurrence, duration of symptoms, and patient's ability to reduce the dislocation himself or herself.
- Physical examination should focus on both diagnosis and identification of associated injuries.
  - The apprehension-relocation test (Fowler test) is the most sensitive. The arm is placed into abduction and external rotation. As the arm is

brought into this position, the patient experiences a sense of instability. The examiner then places a posterior force on the arm and the sense of instability is relieved.

- The load-and-shift test can be used to classify degrees of instability on the basis of distance of humeral head translation: 1+: 0–1 cm of translation to before glenoid rim; 2+: 1–2 cm of translation to glenoid rim; 3+: >2 cm translation or over glenoid rim.
  - An evaluation of generalized laxity should be performed.

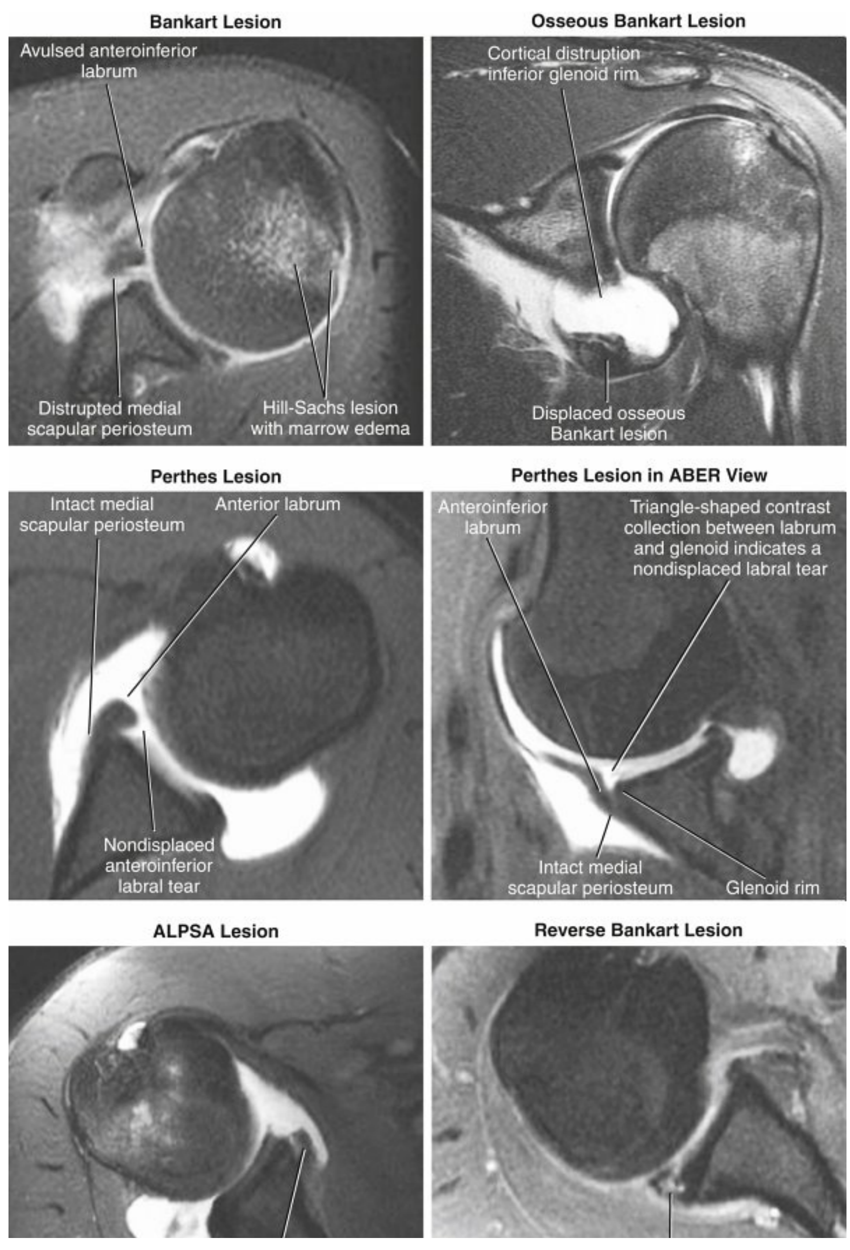
□ Imaging

- Radiographs, CT, and MRI all have a role.
- Standard radiographs, including an axillary view, are obtained to ensure that the shoulder is located.
- Specialized views are helpful for detecting glenoid and humeral head bone loss (see Table 4.6).
- CT (Fig. 4.42)
  - Permits accurate identification of glenoid bone loss. Later studies suggest that three-dimensional reconstructions are more reliable for measurement purposes.
- MRI (Fig. 4.43)
  - Typically an MR arthrogram is performed for greater sensitivity.
  - An *ab*duction-*e*xternal *r*otation (ABER) view further increases sensitivity

FIG. 4.42 Three-dimensional reconstruction of CT scan of the glenoid and scapula demonstrating approximately 20% anterior glenoid bone loss.

□ Treatment
- Reduction
    - Variety of techniques described. Traction-countertraction is most commonly employed. The Milch maneuver (slow abduction and external rotation) has some evidence suggesting higher success rates.
    - Cochrane review suggests no difference between intraarticular injection of lidocaine and intravenous sedation with regard to the success rate of reduction, pain during reduction, and postprocedural pain.
    - An axillary view radiograph is mandatory to confirm reduction.
- Sling immobilization
    - Duration of immobilization has not been found to influence rates of recurrent dislocation.

    - Positioning the arm in external rotation has shown some success in the literature in reducing redislocation rates. However, later studies have been unable to confirm these early results, and meta-analyses suggest no difference between immobilization in internal rotation and that in external rotation.
- Surgical stabilization (Table 4.9)
    - Management of the first-time shoulder dislocation remains controversial. There is support in the literature for stabilization of first-time dislocation, with reduced rates of redislocation and improved quality-of-life outcome measurements.
    - A multitude of surgical techniques have been described. Many are historical, but some of these are still important to be aware of because their long-term complications continue to be clinical concerns.
- Surgical techniques (see Table 4.9 and Fig. 4.44)
    - Debate continues on whether arthroscopic Bankart repair produces results equivalent to those of the current gold standard, open Bankart repair.



Bankart Lesion
Avulsed anteroinferior labrum
Distrupted medial scapular periosteum
Hill-Sachs lesion with marrow edema
Osseous Bankart Lesion
Cortical distruption inferior glenoid rim
Displaced osseous Bankart lesion
Perthes Lesion
Intact medial scapular periosteum
Anterior labrum
Nondisplaced anteroinferior labral tear
Perthes Lesion in ABER View
Anteroinferior labrum
Triangle-shaped contrast collection between labrum and glenoid indicates a nondisplaced labral tear
Intact medial scapular periosteum
Glenoid rim
ALPSA Lesion
Reverse Bankart Lesion

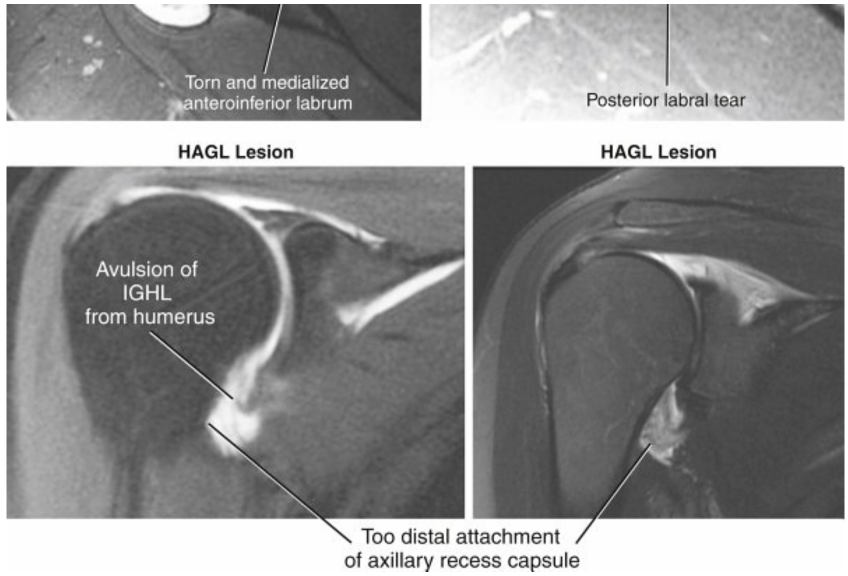


FIG. 4.43 MRI appearance of the various soft tissue pathologies associated with shoulder instability.

Table 4.9

Surgical Options for Anterior Shoulder Instability

Procedure	Essential Features	Comments, key Complications
OPEN		
Bankart repair	Reattachment of labrum and IGHL to anterior glenoid; often combined with capsular shift	Gold standard; occasionally preferred in contact athletes
Latarjet coracoid transfer	Distal 2 cm of coracoid transferred to anterior glenoid neck with two-screw fixation and reattachment of CA ligament to anterior glenohumeral capsule	Primary procedure in patients with >25% glenoid bone loss
Anterior capsulolabral reconstruction	Glenoid-based capsular shift	Designed for overhead-movement athletes; may be performed as adjunct to Bankart
ARTHROSCOPIC		
Bankart repair	Reattachment of labrum and IGHL to anterior glenoid with use of suture	Most common operation for anterior instability

	anchors	
Coracoid transfer (hybrid Bristow-Latarjet)	Distal 2 cm of coracoid transferred to anterior glenoid neck; CA ligament preserved	Investigational
SUPPLEMENTARY		
Remplissage	Arthroscopic infraspinatus and posterior capsule fixation into Hill-Sachs lesion using suture anchors	Investigational; performed in moderate to large Hill-Sachs lesions; medialized sutures limit external rotation
Humeral head allograft	Osteoarticular allograft inserted into Hill-Sachs lesion	Performed in large Hill-Sachs lesions
Partial humeral head resurfacing	Cobalt-chrome component inserted into Hill-Sachs lesions; typically performed with Latarjet procedure	Alternative to humeral head allograft
Rotator interval closure	Open or arthroscopic superior capsular shift of MGHL to SGHL	Limits external rotation
REVISION		
Allograft bone grafting of glenoid	Iliac crest or distal tibia secured to anterior glenoid neck with screws	Performed in severe glenoid bone loss
Humeral hemiarthroplasty	Humeral component retroverted 50 degrees to achieve stability	Indicated in older patients with >45% humeral head bone loss and glenohumeral arthritis
Rotational humeral osteotomy	Subcapital external rotational osteotomy to rotate Hill-Sachs lesion outside glenoid track	Performed in severe Hill-Sachs lesions
Allograft anterior capsulolabral	Allograft tendon used to reconstruct	Performed in severe capsular deficiency

reconstruction	anterior band of IGHL and MGHL	due to systemic soft tissue disorders, electrothermal capsular necrosis, or repeated surgical procedures without bone loss
HISTORICAL		
Bristow coracoid transfer	Distal 1 cm of coracoid transferred and secured with 1 screw; CA ligament preserved	Higher rate of recurrence
Caspari technique	Arthroscopic transglenoid suture repair of glenoid labrum	Higher rate of recurrence; injury to suprascapular nerve
Staple capsulorrhaphy	Reattachment of capsule to glenoid neck with a staple	High rate of pain, higher rate of recurrence, reduced internal and external rotation, staple migration
Putti-Platt	Subscapularis advancement and shortening	Reduced external rotation, posterior glenoid arthritis
Magnusson-Stack	Subscapularis transfer to greater tuberosity	Reduced external rotation
Thermal capsular shrinkage	Use of thermal energy to reduce capsular volume	Higher rate of recurrence; can result in capsular deficiency and chondral damage

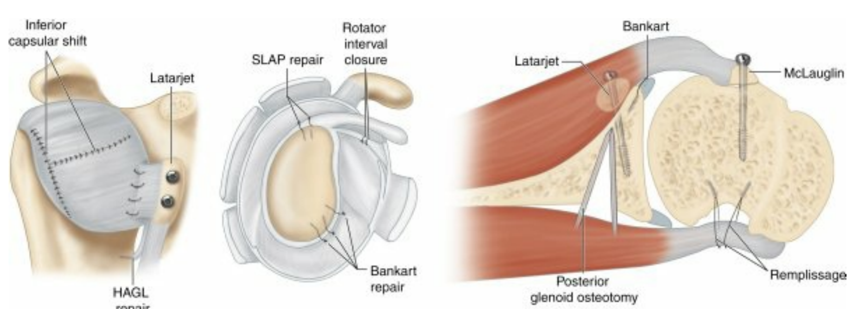


FIG. 4.44 Various surgical procedures for treatment of shoulder instability.

- Several smaller randomized controlled trials have demonstrated similar outcomes.

    - Mohtadi and colleagues, who performed the largest randomized trial to date, have shown equivalent patient quality-of-life scores but significantly higher redislocation rates in patients undergoing arthroscopic repair.

- In the patient undergoing a bony Bankart repair, the bone fragment should be incorporated into the repair.
- A Latarjet procedure should be considered when glenoid deficiency is more than 20%–25% of the glenoid width. The Latarjet procedure should also be considered for off-track lesions. It is also useful in a revision setting.
    - The mechanism of stabilization of the Latarjet is threefold: (1) sling effect from subscapularis and conjoint tendon, (2) bone block effect from the transferred coracoid, and (3) capsular repair effect of suturing the coracoacromial ligament to the capsule.
- Chronic dislocations with humeral articular deficiency greater than 40% should be treated with allograft in younger patients and hemiarthroplasty in older patients.
- Rotator interval closure results in decreased external rotation when the shoulder is in adduction and posteroinferior translation.
- *Remplissage,* which means “to fill” in French, involves tenodesis of the posterior capsule and infraspinatus into a Hill-Sachs lesion. Precise indications are not yet defined, but early evidence suggests medium to large or engaging Hill-Sachs lesions in older patients.
- Thermal capsular shrinkage is no longer recommended because of high rates of redislocation and the potential for capsular necrosis and subsequent capsular deficiency. Post-thermal capsular necrosis is treated with allograft anterior capsulolabral reconstruction.

- Postoperative rehabilitation
  - Following Bankart repair, the shoulder is typically immobilized for 3–6 weeks.
- Complications
  - Depend on the procedure
  - **Recurrent instability is the most common,** occurring in upwards of 10% of patients.
  - Infection and axillary nerve injury are other common complications of almost all instability procedures.
  - Dislocation arthropathy is a common late-occurring condition.
  - Complications of the Latarjet procedure include injury to the musculocutaneous nerve, fibrous union or nonunion of the coracoid, and screw breakage.

▪ **Posterior instability**

- Much less common than anterior instability
- May have traumatic or atraumatic causes
- Trauma to the arm in flexion, adduction, and internal rotation is the most common cause.
  - Typically the result of higher-energy trauma
  - Electric shocks and epileptic seizures are also frequent causes. These events result in **posterior dislocation because the stronger shoulder internal rotators** (latissimus dorsi, pectoralis major, subscapularis and teres major) overpower the weak external rotators (infraspinatus and teres minor).
- Weightlifters, football linemen, swimmers, and gymnasts are the most commonly affected athletes.
- Results of load-and-shift and jerk tests may be positive.
- Acute posterior dislocations are frequently missed.
- A fixed posterior shoulder dislocation is diagnosed from a **lack of external rotation.**
- Patients may present with their arms internally rotated and with observable coracoid and posterior prominence.
- AP radiographs are unreliable but may demonstrate a “lightbulb” sign. An axillary lateral radiograph is critical in making the diagnosis (Fig. 4.45).

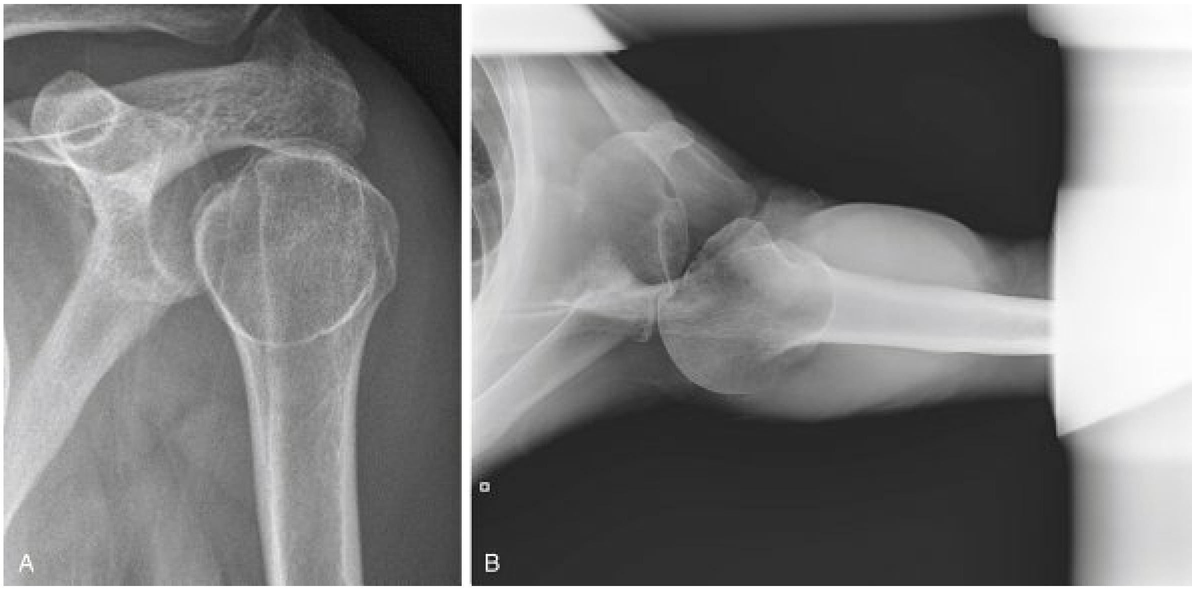


FIG. 4.45 Posterior shoulder dislocation. (A) AP radiograph demonstrating lightbulb sign, where humeral head is in the same axis as the shaft. (B) Axillary lateral radiograph showing posterior dislocation.

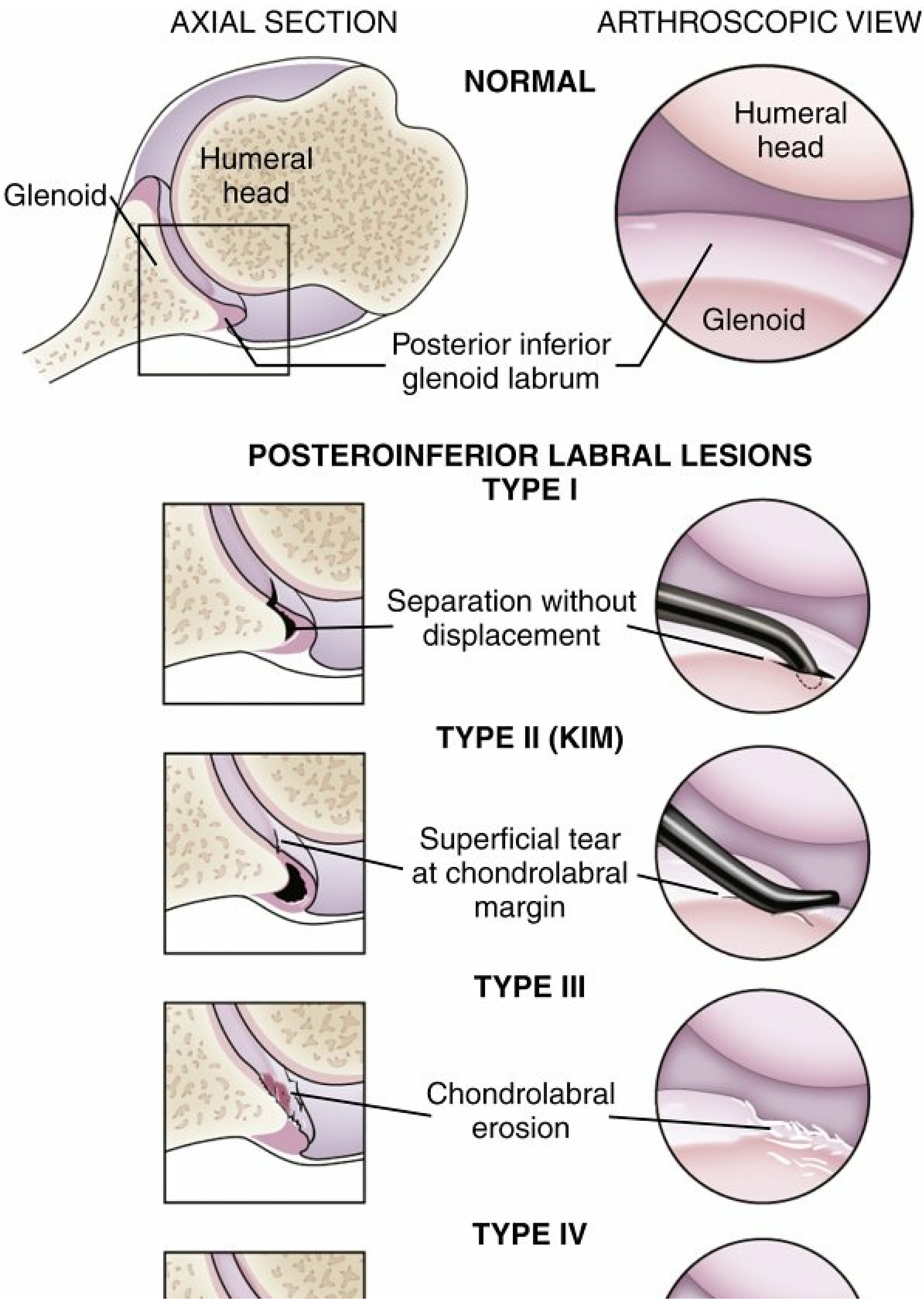
- When they are recognized, posterior dislocations respond well to acute reduction and immobilization.
- Rehabilitation focuses on rotator cuff and deltoid strengthening.
- Surgical intervention is typically performed only after rehabilitation has failed.
    - Patients with traumatic causes have been traditionally viewed as having a better prognosis following surgery.
    - The surgical procedure depends on the pathology. Posterior labral repair is most common.
    - Closure of the rotator interval may augment repairs.
    - Posterior glenoid version may be corrected with a posterior glenoid osteotomy.
- For chronic unrecognized posterior dislocations, several procedures may be performed, depending on the extent of bone loss in both the humeral head and the glenoid.
    - The Neer modification of the McLaughlin procedure involves transfer of the lesser tuberosity and associated subscapularis tendon into the reverse Hill-Sachs lesion.
    - Hemiarthroplasty or total shoulder arthroplasty is recommended when more than 35%–40% of articular humerus-side loss is present. Segmental reconstruction with allograft has initial promising results.
- A Kim lesion is an incomplete and concealed avulsion of the posteroinferior labrum (Fig. 4.46).
    - May be associated with posterior and multidirectional instability
    - The jerk (posterior lesion) and Kim (posteroinferior lesion) tests have been shown to be highly sensitive and specific.

- MR arthrography can be helpful in establishing the diagnosis, but findings may be subtle or falsely negative.
- After failure of conservative treatment, arthroscopic labroplasty (with a posterior capsular shift in primary posterior instability) or posterior labroplasty (with an inferior capsular shift and rotator interval closure when associated with multidirectional instability) has been effective.

- **Multidirectional instability (MDI)**
  - Represents the AMBRI spectrum of instability; fundamentally thought to be the result of capsular laxity, but scapular muscular dysfunction is also a critical portion.
  - Typically manifests as an insidious onset of pain and sensation of looseness about the shoulder. Traumatic onset is rare. May affect both shoulders; often occurs in gymnasts, swimmers, and volleyball players.
  - Physical examination reveals increased generalized laxity (Beighton criteria) and presence of the sulcus sign. The sulcus sign should reproduce the patient's symptoms. Scapular dyskinesis is common.
  - The focus of treatment is prolonged rehabilitation. This should focus on rotator cuff and deltoid strengthening, as well as correction of scapulothoracic mechanics.
  - If **6 months to 1 year of rehabilitation** has failed, inferior capsular shift or arthroscopic capsular plication is considered.
    - Five plication stitches are equivalent to an open capsular shift.

Subacromial Impingement Syndrome

- **An extremely common cause of shoulder pain**
- **Debate exists as to the etiology, but the syndrome likely represents a combination of extrinsic compression and intrinsic degeneration.**
  - Extrinsic compression is from the anterior acromion, the coracoacromial ligament, and the AC joint.


AXIAL SECTION
ARTHROSCOPIC VIEW
NORMAL
Humeral head
Glenoid
Humeral head
Glenoid
Posterior inferior glenoid labrum
POSTEROINFERIOR LABRAL LESIONS
TYPE I
Separation without displacement
TYPE II (KIM)
Superficial tear at chondrolabral margin
TYPE III
Chondrolabral erosion
TYPE IV

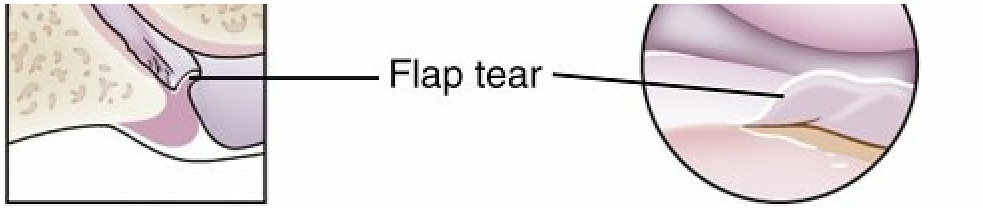


FIG. 4.46 Posterioinferior labral lesions. The Kim lesion is an incomplete and concealed avulsion of the posteroinferior labrum that may be associated with posterior and multidirectional instability.

- ▫ Intrinsic degeneration occurs in the supraspinatus, and the resultant weakness causes narrowing of the subacromial space and abutment of the rotator cuff against the acromion.
  - Histologically, tendinopathy is characterized by disorganized collagen fibers and mucoid degeneration. Inflammatory cells are typically absent.

- **Patients present with an insidious onset of pain that is worse with overhead activity and at night. Neer and Hawkins signs are present. Strength is normal.**
- **Outlet view radiographs may demonstrate a hooked acromion.**
- **Physical therapy, NSAIDs, and subacromial corticosteroid injections are the mainstays of treatment.**
- **Symptoms that do not respond to a minimum of 4–6 months of nonoperative treatment may respond favorably to subacromial decompression and acromioplasty.**
  - ▫ Exceptions to treatment with decompression include massive irreparable rotator cuff tears that may benefit from débridement, with preservation of the coracoacromial arch to prevent anterosuperior humeral migration.
  - ▫ Additional exceptions include the acute traumatic rotator cuff tear and injury in the overhead-movement athlete, who may benefit from limited acromial smoothing and bursectomy, which is required for visualization and limiting postoperative irritation of the repair site.
- **Patients with workers' compensation claims have poor subjective outcomes after subacromial decompression.**

Rotator Cuff Disease

- **Overview**
  - ▫ Rotator cuff disease is a continuum beginning with mild impingement and progressing through partial tear, full-thickness tear, and massive tear, to rotator cuff tear arthropathy.
  - ▫ Tears associated with chronic impingement syndrome typically begin on the bursal surface or within the tendon substance, in contrast to those that occur on the articular surface because of tension failure in younger athletes participating in overhead activities or owing to

intrinsic degeneration.

Bursa-side tears are considered more ominous (mnemonic: "Bursa is bad")

- ▫ A variety of types of rotator cuff tears exist (Fig. 4.47).
  - Full-thickness tears may have a crescent shape, U shape, L shape, or massive contracted pattern.
- ▫ The majority of tears involve the supraspinatus and infraspinatus.
- ▫ Subscapularis tears are discussed in the following section.
- ▫ DeOrio and Cofield classification is based on tear size:
  - **Small: less than 1 cm**
  - **Medium: 1–3 cm**
  - **Large: 3–5 cm**
  - **Massive: larger than 5 cm (two tendons)**
    - Classification does not predict prognosis
- ▫ As tears increase in size or in chronicity, the muscle atrophies and fatty infiltration occurs.

▪ **Epidemiology**

- ▫ 28% of patients older than 60 years, in contrast to 65% of those older than 70 years, have full-thickness tears.
- ▫ The patient older than 60 with a single rotator cuff tear has a 50% risk of having bilateral tears.
- ▫ The patient with a unilateral painful full-thickness tear has a 56% chance of having an asymptomatic contralateral full- or partial-thickness tear.
- ▫ Of those with asymptomatic tears, 50% experience symptoms in 3 years, and in 40% of the latter group, the tears may progress.

▪ **History and physical examination**

- ▫ Patients typically present with an insidious onset of pain exacerbated by overhead activities.
- ▫ Complaints of night discomfort, pain in the deltoid region, muscular weakness, and differences in active versus passive ROM are common; more significant weakness and loss of motion indicate a higher degree of cuff involvement.
- ▫ Acute pain and weakness may be seen after traumatic rotator cuff rupture.
- ▫ In young athletes, it is critical to confirm or exclude glenohumeral instability that causes a secondary impingement (nonoutlet impingement) from primary impingement syndrome (pathologic process within the subacromial space).
- ▫ Specific examination points for rotator cuff disease are listed in Table 4.7.

▪ **Imaging**

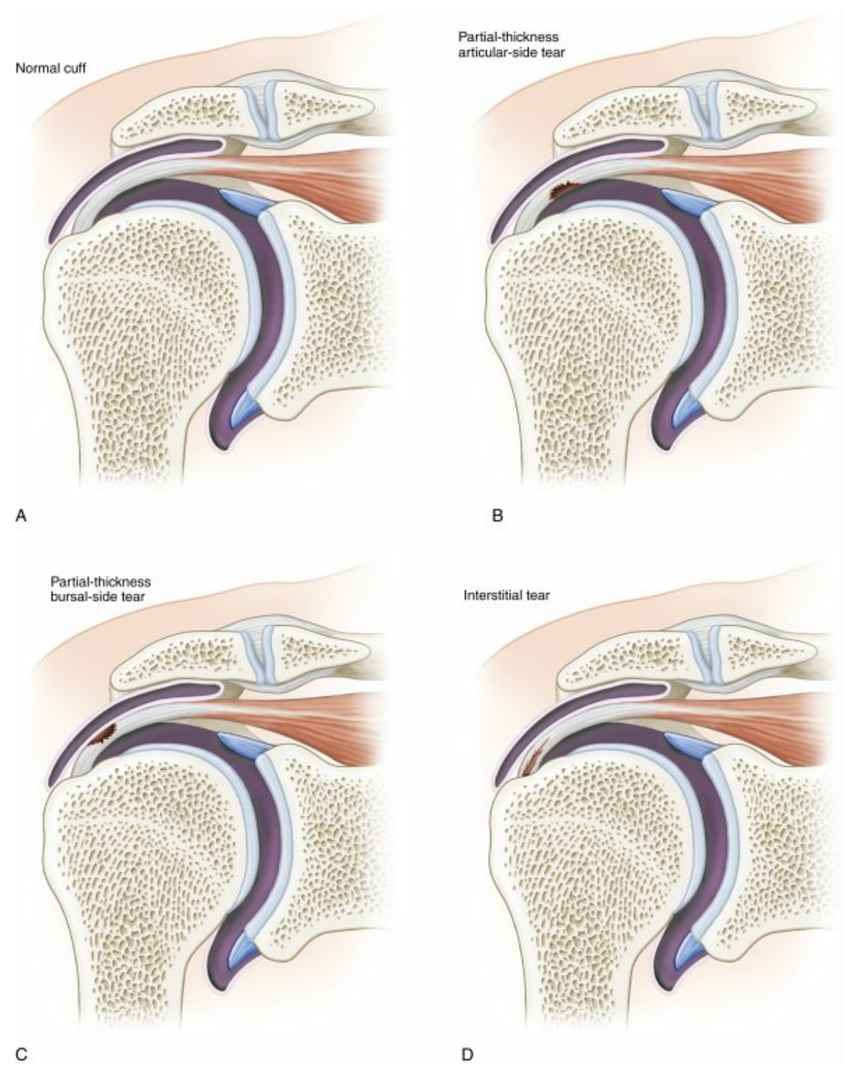
- ▫ May demonstrate classic changes within the acromion or coracoacromial ligament (spurring and calcification) in addition to cystic changes within the greater tuberosity

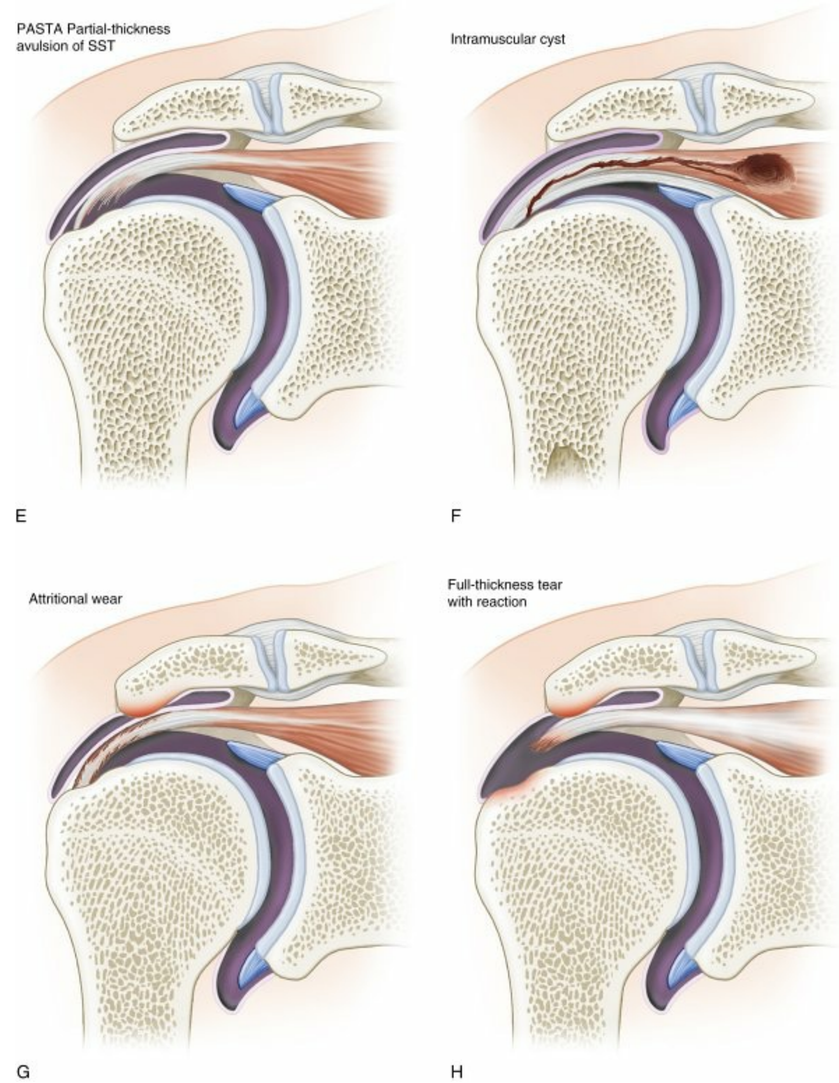
- With chronic rotator cuff disease, superior migration of the humeral head with extensive degenerative change may be present.
- Ultrasonography is increasing in popularity as a tool both for diagnosis of rotator cuff disease and for confirmation of intraarticular or subacromial location of injections.
- MRI is used to define the extent of tear, degree of tear retraction, and presence of muscular atrophy (Fig. 4.48).
  - MRI is key for evaluating fatty infiltration, although the Goutallier classification was originally based on CT.
    - The *tangent sign* is defined as failure of the supraspinatus muscle belly to cross a line from the superior border of the coracoid to the superior border of the scapular spine (Fig. 4.49).
      - It has been found to correlate with muscle atrophy and fatty infiltration of the supraspinatus. **Patients with the presence of tangent sign are more likely to have an irreparable rotator cuff tear.**

- **Treatment**
  - Nonoperative treatment
    - Asymptomatic full-thickness tears should be treated nonoperatively.
    - Indicated for noncompliant patients, elderly patients (>65 years), patients with medical contraindications to surgery or rotator cuff arthropathy, and athletes with a combined situation of instability and cuff tearing resulting from articular-side partial-thickness failure
    - Activity modification, avoidance of repeated forward flexion beyond 90 degrees, and an aggressive program for strengthening the rotator cuff and stabilizing the scapula are initiated.
    - In addition, oral antiinflammatory medications, therapeutic modalities, and judicious use of subacromial steroid injections may be implemented.
  - Operative treatment
    - Primary indication for surgical intervention is significant pain.
    - Chronic full-thickness tears that have failed to respond to nonoperative management may be treated surgically.
      - AAOS Clinical Practice Guidelines indicate only

weak evidence supporting surgical repair for such lesions.

- **Full-thickness acute tears should be repaired early because the disease process is accelerated in this setting.**
- Surgery reliably decreases pain and improves motion and function.
- Surgical techniques
  - The operative approach has evolved from a classic open approach to a "mini-open" or deltoid-sparing approach and now to an all-arthroscopic technique.
  - Regardless of the technique, the rate-limiting step for recovery is biologic healing of the rotator cuff tendon to the humerus, which is estimated to require a minimum of 8–12 weeks.
  - Routine acromioplasty is no longer recommended during rotator cuff repair.




PASTA Partial-thickness avulsion of SST
Intramuscular cyst
E
F
Attritional wear
Full-thickness tear with reaction
G
H

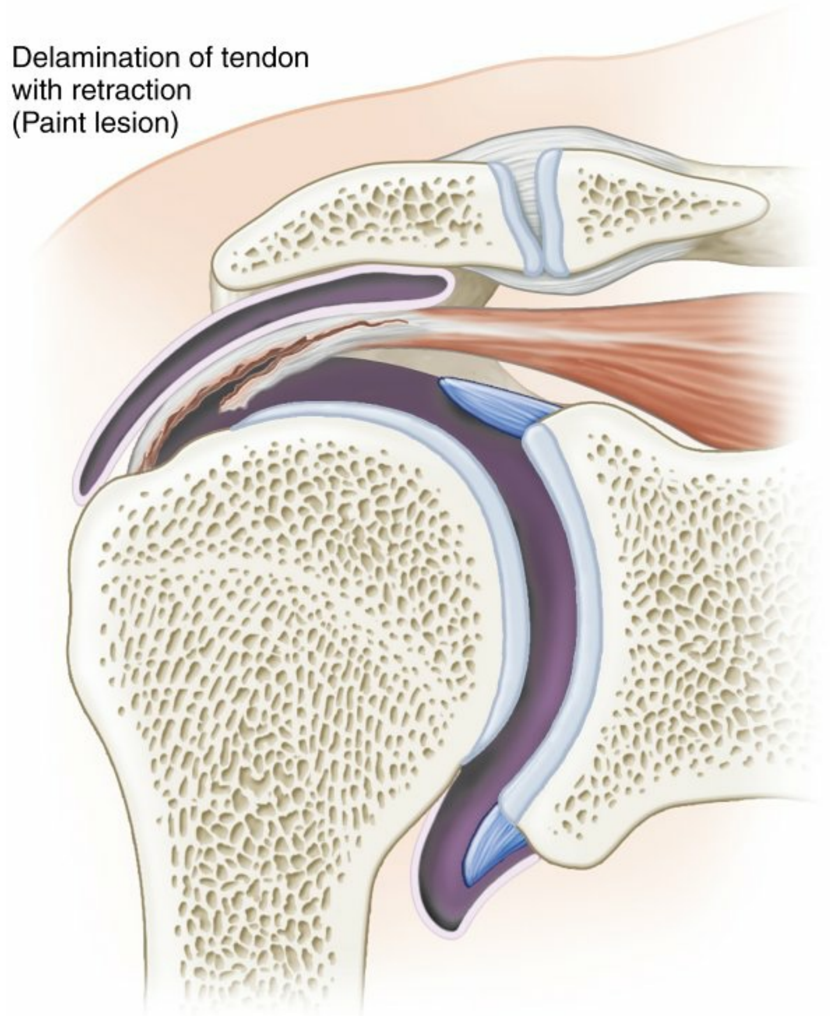


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FIG. 4.47 Patterns of rotator cuff tear. (A) Normal rotator cuff. (B) Partial-thickness articular-side tear. (C) Partial-thickness bursa-side tear. (D) Partial-thickness interstitial tear. (E) Partial-thickness articular surface supraspinatus avulsion (PASTA lesion). (F) Partial-thickness articular-side tear with intramuscular cyst. (G) Attritional fraying of the tendon. (H) Full-thickness tear with reaction. (I) Partial-thickness articular-side tear with delamination and retraction of the deeper fibers.

- Surgical techniques have evolved to include double-row and suture-bridge fixation techniques, which have improved biomechanical strength in vitro. Clinical correlation remains controversial.
- Blood flow to the repaired rotator cuff is achieved from the peribursal tissue and bone anchor site. Vascularity has been shown to increase with exercise.

▪ **Special situations**

□ Articular-side partial-thickness tears (e.g., partial articular supraspinatus tendon avulsion [PASTA]): whether these lesions should be treated with débridement or repair remains controversial. Tears in which more than 7 mm of bone lateral to the articular margin is exposed, which represents 50% of the tendon insertion, should be considered significant.

- Considerations include depth of the tear, pattern of the tear (avulsion versus degeneration), amount of footprint uncovered, and activity level of the patient.
- Patients with a preponderance of impingement findings and a tear of less than 50% thickness may benefit from débridement and subacromial decompression.

□ Large and massive tears

- The failure rate for repair is higher; tissue failure is most common.
- Irreparable tears are more likely to occur when the acromiohumeral distance appears shorter (<7 mm) on AP radiograph.
- Larger, more retracted tears (>40 mm length/width) are characterized by fatty atrophy, supraspinatus width of less than 5 mm at glenoid margin, and high signal in infraspinatus.
- Regardless of healing, most patients report clinical improvement following repair.

□ Irreparable tears

- Combined tears of supraspinatus and infraspinatus may be treated with latissimus dorsi tendon transfer to the greater tuberosity in patients younger than 65 years who do not have glenohumeral osteoarthritis.
- In patients in whom pain is the major symptom and motion remains preserved, débridement with biceps tenotomy has been found to be useful.
- There has now been enthusiasm for a procedure termed “superior capsular reconstruction” using either fascia lata autograft or allograft. Rigorous clinical outcome studies are still lacking.
- If pseudoparalysis and glenohumeral arthritis are present, a reverse total shoulder arthroplasty (RTSA) may be performed. RTSA is seeing more use in nonarthritic but irreparable rotator cuff tears; this indication remains controversial.
- Xenograft patches have not been found to be helpful.

▪ **Results**

□ Although excellent results have been reported with rotator cuff repair, a high percentage of such tears either do not heal completely or recur.

- The majority of failures occur within the first 3–6 months.
- Failure is typically caused by tissue pulling through the sutures.

□ Despite this outcome, functional and subjective results remain excellent. A correlation appears to exist between younger patient age and repair success.

□ Failure rates have been reported to be higher in patients with the following characteristics:

- Age 65 years or older
- Massive tear
- Moderate to severe muscle atrophy on T1-weighted oblique sagittal MRI
- >50% fatty infiltration of the involved rotator cuff muscle belly
- Tear retraction to the level of the glenoid
- Diabetes
- Smoking
- Inability to participate in rehabilitation

▪ **Rehabilitation**

□ Rehabilitation following rotator cuff repair is controversial.

□ Newer reports suggest no difference in clinical outcomes or healing rates between early motion and delayed motion protocols.

▪ **Complications**

□ Approximately 6%–8% of patients have continued pain and weakness after rotator cuff repair.

□ Ultrasonography is the imaging modality of choice for evaluation of a failed rotator cuff repair, but accuracy is highly technician dependent. MRI is also very helpful.

□ Revision repair should be performed in the symptomatic patient who is younger than 65 years and has no significant fatty atrophy, no significant tendon retraction, no glenohumeral arthritis, and no pseudoparalysis.

- A well-balanced partial repair is comparable to total repair.

□ Latissimus dorsi tendon transfer may be considered in the younger patient with massive rotator cuff tear or significant fatty atrophy.

□ An RTSA may be considered in an older patient with massive rotator cuff tear and other poor prognostic indicators for healing of a revision repair.

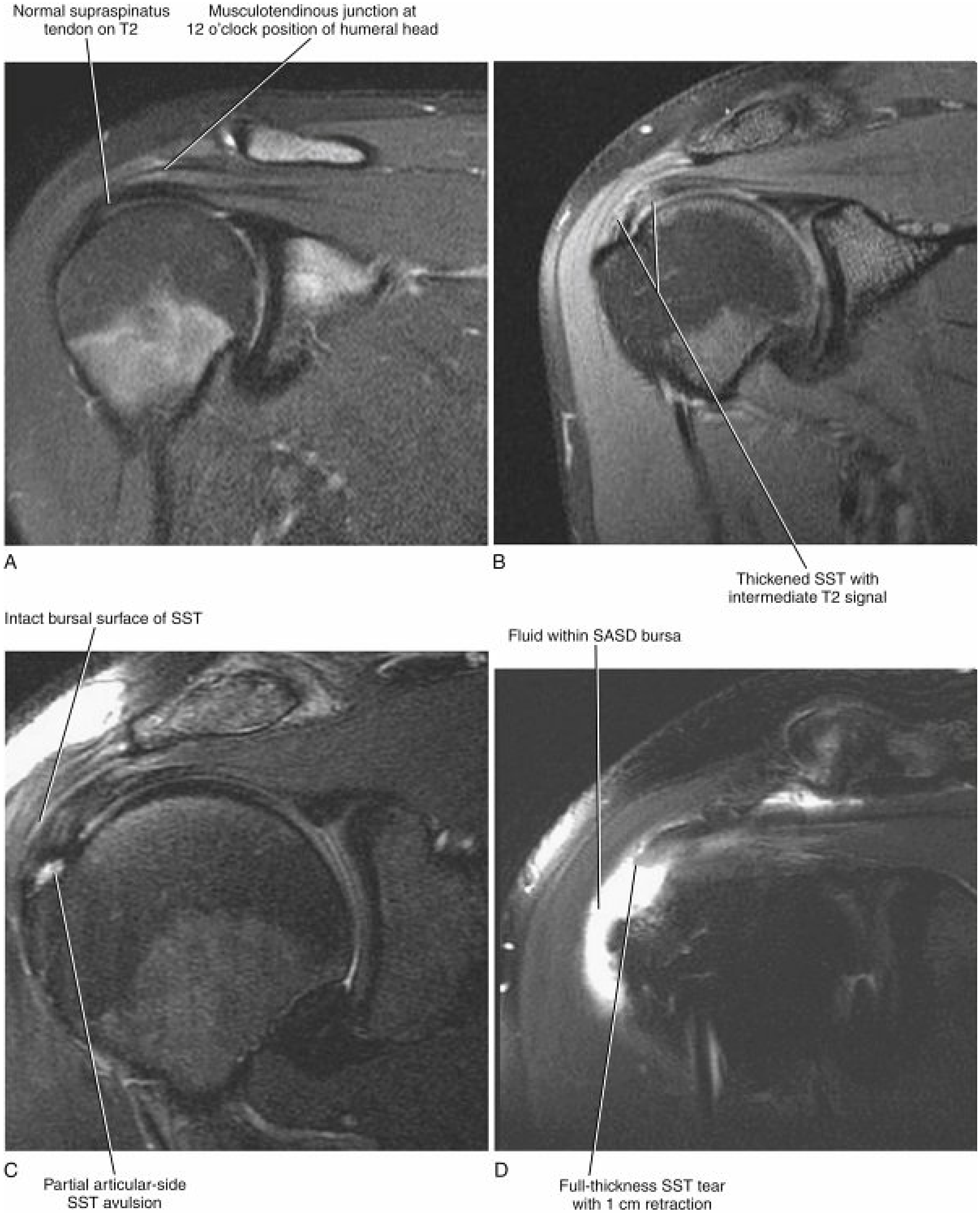


FIG. 4.48 Appearance of rotator cuff tears on MRI. (A) Normal. (B) Thickened supraspinatus tendon *(SST)*. (C) Partial SST avulsion. (D) Full-thickness SST tear with fluid within subacromial-subdeltoid *(SASD)* space.

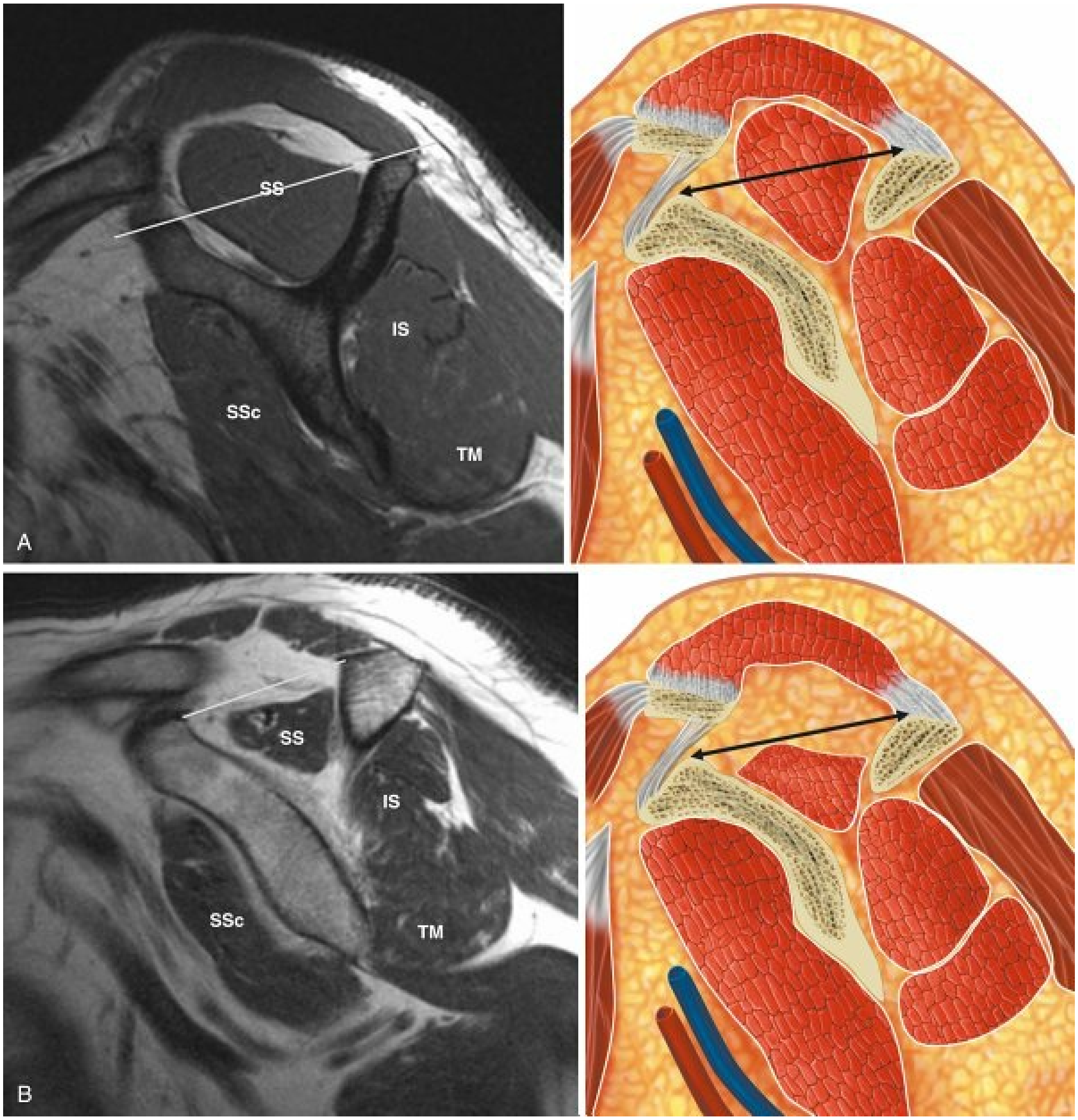


FIG. 4.49 MRI appearance and drawing of the tangent sign, defined as failure of the supraspinatus *(SS)* muscle belly to cross a line from the superior border of the coracoid to the superior border of the scapular spine (white line on MR images; double-headed arrow line on drawings). This finding correlates with muscular atrophy and fatty infiltration of the supraspinatus. (A) Normal. (B) Presence of tangent sign. *IS,* Infraspinatus; *SSc,* subscapularis; *TM,* teres minor.

Subscapularis Tears (Fig. 4.50)

- **May occur after anterior dislocation and anterior shoulder surgery (e.g., shoulder arthroplasty)**
- **Symptoms include increased external rotation and positive result of a liftoff, modified liftoff, bear-hug, or belly-press test.**
- **The appearance of an empty bicipital groove** on axial MRI, with tear of the transverse humeral ligament, is often associated with subscapularis tear (see Fig. 4.50).
- **At arthroscopy, a chronic subscapularis tear can be identified by the** *comma sign,* which represents an avulsed SGHL and CHL (so-called comma tissue).

▪ **Surgical treatment, either open or arthroscopic, is generally indicated; in chronic cases, a pectoralis transfer is occasionally required.**
  ◻ Transfer of the pectoralis major places the musculocutaneous nerve at risk.

Rotator Cuff Tear Arthropathy

▪ **Defined as a massive rotator cuff tear combined with fixed superior migration of the humeral head and severe glenohumeral arthrosis, presumably caused by chronic loss of the concavity-compression effect**

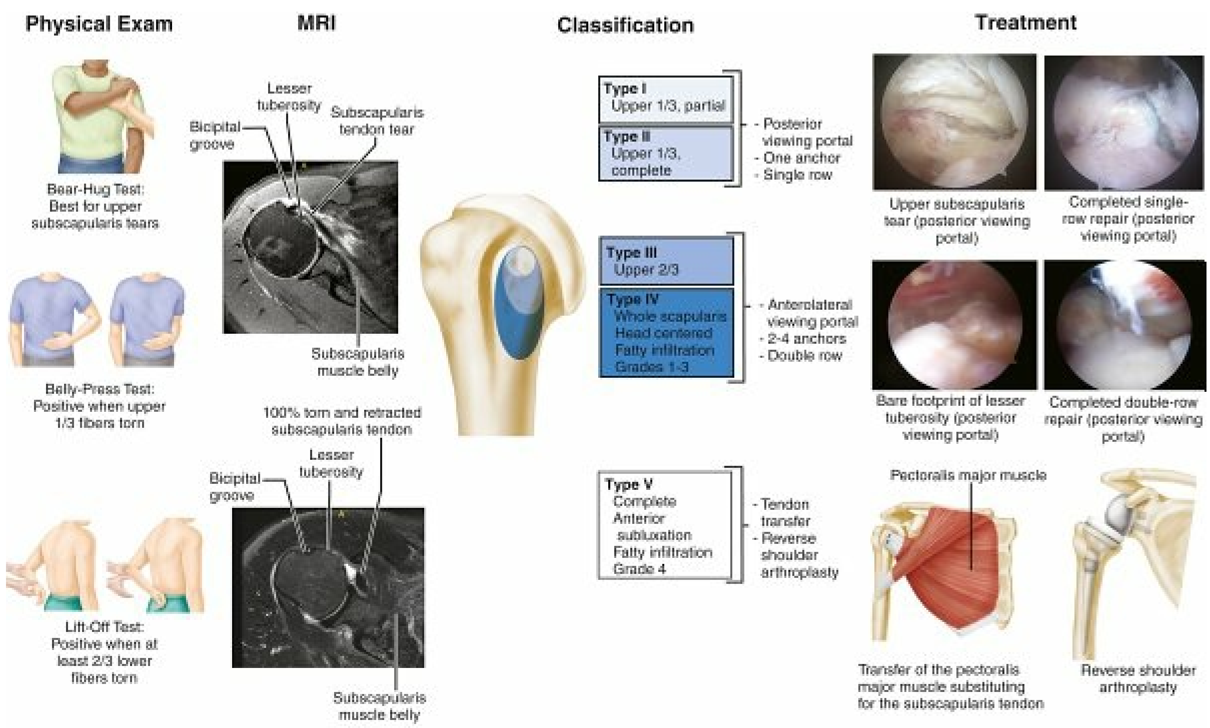


FIG. 4.50 Subscapularis tear. *Left,* Physical examination findings. *Middle left,* MRI findings. *Middle right,* Classification and treatment. *Right,* Arthroscopic images.

▪ **Tendon transfer (latissimus/teres) for younger, active patients has been advocated.**
  ◻ Inferior results have been reported for latissimus transfer in the presence of a subscapularis tear. The reason is a loss of the centering effect of the subscapularis on the humeral head during abduction and elevation.

▪ **With improvements in reverse shoulder replacements, hemiarthroplasty has largely fallen out of favor for this problem, although it can be helpful for pain relief.**

▪ **Use of an RTSA has become increasingly popular for treatment of rotator cuff arthropathy (see Shoulder Arthroplasty in Chapter 5).**
  ◻ It requires a competent deltoid and good glenoid bone stock.
  ◻ It has traditionally been recommended only for older patients

(typically >70 years) with low functional demands, but newer literature supports its use in younger patients (55 years or older).
  - More predictable functional results are seen with the reverse prosthesis than with hemiarthroplasty.
  - Complication rates were traditionally considered to be high (40%), but in modern studies such rates are nearly equivalent to those of anatomic shoulder arthroplasty.

Subcoracoid Impingement

- **The patient with a long or excessively laterally placed coracoid process may have impingement of this process on the proximal humerus with forward flexion (120–130 degrees) and internal rotation of the arm.**
- **It may occur after surgery that causes posterior capsular tightness and loss of internal rotation.**
- **Local anesthetic injection should relieve the symptoms.**
- **CT performed with the arms crossed on the chest is helpful in evaluating this problem.**
- **A distance of less than 7 mm between the humerus and coracoid process is considered abnormal.**
- **Treatment of chronic symptoms involves resection of the lateral aspect of the coracoid process and reattachment of the conjoined tendon to the remaining coracoid.**
- **Arthroscopic coracoplasty has also been successful in treating subcoracoid impingement without detachment of the conjoined muscle group.**

Internal Impingement

- **Defined as contact between the articular side of the rotator cuff and the posterosuperior rim of the glenoid labrum when the arm is abducted and externally rotated**
  - Occurs in the late cocking and early acceleration phases of throwing
  - Etiology somewhat controversial
  - Alteration in glenohumeral kinematics results in posterosuperior shift of the humeral head; abduction and external rotation of the arm, in turn, lead to internal impingement.
  - It is often associated with GIRD secondary to a tight posteroinferior capsule. (See discussion of throwing in Biomechanics part of this section.)
  - This may cause pain associated with **SLAP/biceps anchor disease as well as with undersurface rotator cuff tears of the posterior aspect of the supraspinatus and infraspinatus tendons.**

▪ **Manifests as pain in the late cocking phase of throwing and associated loss of velocity and lack of command**

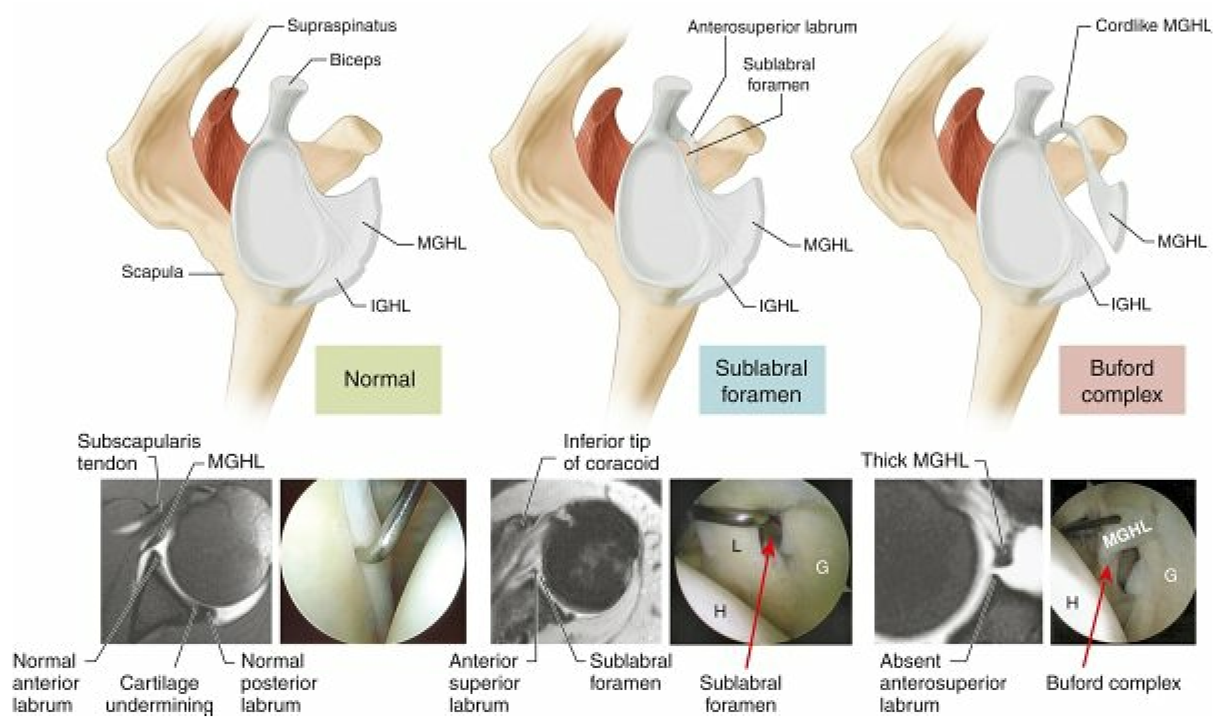


FIG. 4.51 Common anterior labral variations, with MRI and arthroscopic correlations. *G,* Glenoid; *H,* humerus; *L,* labrum.

▪ **Bennett lesion (mineralization of the posterior inferior glenoid) is occasionally seen on radiographs or CT.**

▪ **Diagnosis can be aided with MR arthrography.**
  - □ An ABER view may show the internal impingement and associated lesions.

▪ **Treatment**
  - □ Primary treatment should consist of physical therapy and avoidance of aggravating activities.
  - □ Patients with GIRD may benefit from posterior and posteroinferior capsular stretching exercises such as the sleeper stretch, as well as stretching of the pectoralis minor tendon.
  - □ Operative treatment includes arthroscopic débridement or repair of the labrum, with débridement of the undersurface rotator cuff lesion.
    - • A peel-back phenomenon of the superior labrum can be appreciated intraoperatively with abduction and external rotation of the arm.
  - □ Some authorities suggest repairing the rotator cuff if it is significantly thinned either by a transtendinous technique or by removal of the remaining thinned cuff and advancement of the unaffected normal tendon.
  - □ A posterior capsular release can be considered in patients who have GIRD and in whom nonoperative stretching has not caused

improvement.

Slap Tears

- **Introduction**
  - SLAP tears are uncommon, accounting for approximately 5% of all shoulder injuries.
  - The superior labrum is more loosely adherent to the glenoid than the anterior-inferior labrum, typically attaching more medially, off the glenoid face.
  - Biceps tendon insertion into the superior labrum is complex.
    - 50% of tendon fibers insert to superior labrum
    - 50% insert to supraglenoid tubercle
      - 6.6 mm from the glenoid face at the 12-o'clock position
  - A variety of anatomic variations occur at the superior labrum and may be mistaken for pathology (Fig. 4.51).
    - Three most common are a sublabral foramen, sublabral foramen with a thickened mGHL (9% of shoulders), and the *Buford complex*, defined as absence of the anterosuperior labrum with a thickened mGHL (1.5% of shoulders).
    - Attempted repair with attachment of the MGHL to the glenoid rim may result in limited shoulder external rotation.
  - The original Snyder classification is most commonly used and has been expanded from four types to many more (Fig. 4.52; Table 4.10).
    - **Type II is the most common** (IIA is anterior, IIB is posterior, IIC is anterior and posterior [mnemonic, ABC: *a*nterior, *b*ack, *c*ombined]).
- **History and physical examination**
  - May be traumatic or onset of pain and mechanical symptoms may be insidious
    - Traction, compression, or repetitive overhead throwing mechanism
  - No single physical examination maneuver is specific for SLAP tear.
    - O'Brien test, compression-rotation test, Speed test, dynamic labral shear test, Kibler anterior slide test, crank test, and Kim biceps load test (see Table 4.7)
- **Imaging**
  - MR arthrography is the modality of choice.

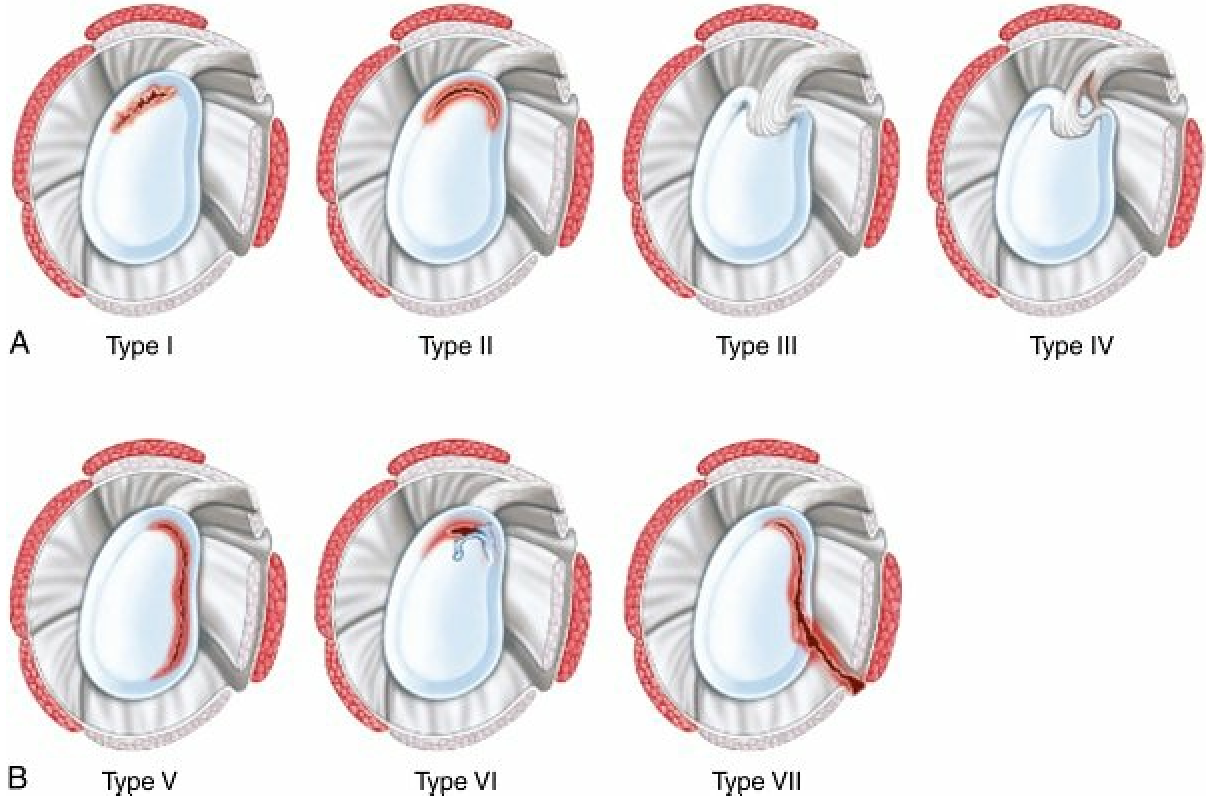


FIG. 4.52 Expanded Snyder classification of SLAP tears. (A) Types I to IV. (B) Types V to VII. (From Kepler CK et al: Superior labral tear. In Reider B et al, editors: *Operative techniques: sports medicine surgery,* Philadelphia, 2009, Saunders Elsevier.)

Table 4.10

Classification and Treatment of SLAP Tears

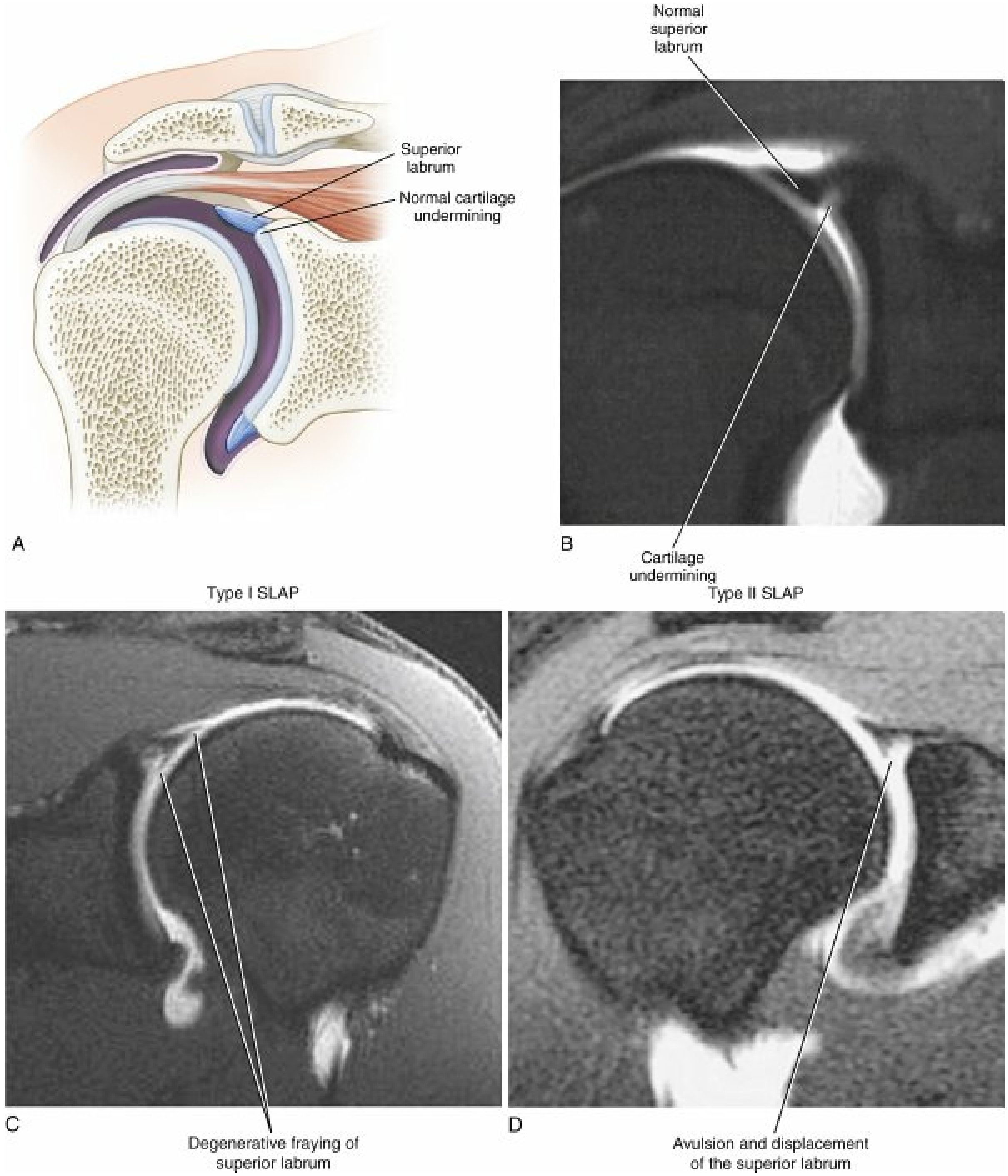
Type	Description	Treatment
I	Biceps fraying, intact anchor on superior labrum	Arthroscopic débridement
II	Detachment of biceps anchor	Repair versus tenotomy/tenodesis
III	Bucket-handle superior labral tear; biceps intact	Arthroscopic débridement
IV	Bucket-handle tear of superior labrum into biceps	<30% of tendon involved: débridement >30% of tendon involved: repair or débridement and/or tenodesis of tendon
V	Labral tear + SLAP lesion	Stabilization of both
VI	Superior flap tear	Débridement
VII	Capsular injury + SLAP lesion	Repair and stabilization

- Diagnosed either from abnormal morphology of the superior labrum or from increased signal in the substance or under the superior labrum (Fig. 4.53)
  - Signal that appears irregular and extends lateral to the glenoid or posterior to the biceps tendon is suggestive of a

SLAP tear.

- A paralabral cyst is indicative of a SLAP tear (or posterior labral tear).
    - Cyst may extend to **spinoglenoid notch** and compress the suprascapular nerve, leading to **infraspinatus wasting.**

- **Treatment (see** Table 4.10)
    - Highly controversial, particularly regarding type II lesions
    - Nonoperative management
        - Should be attempted in virtually all patients
        - Rotator cuff strengthening and scapular stabilization
        - Throwers benefit from stretching of the posterior capsule.
        - Intraarticular injections
    - Operative management
        - Arthroscopy may demonstrate a peel-back phenomenon whereby the posterosuperior labrum detaches in abduction and external rotation (the late cocking phase).
        - Surgical technique is dictated by the type of SLAP tear.
        - Controversy exists regarding repair versus tenotomy/tenodesis of type II lesions.
            - Some consensus that patients older than 40 years with obvious biceps pathology and degenerative labral changes are best treated with débridement and tenotomy/tenodesis
        - If repair is chosen, there is conflicting biomechanical evidence to favor one repair technique over another.
        - For patient with concomitant rotator cuff tear, later studies have found no advantage to repairing SLAP lesion at the time of rotator cuff repair; SLAP repair may result in increased stiffness.
        - Newer studies have suggested that biceps tenotomy/tenodesis should be performed at the time of rotator cuff repair.
    - Postoperative rehabilitation
        - Relatively high incidence of postoperative stiffness, so motion is begun early. Pendulum exercises are initiated immediately.
        - Both resistive biceps exercises and external rotation with the arm in 90 degrees of abduction should be avoided.
    - Complications



Superior labrum
Normal cartilage undermining
A
Normal superior labrum
B
Cartilage undermining
Type I SLAP
Type II SLAP
C
Degenerative fraying of superior labrum
D
Avulsion and displacement of the superior labrum

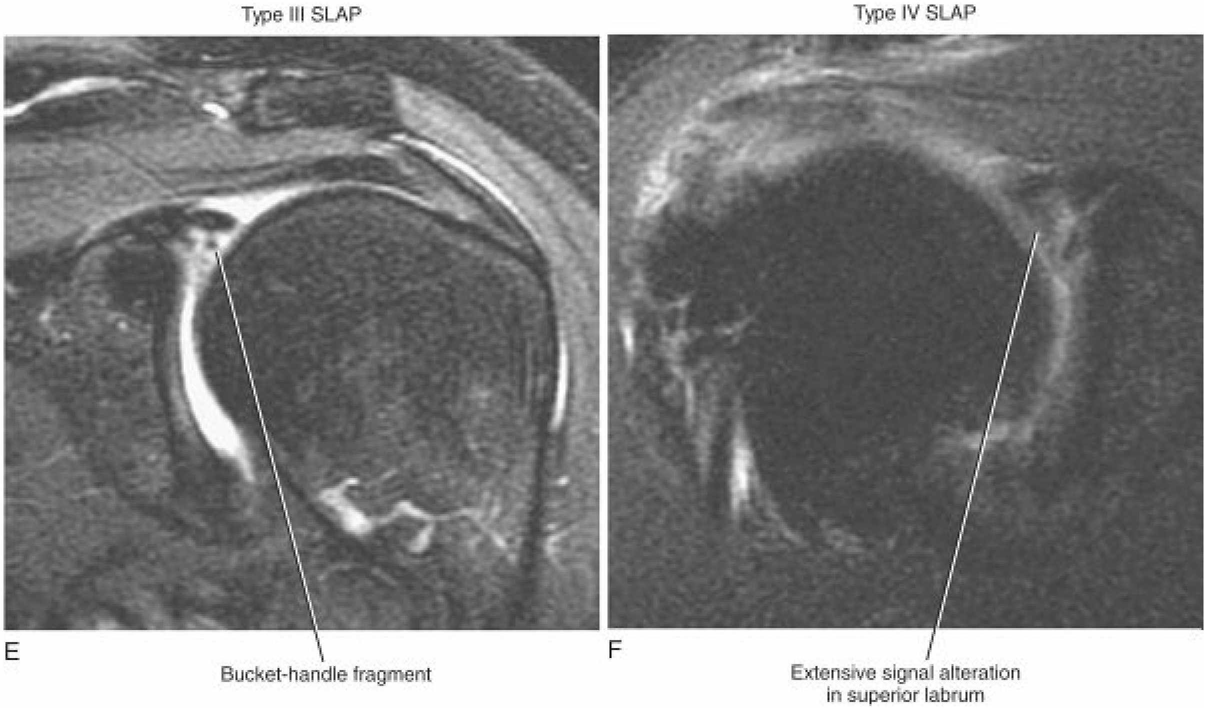


FIG. 4.53 Appearance of SLAP tears on MRI. (A and B) Normal anatomy, drawing and MRI. (C) Type I. (D) Type II. (E) Type III. (F) Type IV.

- Stiffness is common after SLAP repair. One study demonstrated a 78% rate of stiffness.
    - Stiffness should be initially managed with physical therapy. If symptoms persist, arthroscopic capsular release may be performed.
- Persistent symptoms, articular cartilage injury, and loose or prominent hardware are other frequent complications following SLAP repair.

Proximal Biceps Tendon Pathology

- **Biceps tendinitis**
    - Often associated with impingement, rotator cuff tears (subscapularis and leading-edge supraspinatus tears), and stenosis of the bicipital groove
    - Like most other cases of "tendinitis," this is probably best considered a tendinosis.
    - Diagnosis is made by direct palpation with the arm externally rotated 10 degrees, and confirmed with a resisted throwing test, Speed test, and/or Yergason test
    - Initial management includes strengthening exercises and local corticosteroid injection into the biceps sheath.
    - Surgical release (with or without tenodesis) is usually reserved for refractory cases.
    - Tenotomy without tenodesis is associated with subjective cramping

and potential for cosmetic deformity ("Popeye deformity"). Weakness is not associated with tenotomy.
    - Tenodesis may result in "groove pain" if the technique of the tenodesis retains a portion of the tendon in the intertubercular groove. A subpectoral tenodesis technique reduces the risk of groove pain.
- **Biceps tendon subluxation**
    - Most commonly associated with a partial or complete subscapularis tear (Fig. 4.54)
        - Tear of the CHL or transverse humeral ligament may produce tendon subluxation as well.
    - Arm abduction and external rotation may produce a palpable click as the tendon subluxates or dislocates outside the groove.
    - Nonoperative treatment is similar to that for tendinitis, whereas operative treatment includes repair of the subscapularis and supporting structures of the bicipital groove but more often involves tenotomy or tenodesis with or without a subscapularis repair.

Acromioclavicular and Sternoclavicular Injuries

- **Acromioclavicular separation**
    - Overview
        - These injuries are typically caused by a direct blow to the shoulder, are common athletic injuries, and can be classified into six types (Fig. 4.55 and Table 4.11).
        - A Zanca view is obtained to visualize the AC joint. The x-ray beam is directed 10 degrees cephalad at 50% of normal penetrance (see Table 4.6).
        - **Type V injury** is defined by a coracoclavicular distance that is **100% greater than** that of the opposite side (bilateral acromioclavicular views are required).
        - Type IV injury can be diagnosed on only an axillary lateral view.
    - Conservative management
        - A brief period of immobilization followed by rehabilitation is appropriate for types I, II, and many cases of type III.
    - Treatment of type III injuries
        - Management of type III injuries is somewhat controversial; most authorities advocate conservative treatment, especially in elderly patients, inactive patients, or patients who do not perform manual labor. Some authorities advocate surgical reduction and repair or reconstruction.
        - The literature suggests that the need for reoperation is

higher among patients treated immediately with surgery than among those who undergo primary surgery after initial nonoperative treatment.

- Management of types IV through VI injuries
  - These are typically treated surgically.
- Surgical treatment for failure of conservative treatment or acute treatment
  - Reconstruction of the coracoclavicular ligament with a free soft tissue graft is becoming popular to allow for an anatomic reconstruction. Excessive medialization of the clavicular tunnels has been associated with a higher rate of failure.
  - The coracoid tunnel technique is associated with a risk of coracoid fracture.

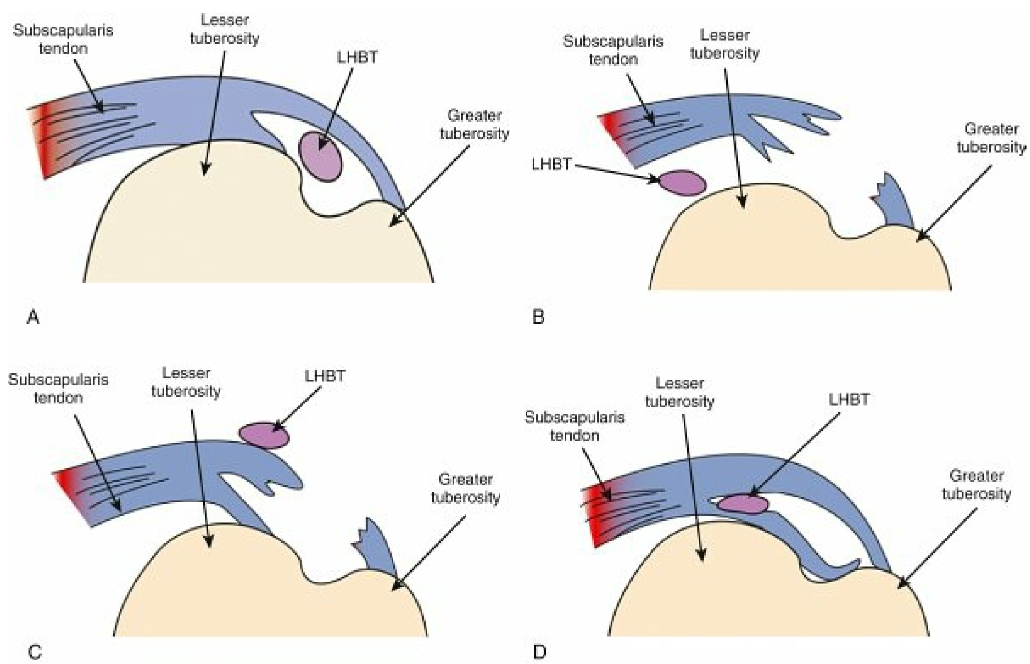


FIG. 4.54 Patterns of medial subluxation of the long head of biceps tendon (LHBT). (A) Normal position of the LHBT in the intertubercular groove. (B) Disruption or avulsion of the deep fibers of the subscapularis tendon off the lesser tuberosity in conjunction with disruption of the CHL allows intraarticular subluxation of the LHBT. (C) Disruption of the transverse humeral ligament and the CHL allows extraarticular medial subluxation of the LHBT. (D) Disruption of the CHL with an intact subscapularis tendon allows the LHBT to sublux medially into the substance of the subscapularis tendon, resulting in an interstitial tear of the subscapularis tendon and muscle.

  - The distal clavicle is often resected in patients with chronic separation, and the coracoacromial ligament may then be transferred to the distal clavicle (modified Weaver-Dunn procedure).
  - Backup coracoclavicular stabilization is usually required for a

successful outcome.

- **Acromioclavicular degenerative joint disease**
  - As a result of the transmission of large loads through a small surface area, the AC joint may begin to degenerate as early as the second decade of life.
  - In addition, direct blows or low-grade AC separation may cause posttraumatic arthritis.
  - Diagnosed by direct palpation; other diagnostic features are pain elicited by crossed-chest adduction, radiographic evidence of osteophytes and joint space narrowing, and pain relief with selective AC joint injection.
  - Treatment includes both open and arthroscopic distal clavicle resections (Mumford procedure) with resection of less than 1 cm of the distal clavicle to preserve the posterior-superior capsule and avoid anterior and posterior instability and pain.
  - Arthroscopic excision has the advantage of allowing evaluation of the glenohumeral joint at time of surgery.
- **Distal clavicle osteolysis**
  - Common in weightlifters and in persons with a history of traumatic injury
  - Radiographs of the distal clavicle reveal osteopenia, osteolysis, tapering, and cystic changes.
  - After failure of selective corticosteroid injection, NSAIDs, and activity modification, this condition responds favorably to distal clavicle excision.
- **Sternoclavicular subluxation and dislocation**
  - Often caused by motor vehicle accidents or direct trauma but can be spontaneous and atraumatic during overhead elevation of the arm
  - The posterior capsule is the most important anatomic restraint for anteroposterior translation.
  - Plain imaging includes the Hobbs and serendipity views; best diagnosed on CT.
  - Closed reduction is often successful.
    - Anterior dislocation should first be treated with acute closed reduction.
      - Often unsuccessful. Treatment is then observation.
    - Posterior dislocation should be treated with closed reduction and open reduction if necessary, particularly with compression of the posterior structures. Consultation with a cardiothoracic surgeon may be appropriate.
  - Use of **hardware should be avoided** whenever possible.
  - Failures of reduction and chronic dislocation are treated conservatively.

Muscle Ruptures

- **Pectoralis major**
  - Injury to the pectoralis major muscle is caused by excessive tension on a maximally eccentrically contracted muscle; often found in weightlifters.

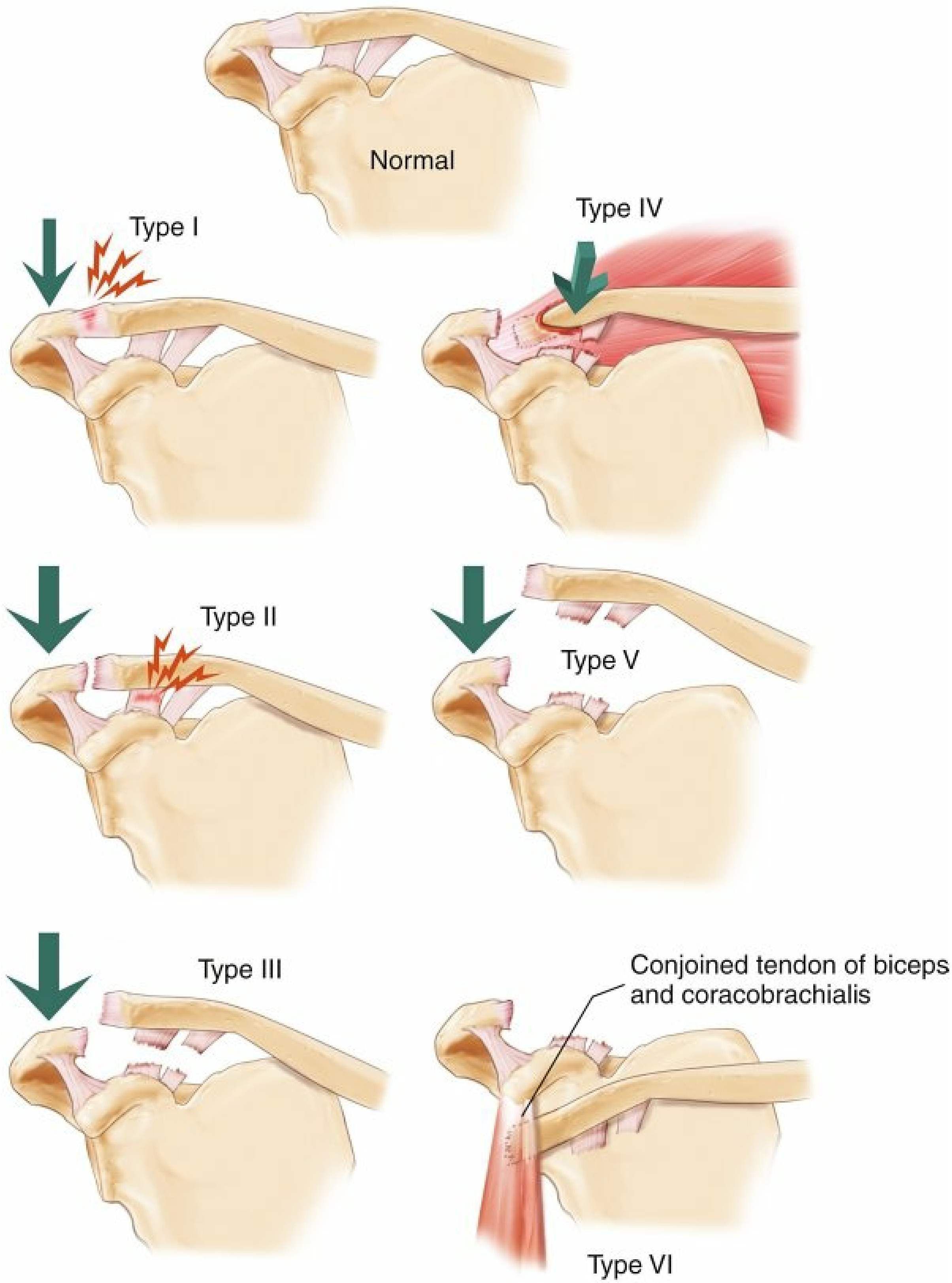


FIG. 4.55 Rockwood classification of acromioclavicular separations.

Table 4.11

Acromioclavicular Joint Injury Patterns and Management

Type	AC Ligament Injury	CC Ligament Injury	Deltotrapezial Fascia	Clinical FINDINGS	Radiographic Findings	Treatment

I	Intact	Intact	Intact	AC tenderness	Normal	Nonoperative
II	Ruptured	Intact	Intact	Pain with motion; clavicle is unstable in horizontal plane	Lateral end of clavicle is slightly elevated; stress views show <100% separation	Nonoperative
III	Ruptured	Ruptured	Mild injury	Clavicle is unstable in both horizontal and vertical planes, extremity is adducted, and acromion is depressed relative to clavicle	Plain films and stress radiographs are abnormal—show 100% separation; in reality, acromion and upper extremity are displaced inferior to lateral clavicle	Nonoperative; operative treatment should be considered if overhead-movement athlete or heavy laborer
IV	Ruptured	Ruptured	Injured as clavicle is posteriorly displaced	Possible skin tenting and posterior fullness	Clavicle is displaced posteriorly on axillary view	Operative
V	Ruptured	Ruptured	Injured and stripped off clavicle	More severe type III injury; shoulder with severe droop; type III injury if shoulder shrug does not reduce it	100%–300% increase in clavicle-acromion distance	Operative
VI	Ruptured	Ruptured	Possible injury	Rare inferior dislocation of distal clavicle; accompanied by other severe injuries; transient paresthesias	Clavicle is lodged behind intact conjoined tendon	Operative

Modified from Miller MS, Thompson SR: *DeLee and Drez's orthopaedic sports medicine,* ed 4, Philadelphia, Saunders, 2014, Table 60-2.

- Most commonly results in a tendinous avulsion
- Localized swelling and ecchymosis, a palpable defect (**axillary webbing**), and weakness with adduction and internal rotation are characteristic findings.
- Surgical repair to bone is performed in complete ruptures. Partial ruptures may be treated nonoperatively. Myotendinous tears should be treated conservatively.
- Pectoralis major ruptures are infrequently reported in women.

- **Deltoid**
  - Complete rupture of the deltoid muscle is unusual; injuries are most often strains or partial tears.
  - Repair to bone is required for complete ruptures.
  - Iatrogenic injury occasionally occurs during open rotator cuff repair; some patients require deltoidplasty, which consists of mobilization and anterior transfer of the middle third of the deltoid; unfortunately, this procedure is not always possible or successful.
- **Triceps**
  - Ruptures of the triceps are most often associated with sporting activities, systemic illness (e.g., renal osteodystrophy), and steroid use.
  - Primary repair of avulsions is indicated.
- **Latissimus dorsi rupture**
  - Rupture of the latissimus dorsi is a very rare condition manifesting as local tenderness and pain with shoulder adduction and internal rotation.
  - Although nonoperative treatment may allow resumption of activities, operative repair has been described for high-demand athletes.
- **Calcific tendinitis**
  - A self-limiting condition of unknown origin that affects predominantly the supraspinatus tendon and occurs slightly more frequently in women.
    - Not related to a generalized disease process
  - Calcium is deposited in the fibrocartilaginous matrix of the tendon as calcium carbonate apatite.
  - Three stages have been elucidated: precalcific, calcific, and postcalcific. Calcific stage is subdivided into formative and resorptive phases.
    - Resorptive phase is associated with acute, sudden onset of extremely severe pain.
  - Radiographs demonstrate characteristic calcification within the tendon (Fig. 4.56).
  - Nonoperative treatment is the rule, consisting of physical therapy, therapeutic modalities, and injections.
  - “Needling and lavage” of the lesion under image guidance has been described and is often successful.

- Arthroscopic or open removal of the deposit is occasionally necessary.
- The rotator cuff should be repaired if it is significantly involved.

Shoulder Stiffness

- **A stiff shoulder may be posttraumatic, postsurgical, or the result of adhesive capsulitis.**
  - Posttraumatic or postsurgical stiffness results from excessive scar formation.
  - Motion loss is related to the area of surgery or trauma and may involve the humeroscapular motion interface between the proximal humerus and overlying deltoid and conjoined tendon, as well as contracture of the rotator cuff and capsule.
  - Initial nonoperative management is the rule.

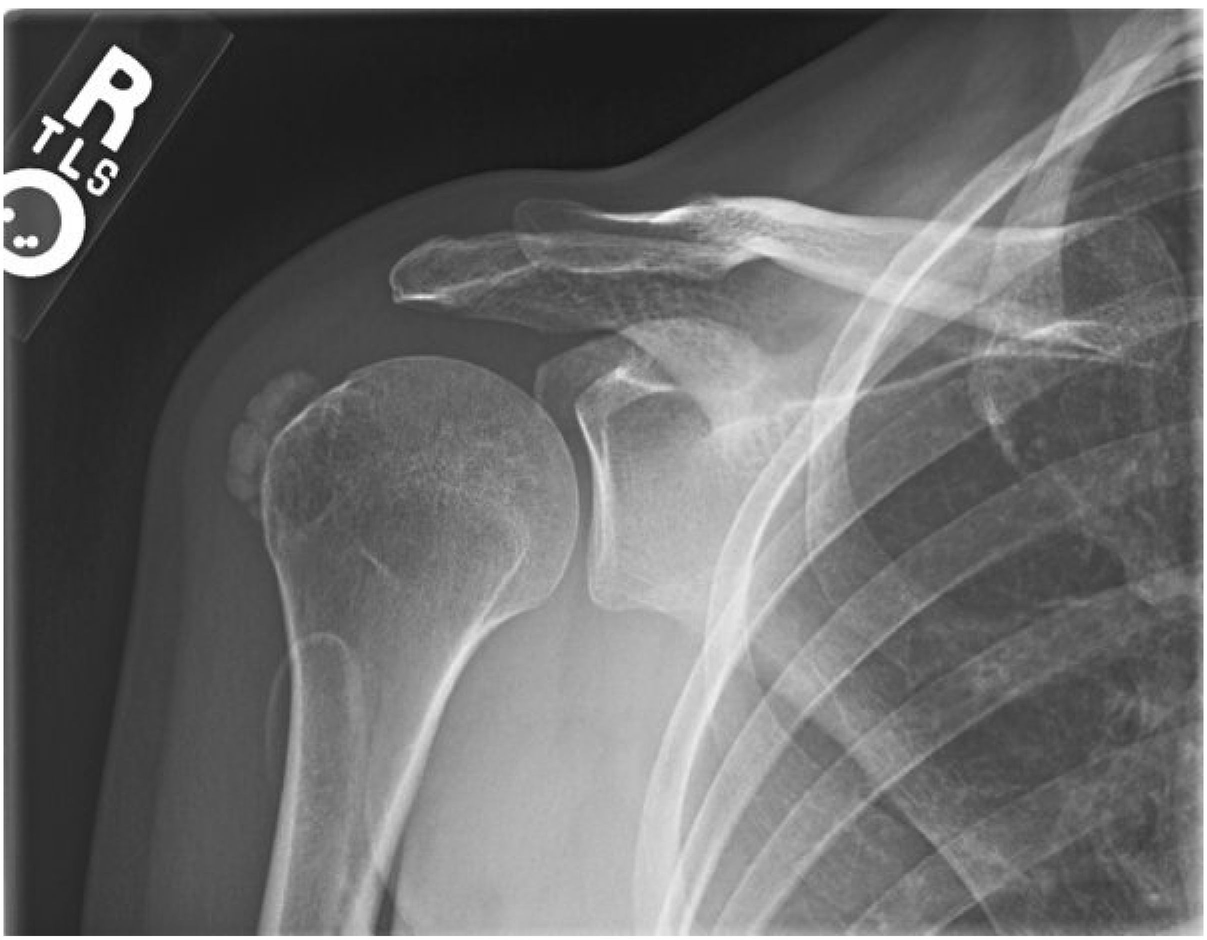


FIG. 4.56 Radiographic appearance of calcific tendinitis.

  - Prolonged posttraumatic shoulder stiffness is unlikely to respond to nonsurgical treatment, and a manipulation under anesthesia and open or arthroscopic lysis of adhesions may be performed.
- **Frozen shoulder**
  - Frozen shoulder (also known as *adhesive capsulitis*) is characterized by pain and restricted glenohumeral joint motion, especially external

rotation.

- Typically affects individuals aged 40 to 70 years. The nondominant side is more frequently affected. Female sex is more common.
- The majority of cases are idiopathic. Patients with diabetes or thyroid disease are disproportionally affected. Other associations are trauma after chest or breast surgery and prolonged immobilization.
- The essential lesion involves the CHL and the rotator interval capsule.
- Histologically there is evidence of inflammation and fibrosis. There is a dense matrix of type III collagen containing fibroblasts and myofibroblasts that appear similar to findings in Dupuytren disease.
- Diagnosis is clinical, typically an insidious onset of pain followed by selective loss of external rotation. In later stages, global ROM loss occurs. Classically, active ROM and passive ROM are equivalent.
- Two other causes of selective loss of external rotation are glenohumeral osteoarthritis and a locked posterior shoulder dislocation. For this reason, radiographs must be obtained before a diagnosis of frozen shoulder is made.
- Arthrography may demonstrate a **loss of the normal axillary recess**, revealing contracture of the joint capsule.
- MRI may show thickening of the glenohumeral joint capsule along the axillary pouch, thickening of the CHL, obliteration of the subcoracoid fat triangle, and rotator interval synovitis. However, none of these findings is pathognomonic.
- Overwhelmingly the majority of cases of frozen shoulder may be treated nonoperatively. Approximately 90% respond to physical therapy, corticosteroid injection, and NSAIDs. Occasionally, distention arthrography is employed.
- Patients in whom 12–16 weeks of nonsurgical treatment fail are offered arthroscopic capsular release.
    - This procedure places the axillary nerve at risk.
    - Selective capsular release versus complete capsular release techniques are employed.

Nerve Disorders

- **Brachial plexus injury**
    - Minor traction and compression injuries, commonly known by football players as “burners” or “stingers,” can be serious if they are recurrent or persist for more than a short time.
        - Must be unilateral; bilateral stingers raise concern for possible cervical spinal cord or nerve root pathology.
    - Results from compression of the plexus between the shoulder pad and

the superior medial scapula when the pad is compressed into the Erb point (superior to the clavicle).
  - **Complete resolution of symptoms is required before the patient returns to play.**
  - If burners occur more than one time, the player should be removed from competition until cervical spine radiographs can be obtained.
  - Brachial plexus injuries can also be seen following anterior glenohumeral dislocations and should not be confused with massive rotator cuff tears.
- **Thoracic outlet syndrome**
  - Results from compression of the nerves and vessels that pass through the scalene muscles and first rib
  - This condition can be associated with cervical rib, scapular ptosis, or scalene muscle abnormalities.
  - Patients may note pain and ulnar paresthesias.
  - Positive results of the Wright test (see Table 4.7) and of neurologic evaluation can be diagnostic.
  - First-rib resection is occasionally required.
- **Long thoracic nerve palsy**
  - Injury to the long thoracic nerve can result in medial scapular winging secondary to serratus anterior dysfunction (see later discussion of scapular winging).
  - This condition can be caused by a compression injury (e.g., in backpackers), an iatrogenic problem (lymph node dissection for breast cancer), or a traction injury (as seen in weightlifters).
  - Simple observation is usually called for because many of these injuries spontaneously resolve within 18 months.
  - Treatment with a modified thoracolumbar brace may be beneficial, and in rare cases, pectoralis major transfer may be required for chronic palsies that do not improve.
- **Suprascapular nerve compression**
  - The suprascapular nerve may become compressed by various structures, including a ganglion in the spinoglenoid notch or suprascapular notch and a fracture callus in the area of the transverse scapular ligament (Fig. 4.57).
  - **Weakness and atrophy of the supraspinatus (proximal lesions) and infraspinatus** are present along with pain over the dorsal aspect of the shoulder.
  - Cysts within the spinoglenoid notch affect only the infraspinatus.
  - Electrodiagnostic studies and MRI may confirm and elucidate the nature of the nerve compression.
  - Compression caused by a cyst in association with a SLAP lesion may respond to arthroscopic decompression and labral repair (Fig. 4.58).

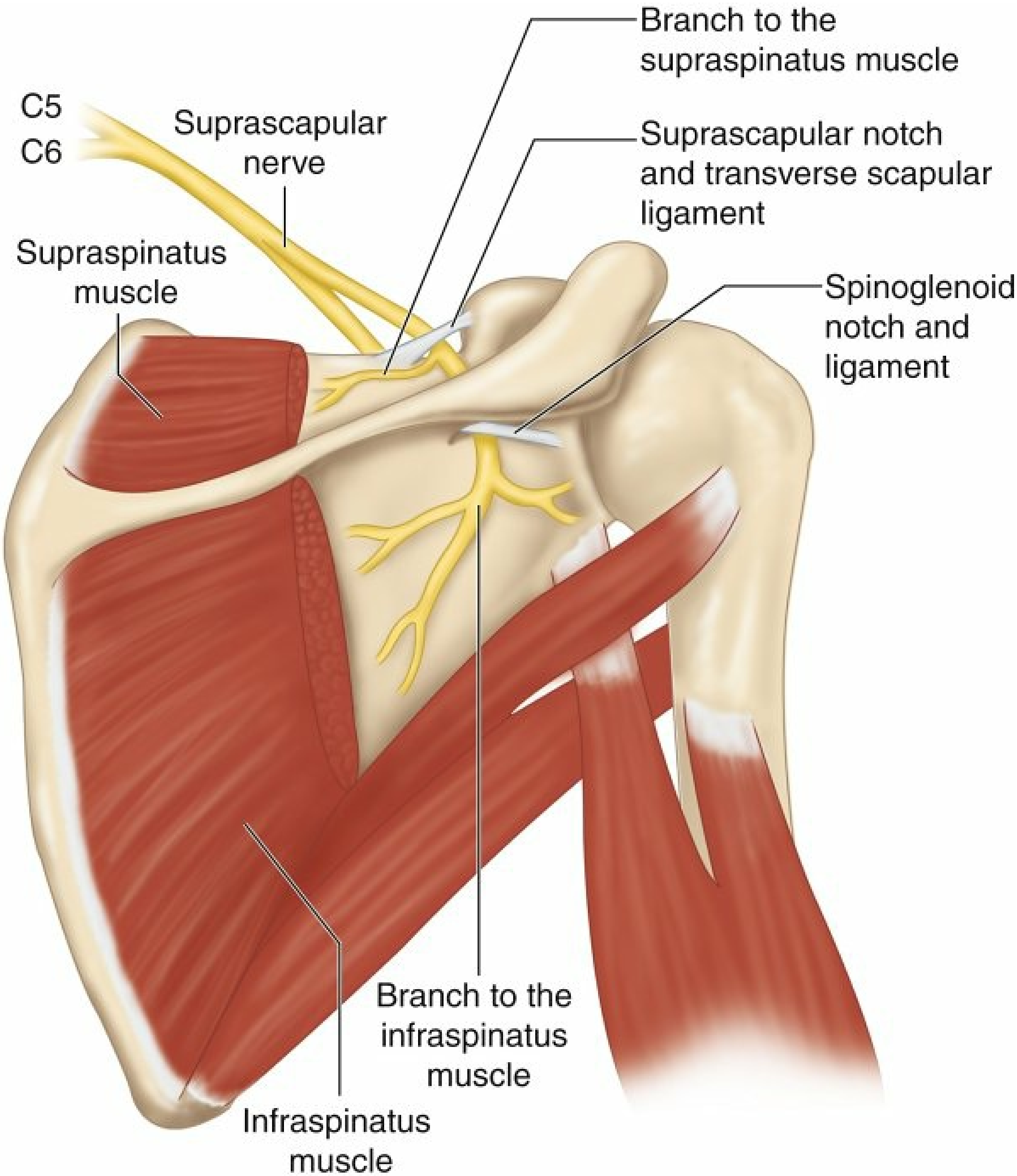


FIG. 4.57 Anatomy of the suprascapular nerve and potential sites of compression.

FIG. 4.58 SLAP tear with adjacent paralabral cyst. Coronal T2-weighted MR image demonstrates abnormal signal within the superior labrum, representing a SLAP tear, and an adjacent paralabral cyst dissecting into the suprascapular notch.

- In the absence of a structural lesion, release of the transverse scapular ligament may provide relief.

- **Quadrilateral space syndrome**
  - Defined as axillary nerve or posterior humeral circumflex artery compression within the quadrilateral space

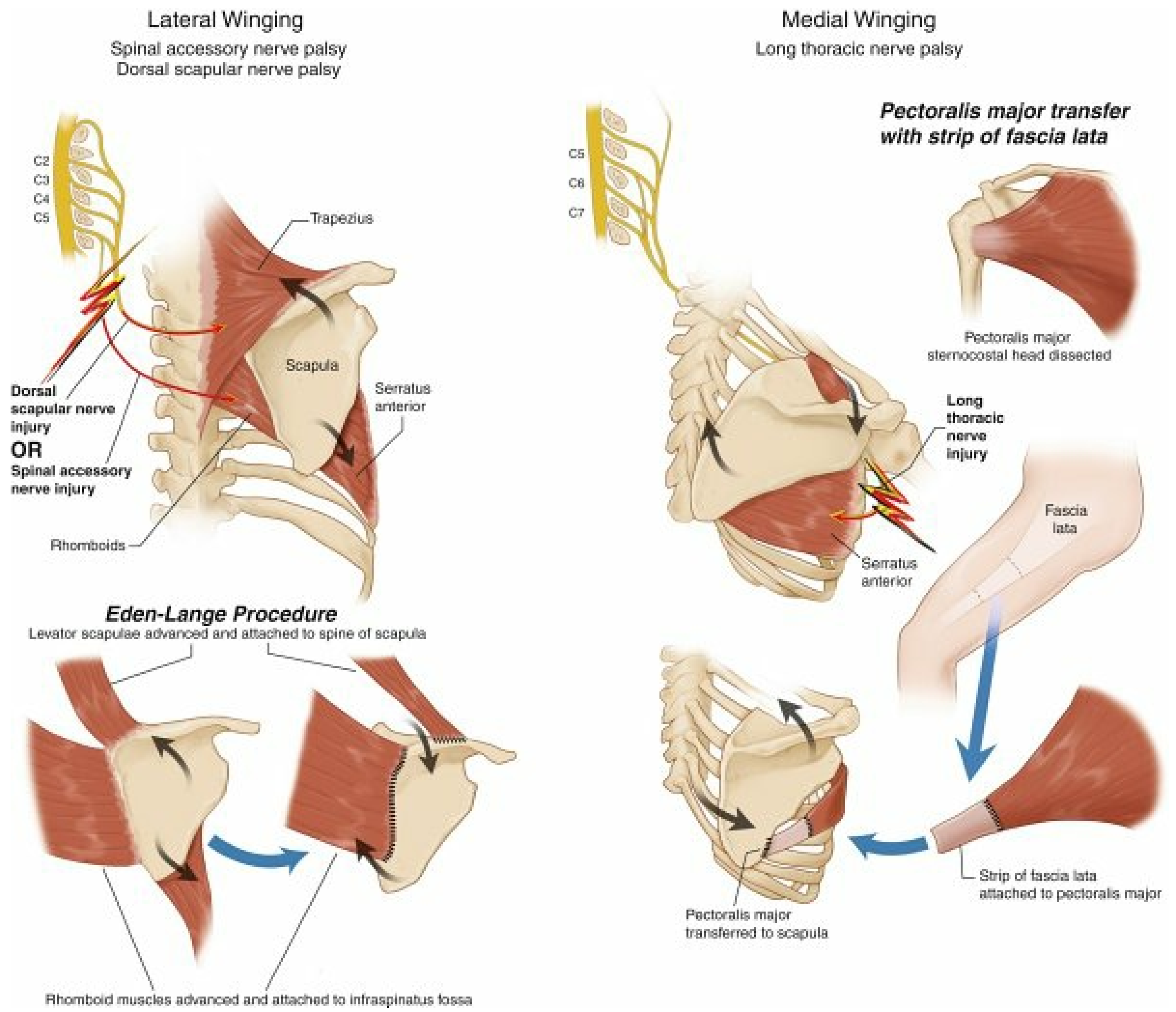


FIG. 4.59 Lateral and medial scapular winging. Lateral winging may be treated with the Eden-Lange procedure, in which the levator scapulae and rhomboid are transferred laterally on the scapula. Medial winging may be treated with pectoralis major transfer supplemented with a strip of fascia lata.

- Most commonly caused by a fibrous band between the teres major and the long head of the triceps
- Characterized by pain and paresthesias with overhead activity as well as weakness or atrophy of the teres minor and deltoid
- This syndrome is most often seen in athletes who participate in throwing activities; associated with late cocking and acceleration with the abducted, extended, and externally rotated arm. Diagnosis is confirmed by the arteriographic appearance of compression of the posterior humeral circumflex artery.

- **Other nerve injuries**
  - Other injuries—including those of the axillary nerve, spinal accessory nerve (lateral scapular winging), and musculocutaneous nerve—are usually the result of surgical injury to these structures.
  - Observation for several months is appropriate before exploration and repair of the affected nerve is considered.
  - Severe combined neurologic injury resulting in rotator cuff and deltoid paralysis for which that neurolysis and tendon transfer have failed may

be treated with shoulder arthrodesis.

Other Shoulder Disorders

- **Glenohumeral degenerative joint disease (see shoulder section of** Chapter 5)
- **Scapular winging (** Fig. 4.59)
  - Can occur as a result of a nerve injury, bony abnormality, muscle contracture, or intraarticular disease, or can be performed voluntarily
  - The description of the direction of the winging is based on the movement of the inferior border of the scapula.
  - Nerve injuries include injury to the spinal accessory nerve (trapezius palsy, lateral winging), the long thoracic nerve (serratus anterior palsy, medial winging), and the dorsal scapular nerve (rhomboid palsy).

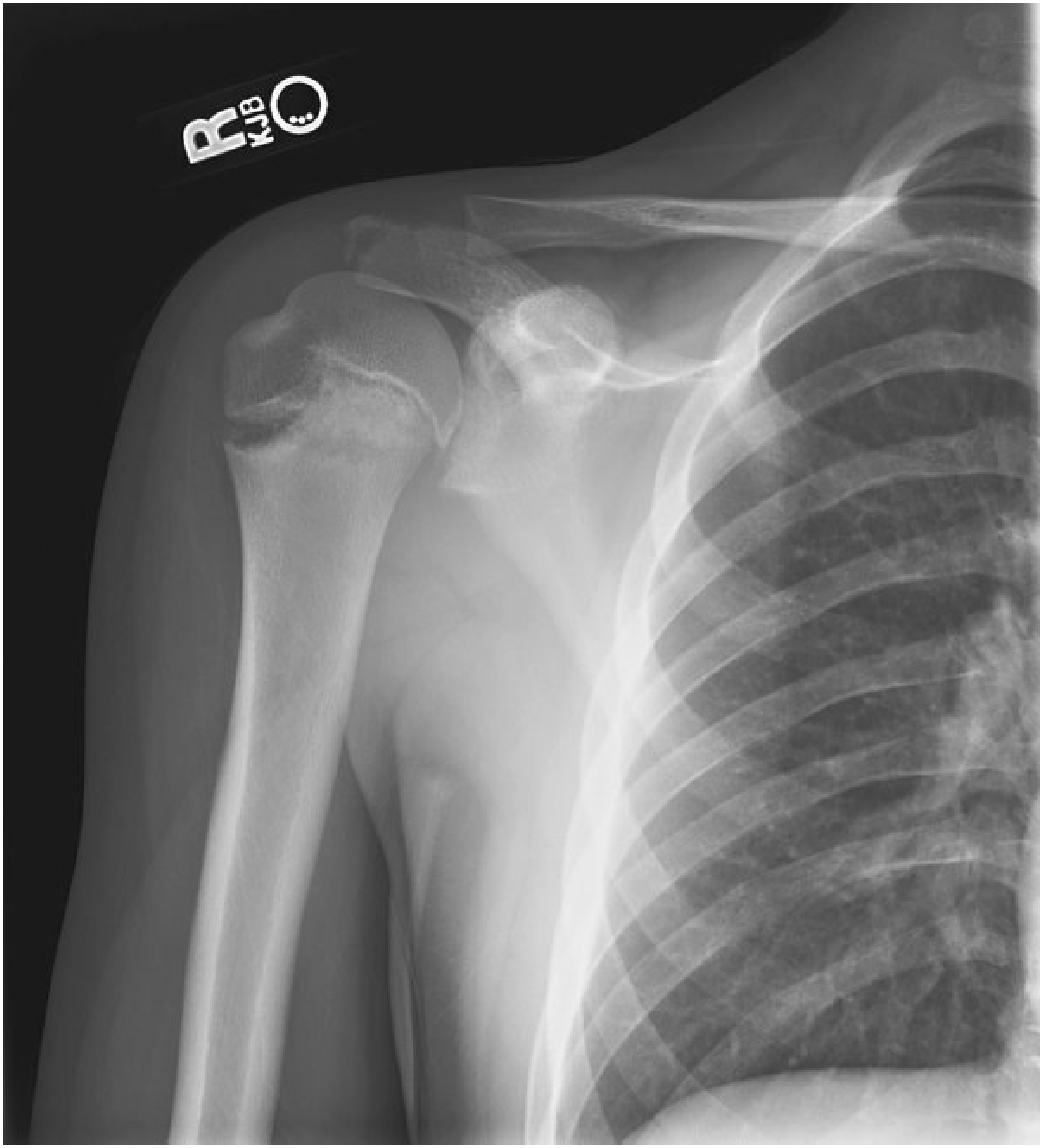


FIG. 4.60 Radiographic appearance of little leaguer shoulder demonstrating widening of the proximal humeral physis.

- Osseous causes include osteochondromas and fracture malunions.
- Selective muscle strengthening may ameliorate winging.
- Surgical treatment includes lateral transfer of the levator scapulae and rhomboid muscles (Eden-Lange procedure) for lateral winging and pectoralis major transfer for medial winging.

- **Complex regional pain syndrome (formerly known as** *reflex sympathetic dystrophy*)
  - As in the knee, this condition responds poorly to both conservative and surgical treatments.
  - In a litigious medicolegal environment, it is often associated with malingering and issues of secondary gain.
  - Diagnosis may be confirmed with a three-phase bone scan.
  - Treatment options are numerous and may include sympathetic nerve block.

- **Little leaguer shoulder**
  - Commonly occurs in young baseball players and is a Salter-Harris I fracture or stress reaction of the proximal humerus
  - Overuse of the shoulder as a result of failure to **limit pitch count** and provide periods of adequate rest are the key factors implicated in the development of this condition.
  - It has also been suggested that young pitchers not throw breaking pitches until after skeletal maturity.
  - Radiographs may demonstrate widening of the affected proximal humeral physis in comparison with the contralateral proximal humerus (Fig. 4.60).
  - MRI can assist with the diagnosis if it is in question.
  - The condition responds to rest and activity modification, with return to play allowed when symptoms have resolved completely.
  - Recommendations regarding age and pitch counts have been made.

Preparticipation Physical Examination

- **History and physical examination are most helpful and cost-effective for identifying musculoskeletal and medical problems.**
- **Family history of sudden cardiac death or any personal history of exertional chest pain or dyspnea necessitates further evaluation and cardiac workup.**
- **For National Collegiate Athletic Association (NCAA) purposes, final responsibility for medical disqualification rests with the team physician. Life-threatening illnesses must be reported and are adequate grounds for disqualification from participation.**

Cardiac Abnormalities in Athletes

- **Sudden cardiac death (** Fig. 4.61)
  - Usually related to an underlying heart condition
  - **Hypertrophic cardiomyopathy** is the most common cause of sudden death in young athletes. Commotio cordis is the second most common.
  - Screening that includes ECG can identify this problem early.
    - Universal screening of athletes with an ECG is controversial and varies across the world.
  - Diastolic murmurs found on routine examination warrant further cardiac evaluation.
- **Hypertrophic cardiomyopathy**
  - Autosomal dominant with variable penetrance; thousands of mutations affect more than 10 genes.
  - Associated with thickening of the left ventricular wall and septum
  - May be asymptomatic or may manifest as exertional dyspnea or fatigue
  - Murmurs that increase in intensity with Valsalva maneuvers
  - Sports participation is contraindicated.
- **Commotio cordis**
  - Defined as sudden death from relatively mild chest wall impact
  - Precise mechanism is unknown but may be due to onset of ventricular fibrillation from direct impact. The timing of impact during the cardiac cycle may be critical; experimental evidence suggests that the impact must occur 15–30 milliseconds before the T-wave peak.
    - This period represents only 1% of the cardiac cycle and may help explain the rarity of the condition.
  - Typically occurs in adolescents, with males accounting for 95% of cases
    - More compliant chest walls are thought to be the reason for

young-age affliction.

- Management is **immediate** cardiopulmonary resuscitation and **cardioversion.**

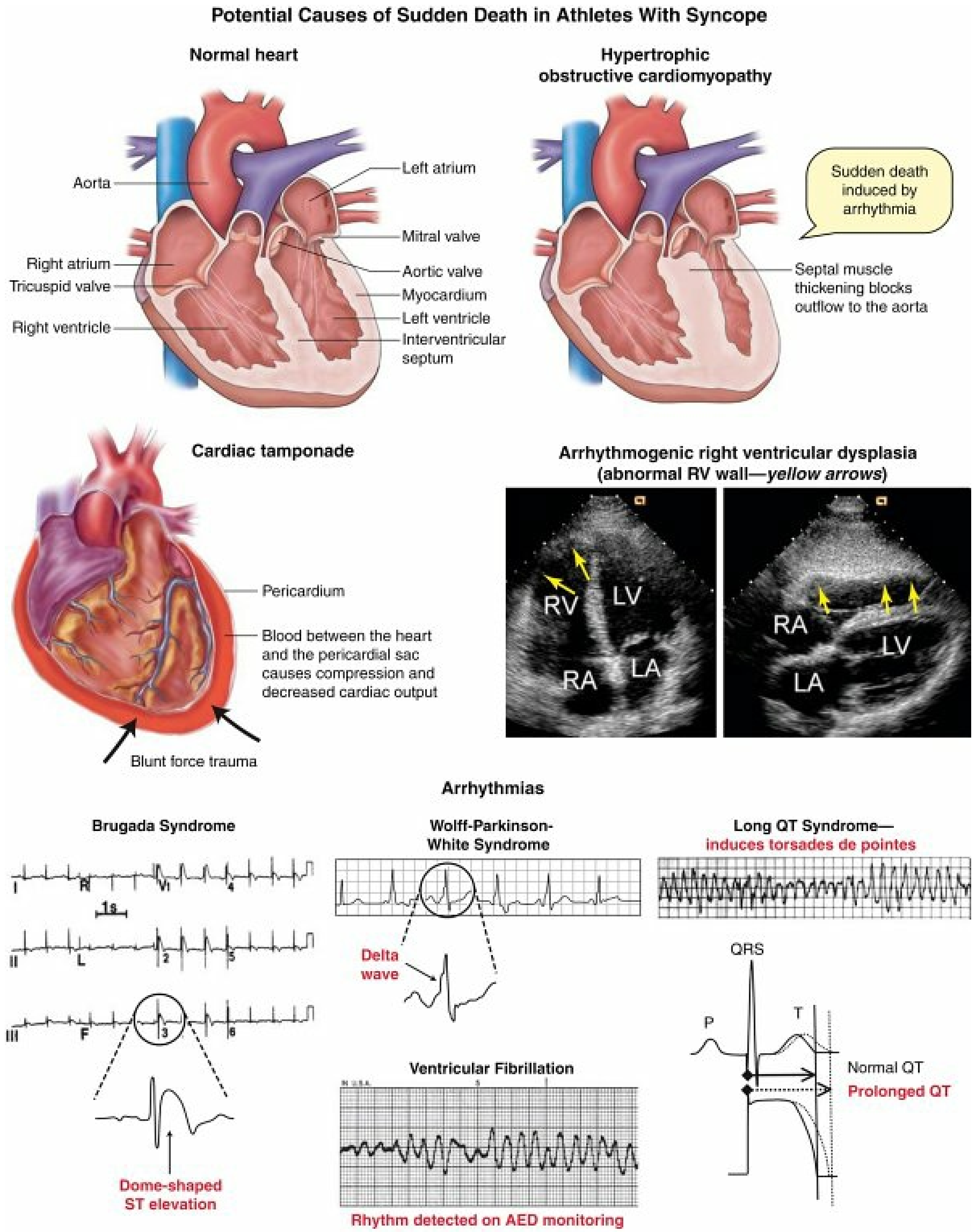


FIG. 4.61 Cardiac abnormalities in athletes. *RV,* Right ventricular. (From Miller M et al: *Sports medicine conditions: return to play: recognition, treatment, planning,* 2013, LWW.)

- Previous reported survival rates were between 10% and 25%, but newer reports suggest better rates owing to increased awareness and availability of defibrillators.

Concussion

- **Defined as a brain injury due to an impulsive force transmitted to the head**
  - Typically results in functional impairment with no structural injury
  - Symptoms and signs of concussion are highly variable.
  - 90% of concussions do *not* involve a loss of consciousness.
  - Can manifest as headache, emotional lability, cognitive impairment, behavioral changes, and sleep disturbance
- **Sideline evaluation**
  - First priority is to exclude a cervical spine injury.
  - A cervical spine injury cannot be excluded if the patient is unconscious.
  - If cervical spine injury is suspected, a cervical collar should be placed and the patient transported on a backboard to the hospital for further evaluation.
  - Concussion should be evaluated using a sideline assessment tool such as the Sport Concussion Assessment Tool 5 (SCAT5). This tool includes concentration and memory tasks as well as the Balance Error Scoring System and Glasgow Coma Scale.
    - Most schools have started performing baseline concussion tests.
  - The patient should be closely monitored.
  - Any player with diagnosed concussion is **not allowed to return to play/sport on the day of injury.** The player must be cleared by a licensed health care professional prior to returning to play/sport.
- **Concussion investigations**
  - Brain CT is not routinely obtained unless evaluation suggests an intracerebral or structural lesion.
    - Indications include loss of consciousness for more than 5 minutes, a focal neurologic lesion, Glasgow Coma Scale score less than 15, and worsening symptoms.
  - Neuropsychological testing
    - Useful as an adjunct but should not be used as a sole determination of when to return to play/sport.
- **Management**
  - Same-day return to play/sport is prohibited.
  - Physical and cognitive rest are the cornerstones of management.
  - Approximately 90% of patients recover within 10 days.
  - Persistent symptoms should be managed in a multidisciplinary fashion.
  - A gradual return-to-play/sport and return-to-school protocol should be followed (Table 4.12)
- **Second impact syndrome**
  - May occur with a second minor blow before initial symptoms have

resolved
- Leads to loss of autoregulation of the brain's blood supply and potential herniation
- Second impact syndrome is associated with a mortality rate of 50%; it more often affects younger patients.

- **Complications**
    - Posttraumatic headaches
        - Newer research has demonstrated that athletes who have headaches following concussion have protracted recovery time.
    - Depression
    - Chronic traumatic encephalitis (CTE)
        - Mean age of onset 42 years
        - Earliest sign is cognitive difficulty.
        - Mood disturbance and suicidal ideation may be present.
    - Chronic neurobehavioral impairment

Sickle Cell Disease

- **Sickle cell disease is a condition of red blood cells; due to defect in the β globin chain of adult hemoglobin (HbA) that produces sickle hemoglobin (HbS)**
    - Inheritance of two copies of *HbS* gene results in an HbSS phenotype and sickle cell disease.
    - Inheritance of a single copy of *HbS* gene results in an HbAS phenotype and sickle cell trait.
- **Sickle cell trait is extremely common in African Americans, with a prevalence of 8%–10%.**
    - Typically, sickle cell trait is an asymptomatic condition.
        - However, intense heat, extreme altitude, or significant exertional activity, such as sports participation or military training, can result in exertional sickling.
    - Newer data have demonstrated that athletes with sickle cell trait have a 37 times greater relative risk of sudden death.
    - Many sporting organizations, including the NCAA, require screening for the trait via blood tests.
        - Notably, all U.S. states perform neonatal screening for sickle cell trait.
    - Three major concerns with sickle cell trait:
        - Exertional rhabdomyolysis
            - Life-threatening
            - Sickled red blood cells cause muscle ischemia and rhabdomyolysis.

Table 4.12

Zurich Graduated Return-to-Play/Sport Protocol

Rehabilitation Stage	Functional Exercise at Stage	Objective of Stage
No activity	Complete physical and cognitive rest	Recovery
Light aerobic exercise	Walking, swimming, or stationary cycling, keeping intensity <70% of maximum predicted heart rate No resistance training	Increase heart rate
Sport-specific exercise	Skating drills in ice hockey, running drills in soccer; no head impact activities	Add movement
Noncontact training drills	Progression to more complex training drills, such as passing drills in football and ice hockey Progressive resistance training may be started	Exercise, coordination, and cognitive load
Full contact practice	After medical clearance, participation in normal training activities	Restores confidence and allows coaching staff to assess functional skills
Return to play/sport	Normal game play/sport	

- Splenic infarction
  - Often precipitated at higher altitudes
  - Manifests as left upper quadrant abdominal pain
- Gross hematuria
  - Typically occurs from left kidney and should prompt medical evaluation

□ Sickle cell trait is not a contraindication to participation in any athletic activity.

□ Important precautions must be taken.

- Maintenance of hydration.
- Ensuring of adequate rest and recovery between intense exercises.
- Access to supplemental oxygen, particularly when at altitude.

Metabolic Issues in Athletes

- **Dehydration (** Fig. 4.62)
  - □ Fluid and electrolyte loss can lead to decreased cardiovascular function and work capacity.

- Absorption is increased with solutions of low osmolarity (<10%).
- **Hyponatremia should be suspected in individuals who have participated in prolonged vigorous exercise and have been consuming free water.**
- Rehydration with carbohydrate-containing fluids is recommended for exercise lasting longer than an hour. This practice also aids sodium absorption.

- **Nutritional supplements**
  - Continue to be a source of controversy
  - Creatine, one of the more popular supplements, increases water retention in cells.
  - In-season use can raise the incidence of **dehydration and cramps.**

Ergogenic Drugs

- **Anabolic steroids**
  - Derivatives of testosterone are abused by athletes attempting to increase muscle mass and strength as well as erythropoiesis.
  - Adverse effects include liver dysfunction, hypercholesterolemia, cardiomyopathy, testicular atrophy, hypercoagulability, fluid and electrolyte imbalances, gynecomastia, acne, mood disturbances (particularly increased aggression), and irreversible alopecia.
    - Heart disease can result from increased plasma levels of LDL cholesterol and decreased levels of HDL cholesterol.
  - Urine sampling has been the standard for evaluation by the International Olympic Committee.
- **Human growth hormone (HGH)**
  - Made from recombinant DNA; illegal use drug common
  - Athletes attempting to increase muscle size and weight abuse this drug, which has side effects similar to those of steroids, as well as hypertension and gigantism.
  - Difficult to detect if suspected
  - Insulin-like growth factor-1 (IGF-1) has effects similar to those of HGH.
- **Prohormones**
  - Derivatives of testosterone, dehydroepiandrosterone (DHEA) and androstenedione, have been used as anabolic agents; their effects are controversial.

Female Athlete–Related Issues

- **Physiologic differences**
  - Women are typically smaller and lighter and have higher percentages

of body fat.

- Lower maximal oxygen consumption, cardiac output, hemoglobin, and muscular mass and strength are also important considerations.
- Other differences contribute to the higher incidence of patellofemoral disorders, stress fractures, and knee ACL injuries in girls and women (especially in basketball, soccer, and rugby players).

- **Female athlete triad (** Fig. 4.63)
  - Originally defined as disordered eating, amenorrhea, and osteoporosis
  - Current definition is low energy availability (with or without an eating disorder), menstrual dysfunction, and altered bone mineral density
    - Energy availability
      - Decreased energy intake may be facilitated by purging, fasting, laxatives, diuretics, and diet pills.
      - Anorexia and bulimia are the most common forms of eating disorders.
    - Menstrual dysfunction
      - *Amenorrhea* is defined as absence of menstrual cycles lasting longer than 3 months. *Oligomenorrhea* is a menstrual cycle longer than 35 days.
        - Oligomenorrhea is extremely common in female athletes. Prevalence may be as high as 20% to 40%.
      - Menstrual dysfunction is thought to be due to low energy availability.
        - Occurs when intake falls below 30 kcal/kg lean body mass per day
    - Bone mineral density (BMD)
      - Dual energy x-ray absorptiometry (DEXA) is the study of choice for evaluating BMD.
      - Z-scores (age- and gender-matched controls) should be used for athletes instead of T-scores (30-year-old adult controls).
        - *Osteopenia* is defined as a Z-score between −1.0 and −2.0
        - *Osteoporosis* is defined as a Z-score below −2.0
      - Stress fractures are extremely common with low BMD.
      - Long-distance female runners have been found to have the lowest average total BMD of any

athletes.

- Low BMD is largely due to the hypoestrogenic state causing increased bone resorption.
    - Lack of suppressive effect of estrogen on osteoclasts

□ Treatment

- Requires a multidisciplinary approach
- Nutritional counseling is critical. Psychotherapy, cognitive-behavioral therapy, and group therapy may be necessary if an eating disorder is present.
- Hormone replacement therapy and oral contraceptives may also be used.
    - If BMD fails to respond to nutritional counseling, an oral contraceptive should be initiated.
    - Bisphosphonates are approved only for postmenopausal osteoporosis. Off-label use should also be avoided owing to potential teratogenic effects.

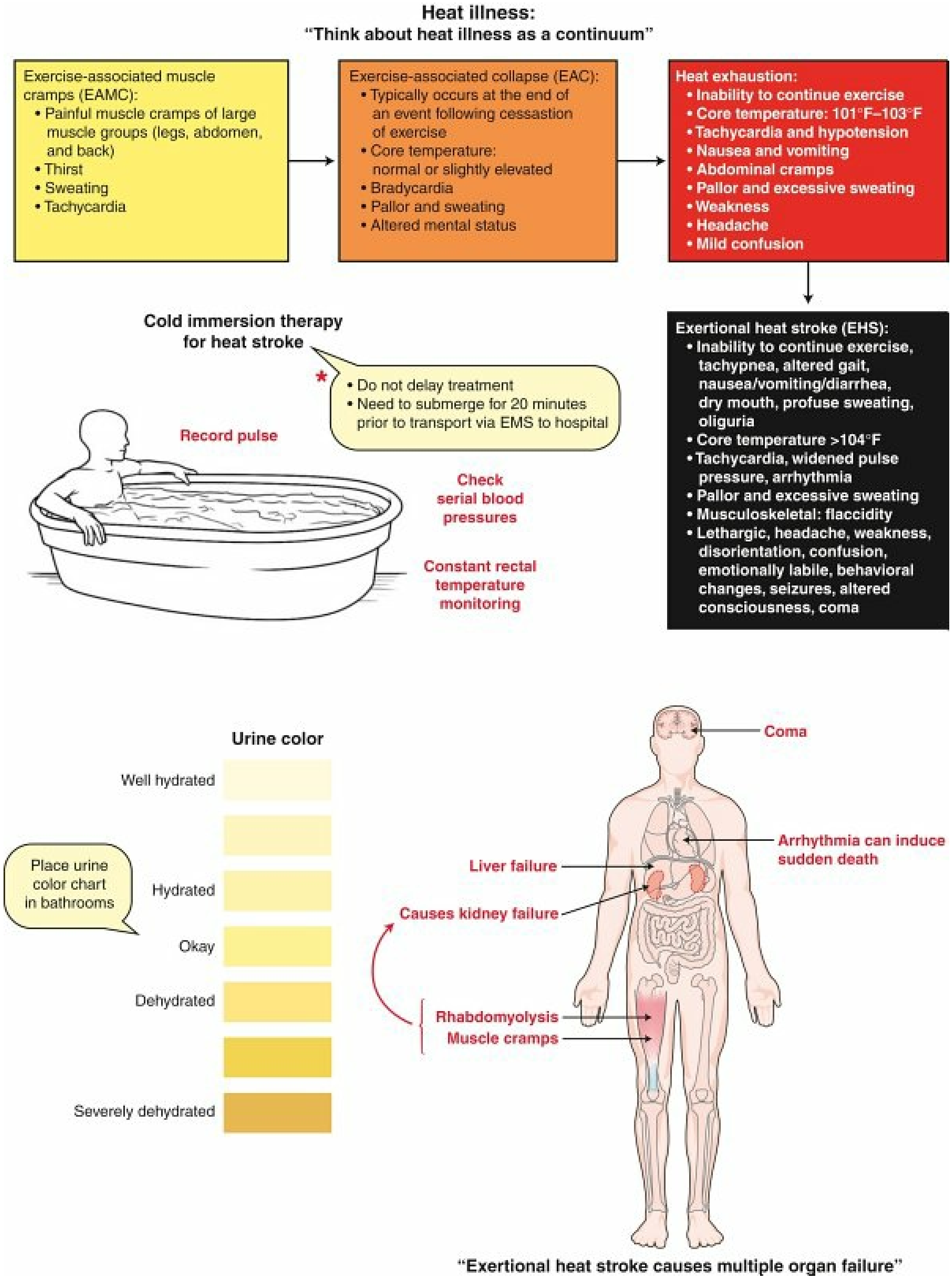


FIG. 4.62 Heat illness. (From Miller M et al: *Sports medicine conditions: return to play: recognition, treatment, planning,* 2013, LWW.)

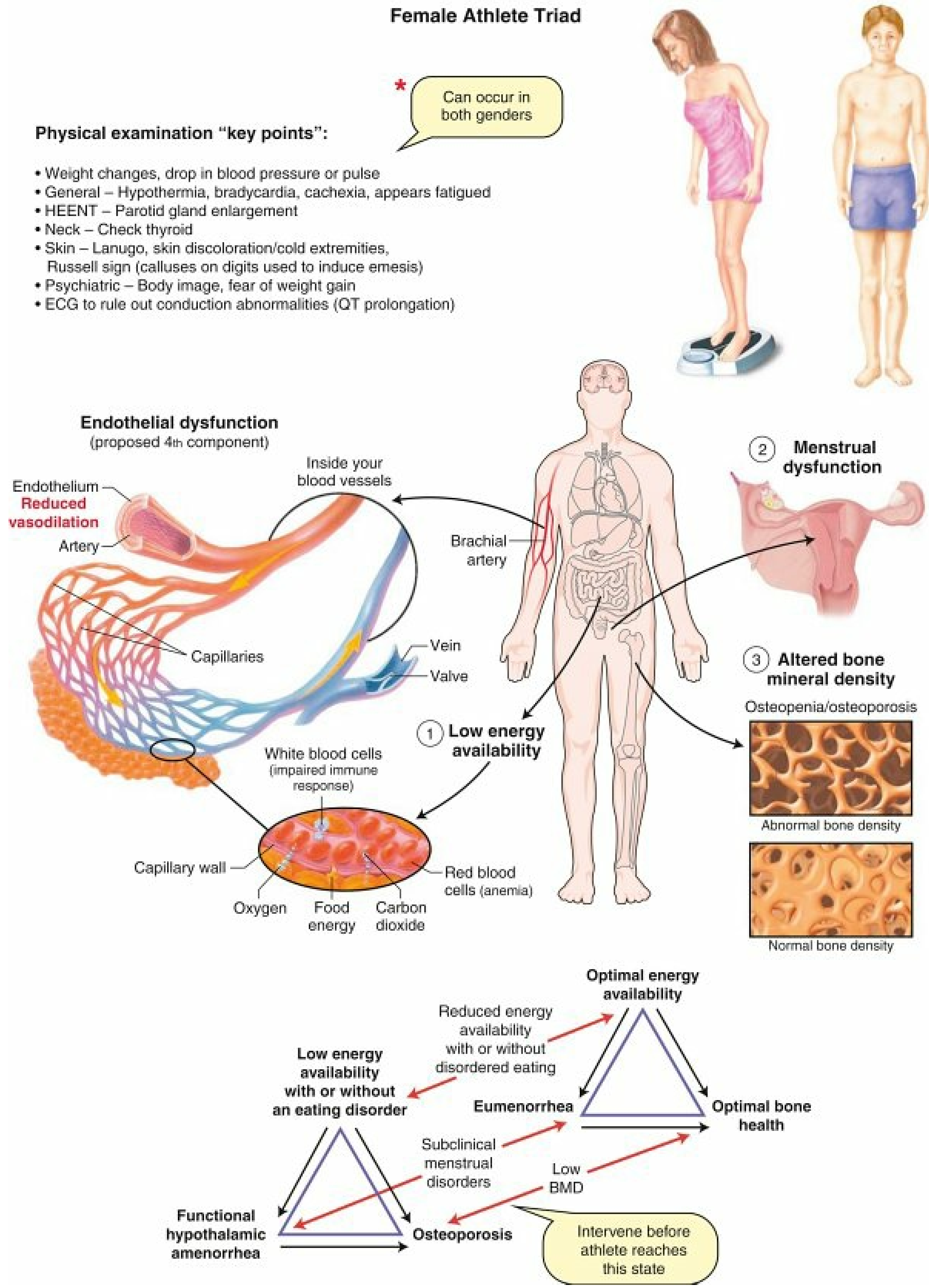


FIG. 4.63 Female athlete triad. *BMD,* Bone mineral density; *HEENT,* head, ears, eyes, nose, and throat. (From Miller M et al: *Sports medicine conditions: return to play: recognition, treatment, planning,* 2013, LWW.)

Infectious Disease in Athletes

- **The skin is the most common site of infection in athletes, representing over half** of all infectious disease outbreaks.**

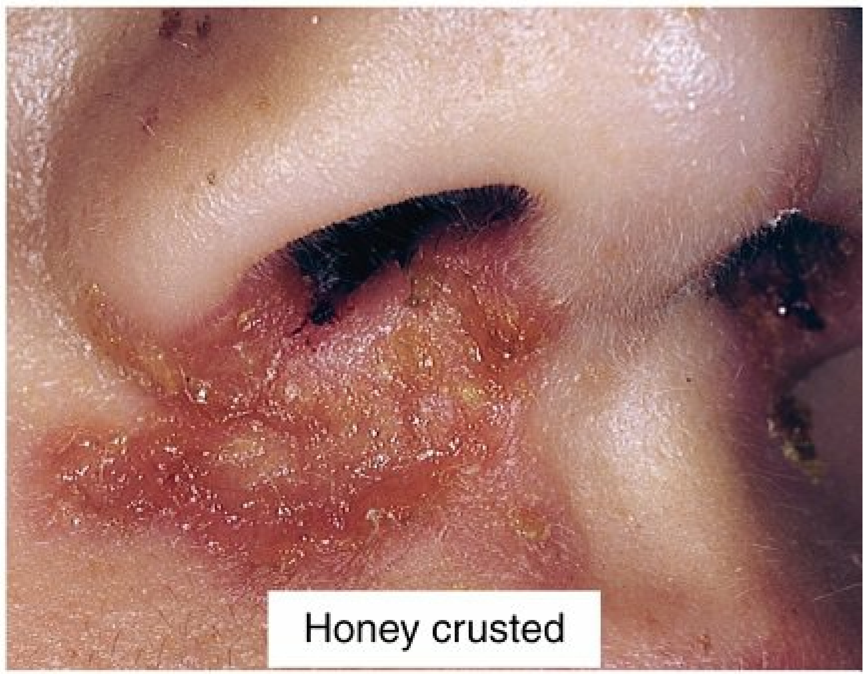
- **Person-to-person contact is the most common mode of transmission.**
- **Football, wrestling, and rugby are the sports most commonly affected.**
- **Herpes simplex virus (HSV) and** *Staphylococcus aureus* infections are the most common pathogens.
- **Bacterial skin infections (** Fig. 4.64)
    - Transmission occurs by means of direct person-to-person contact through disruptions in skin integrity.
    - Prevalence of methicillin-resistant *S. aureus* (MRSA) has significantly increased in the community.
        - Must be considered in the differential diagnosis of any skin lesion
        - Often confused for a spider bite
    - *S. aureus* lesion is typically an erythematous area with a fluctuant mass, yellow or white center, and central head.
    - Diffuse cellulitis suggests *Streptococcus* infection.
    - Simple abscesses may be treated with moist heat and topical mupirocin for 10 days. Incision and drainage may be performed if the infection persists.
    - Oral empirical antimicrobial therapy with coverage for MRSA should be started if the lesions are severe or extensive: 5–10 days of therapy with trimethoprim-sulfamethoxazole, doxycycline, clindamycin, linezolid, or minocycline.
    - Return-to-play/sport criteria:
        - **No new skin lesions for 48 hours**
        - **Oral antibiotic therapy for 72 hours**
        - **No actively weeping or draining lesions**
    - Prevention is key.
        - Good personal hygiene, discouragement of body shaving, avoidance of sharing personal items, cleaning of high-touch surfaces
        - Athletes with infections should avoid common-use water facilities.
- **Herpes simplex virus**
    - HSV-1 is the most common cause of herpes labialis (lips), and HSV-2 is the most common cause of urogenital herpes.
    - Transmitted by skin-to-skin contact or contact with bodily fluids
    - Highly infectious
        - Sparring with an infected partner poses a 33% likelihood of contracting HSV,
    - Lesions typically occur on the lips, head, extremities, and trunk.
    - Diagnosis is made from a cluster of vesicles on an erythematous base.
        - Lesions may crust or scab.

- Tissue culture is not necessary.
- Oral systemic antivirals are taken for 5 days. Acyclovir, valacyclovir, and famciclovir are options.
- Return-to-play/sport criteria:
    - No systemic symptoms
    - **No new lesions for 72 hours**
    - No moist lesions; all lesions dry and surrounded by firm adherent crusts
    - **Oral antiviral therapy for 120 hours**

- **HIV**
    - An athlete's HIV status is confidential; by itself, HIV infection is insufficient reason to restrict athletic participation.

1. Herpes gladitorium

2.Impetigo



3. CA-MRSA

FIG. 4.64 Sports dermatology. *CA*, Community-associated. (From Habif T: *Clinical dermatology*, ed 6, Philadelphia, 2016, Elsevier.)

- Wound care in this population is the same as that for all athletes, with the use of universal precautions, application of compressive dressings, and waiting until bleeding has stopped before a return to play/sport.

- **Infectious mononucleosis**
  - Caused by Epstein-Barr virus
  - Classic triad is high fever, sore throat, and lymphadenopathy.
  - Splenomegaly occurs in 50%–100% of patients.
  - Three complications regarding athletes:
    - Splenic rupture
      - Usually occurs within first 3 weeks of illness
      - Due to lymphocytic infiltration
      - Very rare
    - Severe tonsillar enlargement
      - Upper respiratory tract blockage and acute respiratory compromise
    - Chronic fatigue
      - Can last for 3 months
  - Treatment is symptomatic.
    - Participation in **contact sports should be restricted for 3–5 weeks**, and splenomegaly must have resolved before a return to play/sport.
- **Meningitis**
  - A concern in athletes because of the ease of spread from the "close quarters" environment of the training room
  - Symptoms include fever, headache, and nuchal rigidity.
  - Evaluation of cerebrospinal fluid is important for identifying cases of bacterial meningitis.

Miscellaneous Sports-Related Injuries and Issues

- **Blunt trauma**
  - Can cause injury to solid organs
  - These injuries may be subtle, and diagnosis requires a high index of suspicion.
  - The kidney is the most commonly injured organ (especially in boxing), followed by the spleen (injured in football).
- **Chest injuries**
  - Can be serious and necessitate immediate on-field action
  - Decreased breath sounds, deviated trachea, and hypotension may signify a tension pneumothorax.

        - Treatment entails placing a 14-gauge intravenous needle into the second intercostal space at the midclavicular line, followed by placement of a chest tube.
    - Airway obstructions must also be anticipated and treated.
    - Rib fractures may also occur in contact sports.
    - The player usually has "had the air knocked out" of him or her, which can be related to a problem with the diaphragm.
- **Eye injuries**
    - Best avoided with use of proper protection.
    - A hyphema (blood in the eye) is associated with a vitreous or retinal injury in more than 50% of cases; therefore urgent ophthalmologic consultation is required.
- **Ear injuries**
    - Auricular hematomas ("cauliflower ear"), common in wrestlers, should be treated with aspiration and wrapping.
- **Tooth injuries**
    - The tooth or teeth should be replaced immediately but may be temporarily placed in the buccal fold or in milk or saline if necessary.
    - Crown fracture is the most common maxillofacial injury in ice hockey.
- **Heat illness (see** Fig. 4.62)
    - Heat stroke, common during the football preseason, is characterized by collapse, with neurologic deficits, tachycardia, tachypnea, hypotension, and anhidrosis.
    - Treatment involves rapidly cooling of the body's core temperature and hydration.
    - Heat stroke is the second leading cause of death in football players.
- **Cold injury**
    - Treatment involves rewarming the patient in a warm-water bath (110°–112°F).
- **Exercise-induced bronchospasm**
    - Involves transient airway obstruction that results from exertion
    - Symptoms include the triad of coughing, shortness of breath, and wheezing; commonly occurs in cold-weather sports
    - Provocative pulmonary testing is required for diagnosis, with measurement of low forced-expiratory volume.
    - Treatment is with inhaled glucocorticoids. Inhaled β_2 agonists are used as rescue therapy.
- **Deep venous thrombosis (DVT) after knee arthroscopy**
    - The incidence of DVT after knee arthroscopy is 10%; 2% of the cases are proximal without prophylaxis.
    - For patients at high risk for DVT (older age, personal or family history of DVT, concomitant medical illness), it is prudent to treat with DVT prophylaxis.

- **On-field bleeding**
  - The affected athlete must be immediately removed from the field and may not return until the bleeding has stopped and the wound has been covered with an occlusive dressing.
- **Special athletes**
  - Patients with Down syndrome may have congenital cervical instability, which should be assessed radiographically before sports participation. They may also have congenital heart conditions.
  - An atlanto–dens interval of more than 9 mm on flexion and extension views is an indication for surgical fusion.

Testable Concepts

Section 1 Knee

- The most common causes of an acute hemarthrosis: ACL tear (70%), isolated meniscus tear (15%), osteochondral fracture, patellar dislocation
- The vascular supply of the meniscus is a primary determinant of healing potential; tears in the peripheral third have the highest potential for healing.
- The gold standard for meniscal repair is the inside-out technique with vertical mattress sutures. The saphenous nerve is at risk in medial repairs; the peroneal nerve is at risk in lateral repairs.
- ACL anatomy: AM bundle is an anterior restraint, and PL bundle is a rotatory restraint.
- The sMCL origin is proximal and posterior to the medial epicondyle of the femur. Radiographically, the ligament originates slightly anterior to the junction of the posterior femoral cortex reference line and Blumensaat line.
- The posterior oblique ligament is the primary stabilizer against internal rotation and valgus between 0 and 30 degrees of knee flexion.
- The MPFL femoral attachment is anterior and distal to the adductor tubercle; or proximal to the attachment of the superficial MCL; or proximal and posterior to the medial epicondyle. Radiographically, MPFL originates slightly anterior to the posterior femoral cortex reference line and immediately posterior to the most posterior aspect of the Blumensaat line (Schottle point).
- The LCL femoral origin is proximal and posterior to the lateral femoral epicondyle; or posterior and proximal to the insertion of the popliteus tendon.
- The popliteus femoral insertion is distal, anterior, and deep to the LCL. It rotates the tibia internally.
- The posterior horn of the medial meniscus is a major secondary stabilizer against anterior tibial translation in an ACL-deficient knee.
- Opening of the knee to varus or valgus stress testing at only 30 degrees of knee flexion indicates an isolated collateral injury. Opening of the knee in full extension indicates a combined cruciate and collateral injury.
- During knee arthroscopy, the posterolateral compartment can be best visualized by placement of the arthroscope through the interval of the ACL and lateral femoral condyle or a posterolateral portal.
- Partial meniscectomy increases peak stresses in the affected compartment.
- The gold standard for meniscal repair is the inside-out technique with vertical mattress sutures. Regardless of the technique used, it is essential that the saphenous nerve branches (anterior to both the semitendinosus and gracilis muscles and posterior to the inferior border of the sartorius muscle) be protected during medial repairs, and the peroneal nerve (posterior to the biceps femoris) during lateral repairs.

- Meniscal cysts occur primarily in conjunction with horizontal cleavage tears of the lateral meniscus.
- Discoid menisci should be observed if asymptomatic.
- If meniscal transplantation is considered, ligamentous deficiency and limb malalignment must be addressed. Contraindications include inflammatory arthritis, increased BMI, and significant osteoarthritis.
- Following meniscal transplantation, allograft tissue often remains hypocellular or acellular. The most common complication is meniscal tear.
- The ACL injury rate is two to eight times higher in female athletes than in male athletes because of smaller notches, smaller ligaments, increased generalized ligament laxity, increased knee laxity, and different landing biomechanics in women and girls.
- The Lachman test is the most sensitive examination for acute ACL injuries, whereas results of the pivot-shift test are correlated most closely with outcome after ACL reconstruction. The pivot shift is a reduction of the subluxated lateral tibial plateau by the iliotibial band when the leg is moved from full extension to flexion.
- MRI evaluation of ACL injuries demonstrates characteristic "bone bruises" in more than half of cases; these bruises are typically located near the sulcus terminalis on the lateral femoral condyle and the posterolateral aspect of the tibia.
- Initial management consists of physical therapy for mobilization. Immobilization is avoided. Full range of motion and good quadriceps control should be achieved prior to surgery.
- A more horizontal graft position may reduce rotational instability.
- BPTB autografts demonstrate faster incorporation into the bone tunnels than do hamstring autografts and are often the graft of choice for patients desiring an early return to sports activity.
- The most common technical error in ACL surgery is placement of the femoral tunnel too far anteriorly, which results in limited flexion. Too-vertical graft placement results in decreased rotational stability.
- Arthrofibrosis is the most common complication following ACL reconstruction and is associated with a loss of patellar translation.
- No high-level evidence to suggest that ACL reconstruction reduces the risk of arthritis
- ACL rehabilitation should avoid open kinetic chain quadriceps-activating exercises from 0 to 30 degrees of knee flexion.
- PCL injuries often result from a fall onto the ground with a plantar-flexed foot.
- PCL reconstruction should be reserved for functionally unstable knees or combined injuries. Single-bundle reconstructions should be tensioned in 90 degrees of flexion. Tibial inlay has biomechanical advantages such as avoiding the killer turn.
- PCL rehabilitation should avoid open kinetic chain hamstring-activating exercises.

- Multiple-ligament knee injuries require an immediate neurovascular examination. Vascular consultation should be obtained in any patient with absence of pulses or an ankle-brachial index (ABI) less than 0.9.
- Chronic grade III posterolateral corner injuries often necessitate a valgus open-wedge osteotomy.
- Osteochondritis dissecans should be monitored in children with open physes. Adult lesions do not resolve and should be treated.
- Marrow-stimulating techniques, including microfracture, drilling, and abrasion arthroplasty, involve perforation of the subchondral bone after removal of the "tidemark" cartilage, with eventual clot formation and fibrocartilaginous repair tissue (type I collagen with inferior wear characteristics).
- No definitive research has demonstrated superiority of any cartilage restoration procedure. Current best available research suggests that for smaller lesions, microfracture, OAT, and ACI have similar recovery periods and functional results.
- Patellar tendinitis is associated with pain and tenderness near the inferior border of the patella (worse in extension than in flexion). Treatment is with NSAIDs and strengthening measures, including eccentric exercise and ultrasound.
- Iliotibial band friction syndrome manifests as localized tenderness at the lateral femoral condyle that is worse with the knee flexed 30 degrees.
- MRI evaluation of patellar dislocation demonstrates a classic bone bruise pattern involving the lateral femoral condyle and medial patella.
- Patellofemoral pain syndrome is most often due to muscular weakness, with weak quadriceps, hip abductors, and core musculature. Management is focused on prolonged rehabilitation.
- Conservative management is the mainstay of symptomatic bipartite patella.
- Lateral patellar facet compression syndrome should be treated with a lateral release only in the setting of objective evidence of lateral tilt that has not responded to extensive nonoperative management. Lateral tilt is best evaluated by measuring the lateral patellofemoral angle.

Section 2 Pelvis, HIP, and Thigh

- Quadriceps contusions are acutely managed with overnight immobilization in hyperflexion.
- Athletic pubalgia (sports hernia) is the result of abdominal hyperextension and thigh hyperabduction, which result in injury to the muscles of the abdominal wall and adductor longus. Treatment is primarily nonoperative.
- MRI is the most specific method for detecting stress fractures. Treatment typically includes protected weight bearing, rest, cross-training, analgesics, and therapeutic modalities.
- Femoral neck stress fractures that occur on the inferior surface (compression

side) can be treated nonoperatively.

- FAI manifests as groin pain and limited ROM, especially in flexion and internal rotation. A positive result of an anterior impingement test is reproduction of symptoms with passive flexion, adduction, and internal rotation.
- External snapping hip occurs when the iliotibial band abruptly catches on the greater trochanter, whereas internal snapping hip occurs when the iliopsoas impinges on the hip capsule.
- Complications of hip arthroscopy typically result from traction injuries or iatrogenic neurovascular injury from aberrant portal placement. Use of an anterior portal puts the lateral femoral cutaneous nerve at risk. Use of an anterolateral portal puts the superior gluteal nerve at risk. Use of a posterolateral portal puts the sciatic nerve at risk, especially when the hip is externally rotated.

Section 3 Shoulder

- The most common location for an os acromiale is at the junction of the mesoacromion and metaacromion.
- Humeral head blood supply is primarily from the posterior humeral circumflex artery.
- The contents of the rotator interval include the CHL, SGHL, biceps tendon, and glenohumeral capsule. The SGHL and CHL limit inferior translation and external rotation when the arm is adducted and posterior translation when the arm is flexed forward, adducted, and internally rotated. Rotator interval closure results in decreased external rotation in shoulder adduction and posteroinferior translation.
- The IGHL complex serves as the primary restraint to anterior, posterior, and inferior glenohumeral translation at 45–90 degrees of glenohumeral elevation. The aIGHL is important in external rotation, and the pIGHL in internal rotation.
- In the throwing shoulder, the scapula must rotate during throwing. It retracts during the late cocking phase and then protracts during the acceleration phase. The deceleration phase is associated with tensile failure of the posterior aspect of the supraspinatus and anterior half of the infraspinatus.
- In shoulder arthroscopy, the posterior portal puts the axillary nerve, suprascapular nerve, and suprascapular artery at risk.
- Traumatic anterior shoulder dislocations typically result when the arm is abducted and in external rotation. The axillary nerve is susceptible to injury.
- Instability is often associated with a Bankart lesion (anteroinferior labral tear) with disrupted medial scapular periosteum. A three-dimensional CT scan should be obtained for suspicion of glenoid bone loss.
- A HAGL lesion has an incidence between 1% and 9% and has typically necessitated open repair in the past because of its inferior location. However, newer arthroscopic techniques are being developed.

- Age at time of initial dislocation is an important risk factor for recurrent shoulder instability.
- Several open and arthroscopic techniques have been developed to address instability. Glenoid deficiency greater than 25% of the humeral head is a specific indication for coracoid transfer (Latarjet procedure). Failure of rehabilitation for multidirectional instability is an indication for capsular shift. Chronic dislocation with a deficit greater than 40% of the articular surface is an indication for allograft in young patients and for prosthesis in older patients.
- Remplissage involves tenodesis of the posterior capsule and infraspinatus into a Hill-Sachs lesion. Precise indications are not yet defined, but early evidence suggests medium to large or engaging Hill-Sachs lesions.
- Post-thermal capsular necrosis is treated with allograft anterior capsulolabral reconstruction.
- Physical examination for posterior instability includes load-and-shift and jerk testing.
- A fixed posterior shoulder dislocation is diagnosed from lack of external rotation. AP radiographs are unreliable but may demonstrate a lightbulb sign. An axillary lateral radiograph is critical to making the diagnosis.
- For chronic unrecognized posterior dislocations, several procedures may be performed, depending on the extent of bone loss both in the humeral head and glenoid. The Neer modification of the McLaughlin procedure involves transfer of the lesser tuberosity and associated subscapularis tendon into the reverse Hill-Sachs lesion.
- Multidirectional instability should be treated with extended rehabilitation that focuses on scapular stabilization before operative intervention is considered. Closed kinetic chain exercises should be emphasized.
- The prevalence of asymptomatic rotator cuff tears increases with age: 28% of those older than 60 years have full-thickness tears, compared with 65% of those older than 70 years.
- Asymptomatic full-thickness rotator cuff tears should be treated nonoperatively. The primary indication for surgical intervention is significant pain.
- Blood flow to the repaired rotator cuff is achieved from the peribursal tissue and bone anchor site.
- Acute rotator cuff tears should be repaired early because the disease process is accelerated in this setting.
- Studies of rotator cuff repair rehabilitation show no difference in clinical outcomes or healing rates between early motion and delayed motion protocols.
- Irreparable combined tears of the supraspinatus and infraspinatus may be treated with latissimus dorsi tendon transfer to the greater tuberosity. If pain is the major symptom and motion remains preserved, débridement with biceps tenotomy has been found to be useful. Inferior results have been reported for latissimus transfer in the patient with a subscapularis tear.
- Signs of a subscapularis tear include increased external rotation and the presence

of a liftoff, modified liftoff, or belly-press sign. The appearance of an empty bicipital groove on axial MRI with tear of the transverse humeral ligament is often associated with subscapularis tear. At arthroscopy, a chronic subscapularis tear can be signified by the comma sign, which represents an avulsed SGHL and CHL (so-called comma tissue).

- Athletes who participate in throwing activities have greater external rotation and a loss of internal rotation of the dominant shoulder than of the nondominant shoulder (GIRD). Initial treatment consists of posterior and posteroinferior capsular stretching exercises, such as the sleeper stretch, as well as stretching of the pectoralis minor tendon.
- *Internal impingement* is defined as contact between the articular side of the rotator cuff and the posterosuperior rim of the glenoid labrum when the arm is abducted and externally rotated. Alteration of glenohumeral kinematics causes a posterosuperior shift of the humeral head; abduction and external rotation of the arm, in turn, lead to the internal impingement.
- SLAP tear management is controversial. If repair is undertaken, stiffness is a common complication, and motion should begin early.
- Biceps tenotomy without tenodesis is associated with subjective cramping and potential for cosmetic deformity (Popeye deformity). Weakness is not associated with tenotomy.
- For type III acromioclavicular separations, recommended management is conservative in elderly patients, inactive patients, and patients who do not perform manual labor.
- Distal clavicle resection for AC joint arthritis should entail resection of less than 1 cm of the distal clavicle to preserve the posterior-superior capsule and avoid anterior and posterior instability and pain.
- Sternoclavicular dislocation is best diagnosed by CT. Posterior dislocation should be treated with closed reduction or with open reduction if necessary, particularly with compression of the posterior structures.
- Calcifying tendinitis is a self-limiting condition of unknown origin that affects predominantly the supraspinatus tendon. Radiographs demonstrate characteristic calcification within the tendon.
- Frozen shoulder histologic evaluation demonstrates evidence of inflammation and fibrosis. There is a dense matrix of type III collagen–containing fibroblasts and myofibroblasts that appear similar to those in Dupuytren disease. On examination, active ROM and passive ROM are equivalent.
- Suprascapular nerve compression by a ganglion in the spinoglenoid notch affects only the infraspinatus. Compression caused by a cyst in association with a SLAP lesion may respond to arthroscopic decompression and labral repair.
- *Quadrilateral space syndrome* is defined as axillary nerve or posterior humeral circumflex artery compression within the quadrilateral space, which results in pain and paresthesias with overhead activity as well as weakness or atrophy of the teres minor and deltoid. This syndrome is most often seen in athletes who

participate in throwing activities and is associated with late cocking and acceleration with the arm abducted, extended, and externally rotated.
- Medial scapular winging is caused by damage to the long thoracic nerve. Lateral scapular winging is caused by damage to the spinal accessory nerve.

Section 4 Medical Aspects of Sports Medicine

- The history and physical examination are the most helpful and cost-effective means of identifying musculoskeletal and medical problems in perspective athletes.
- Hypertrophic cardiomyopathy is the most common cause of sudden death in young athletes. This condition contraindicates sports participation.
- Any athlete with diagnosed concussion is not allowed to return to play/sport on the day of injury. The athlete must be cleared by a licensed health care professional prior to returning to play/sport.
- Sickle cell trait is not a contraindication to participation in any athletic activity. Important precautions must be taken: maintenance of hydration, ensuring adequate rest and recovery between intense exercises, access to supplemental oxygen (particularly when at altitude).
- Adverse effects of anabolic steroids include liver dysfunction, hypercholesterolemia, cardiomyopathy, testicular atrophy, gynecomastia, acne, mood disturbances (particularly increased aggression), and irreversible alopecia. Heart disease results from increased plasma levels of LDL cholesterol and decreased levels of HDL cholesterol.
- The *female athlete triad* consists of low energy availability (with or without an eating disorder), menstrual dysfunction, and altered bone mineral density. Insufficient caloric intake is the most common cause of secondary amenorrhea.
- MRSA transmission occurs by direct person-to-person contact through disruptions in skin integrity.
- Athletes with infectious mononucleosis should be restricted from contact sports participation for 3–5 weeks, and splenomegaly must have resolved before they return to play/sport.
- Heat stroke is characterized by collapse, with neurologic deficits, tachycardia, tachypnea, hypotension, and anhidrosis. Treatment involves rapid cooling of the body's core temperature and hydration.

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CHAPTER 5

Adult Reconstruction

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Section 1 Evaluation of the Adult Patient with Hip Pain

Patient assessment of hip pain includes a physical examination and diagnostic radiographic modalities.

Physical Examination Tests for Hip Irritability

- **Impingement test**
  - Hip flexion to 90 degrees
  - Hip adduction and internal rotation yield pain response.
  - Hip internal rotation only yields pain response.
  - Pain located in area of anterior hip with pain radiating to either posterior hip or lateral hip
- **Roll test**
  - Patient is positioned supine. Finger rolling of leg (at calf level) into internal rotation and external rotation.
  - Leg feels stiff or occasionally grabs.
- **Stinchfield test**
  - Patient is positioned supine. Active straight-leg raise of approximately 20 cm against mild resistance by examiner.
  - Patient feels pain in anterior hip against resistance.
- **Patrick test**
  - Patient is positioned supine. Leg is positioned in figure-of-four position.
  - Pain is elicited in area of anterior hip region or posterior hip region.
  - Care should be taken with interpretation of test. Pain located over posterior pelvis indicates referred pain from L5–S1 facets or sacroiliac joint and not hip joint.

Imaging

- **Radiographs**
  - Standard imaging modality for initial evaluation of hip pain
  - See Section 2 for discussion of imaging studies in dysplasia and impingement.
- **Computed tomography**
  - Three-dimensional CT with pelvic remodeling may be indicated for preoperative planning for reconstruction associated with dysplasia surgery, femoroacetabular impingement (FAI), posttraumatic arthritis, or other complex primary total hip arthroplasty (THA).
- **Magnetic resonance imaging**
  - Used when osteonecrosis suspected

- Gadolinium-enhanced MRI arthrogram useful when labral pathology suspected, especially when associated with femoral acetabular impingement
    - May identify gluteus medius and gluteus minimus tears in patients with lateral hip pain and abductor weakness

Natural History

- **Many cases of mild dysplasia or FAI may be asymptomatic and go unrecognized on radiographs.**
- **Hip pain in adults younger than 50 years often the result of an underlying structural problem**
- **Initial presentation of symptoms may be soon followed by degeneration.**
  - Growing evidence suggests that FAI is an important contributing factor to the majority of adult hip arthritis.

Spectrum of Presentation

- **Subtle**
  - Patients may present with symptoms from associated labral pathology.
  - Chondral surface delamination and chondral flap tears may also cause symptoms.
  - Abductor muscle fatigue may be presenting symptom of dysplasia.
- **Advanced morphologic changes with significant arthritis**

Anatomy of Adult Hip Dysplasia

- **Acetabulum (** Box 5.1 and Fig. 5.1)
  - **Shallow acetabulum with lack of anterior and lateral coverage**
  - Decreased acetabular depth (socket less than a hemisphere with upsloping acetabular index)
  - Varying degrees of superolateral subluxation and lateralization of femoral head
  - High articular contact stresses near superolateral rim
  - Crowe classification
    - Grade 1: less than 50% femoral head subluxation and less than 10% proximal displacement of the femur (mild)
    - Grade 2: between 50% and 75% subluxation of the femoral head and 10%–15% proximal displacement of the femur
    - Grade 3: between 75% and 100% subluxation of the femoral head and 15%–20% proximal displacement of the femur
    - Grade 4: more than 100% subluxation of the femoral head with more than 20% proximal displacement of the femur with a deficient true acetabulum
- **Proximal femur**

    - **High neck-shaft angle (coxa valga)**
    - Increased femoral anteversion
- **Clinical syndrome**
    - **Increased contact stresses** can lead to pain and degenerative changes of articular cartilage.

Treatment of Dysplasia

- **Treatment depends on extent of deformity and location.**
- **Surgical correction goals are to relieve pain and correct anatomic deformity. Long-term goal is to reduce occurrence of degenerative joint disease (DJD).**
- **Surgical correction addresses main anatomic deformity: shallow socket and/or proximal femur abnormality.**
- **Periacetabular osteotomy (PAO) (** Fig. 5.2)
    - Most common technique used to correct tilt and version of socket
    - Allows for large degree of correction
    - Permits joint medialization (i.e., center of hip rotation is positioned medially)
    - Lowers joint reactive forces
    - Technical advantages
        - **Does not violate the posterior column**
        - Does not violate abductors
        - Allows early weight bearing
        - Relatively low complication rate and morbidity
    - Goals of surgery
        - Acetabular roof index to zero
        - Head coverage: lateral center edge (CE) angle into normal range
        - Restoration of appropriate socket anteversion
            - Overcorrection, with subsequent retroversion and secondary FAI, should be avoided.
    - Conversion to THA
        - Previous hardware may be left in place if it does not interfere with placement of the acetabular component.
        - Previous osteotomy may have retroverted the socket, and internal landmarks may not be reliable to guide cup placement.

Box 5.1 Acetabular Dysplasia Classical Definitions

Lateral CE angle <20 degrees

- CE angle = head center to acetabular edge angle
- Measured on anteroposterior pelvis radiograph

Anterior CE angle <20 degrees
- Measured on standing lateral (false profile) view

Acetabular index >5 degrees
- Measured on anteroposterior pelvis radiograph

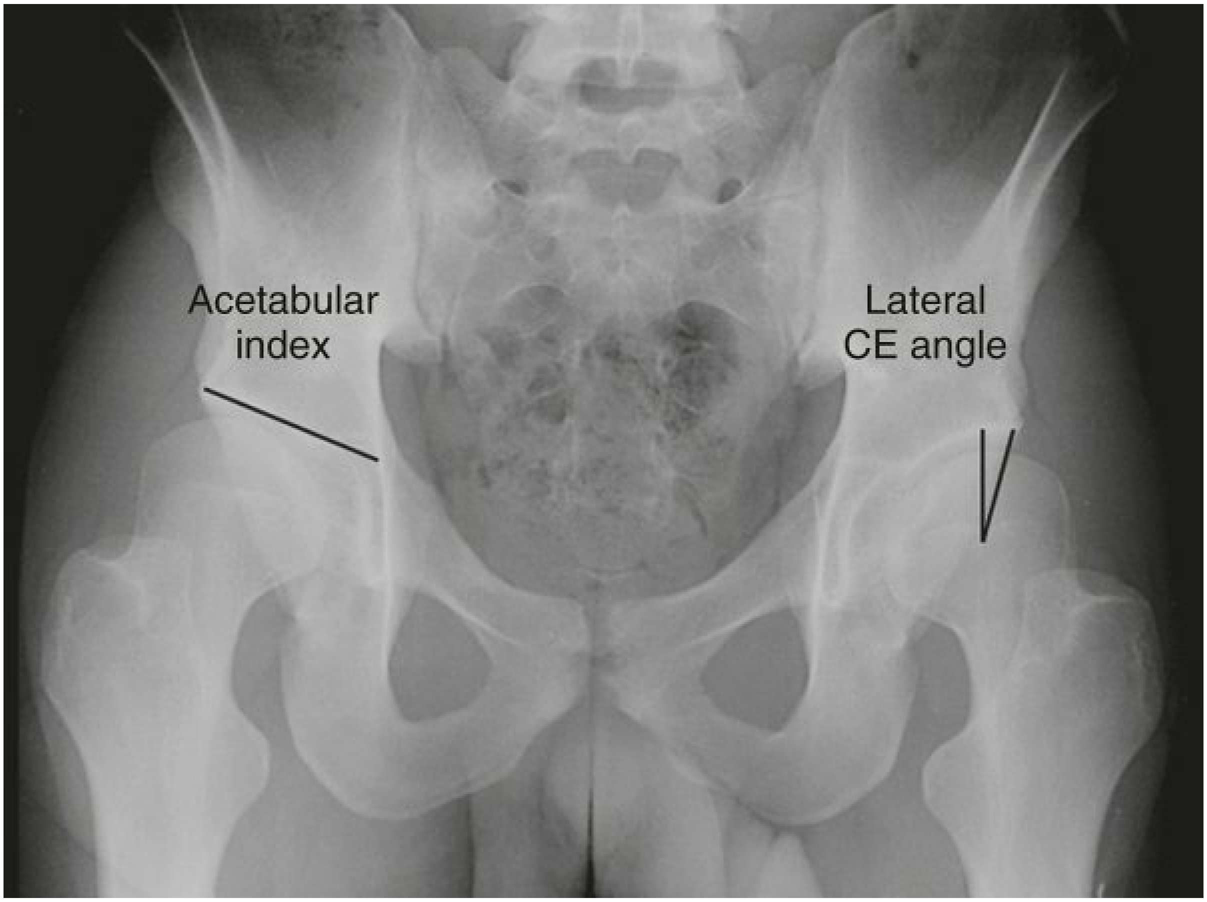


FIG. 5.1 Anteroposterior pelvis radiograph displaying lateral CE angle and acetabular index. Both hips in this case show a shallow socket dysplasia. The acetabular index should normally be horizontal, and the lateral CE angle should be 30 degrees.

- **Proximal femur osteotomy**
- **THA**
  - Reserved for patients with degenerative joint disease who are no longer candidates for hip preservation

Femoroacetabular Impingement

- **Acetabulum (** Fig. 5.3; see Fig. 5.2)
  - Excessive bone present along rim of acetabulum results in overcoverage
    - Acetabular retroversion (crossover sign)
    - Excessively deep socket
      - Coxa profunda occurs when acetabular fossa is medial to ilioischial line.

- Acetabular protrusio occurs when medial aspect of femoral head is medial to ilioischial line.

  - Acetabular index may be downsloping.

- **Proximal femur (**Figs. 5.4 through 5.6)
  - Offset between edge of femoral head and edge of femoral neck is reduced (i.e., reduced head-neck ratio).
  - α-Angle may be used to measure head-neck offset.
    - Normally 40 degrees or less
  - Typically due to excessive bone at junction of femoral head and neck
    - Aspherical head
    - Slipped capital femoral epiphysis (SCFE) deformity
  - Pistol grip deformity may be present on radiographs.
- **Clinical syndrome**
  - Abnormal impingement between femoral neck and anterosuperior acetabulum with flexion and internal rotation of the hip
    - Cam impingement is due to a femoral problem.
    - Pincer impingement is due to an acetabular problem.
    - **The majority of cases have combined cam and pincer impingement.**
  - Activity-related groin pain exacerbated by hip flexion activities
  - Impingement test result is positive.

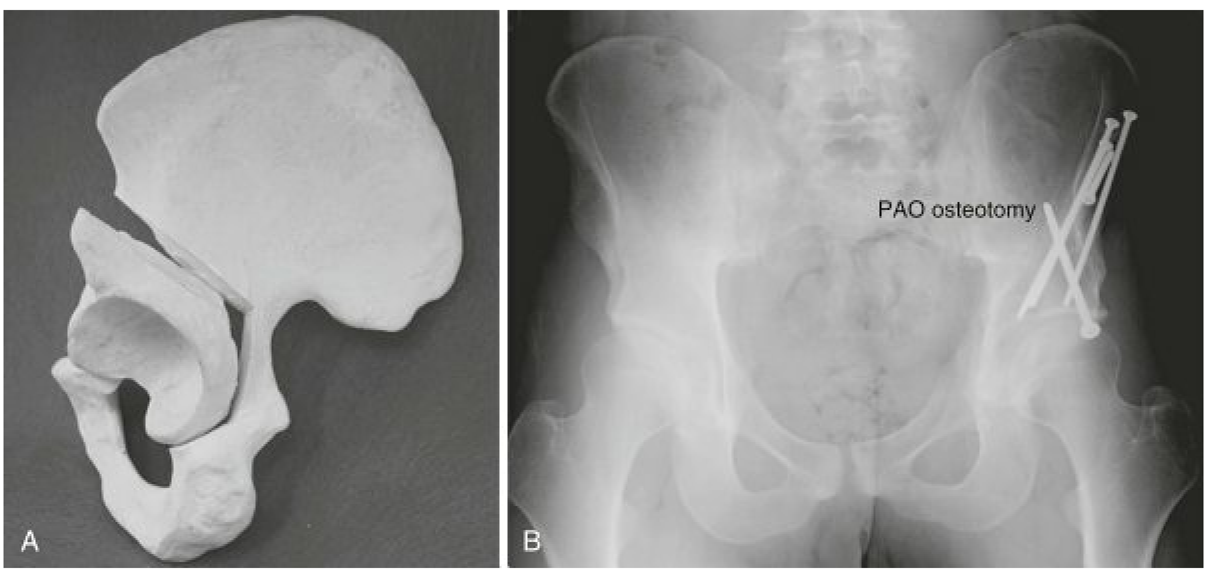


FIG. 5.2 (A) Model demonstrating periacetabular osteotomy. In the PAO technique, the posterior column is preserved. Preservation maintains pelvic stability and allows for significant correction of acetabular tilt and version. (B) Five-year postoperative radiograph of PAO. Notice acetabular index restored to horizontal and improved lateral CE angle.

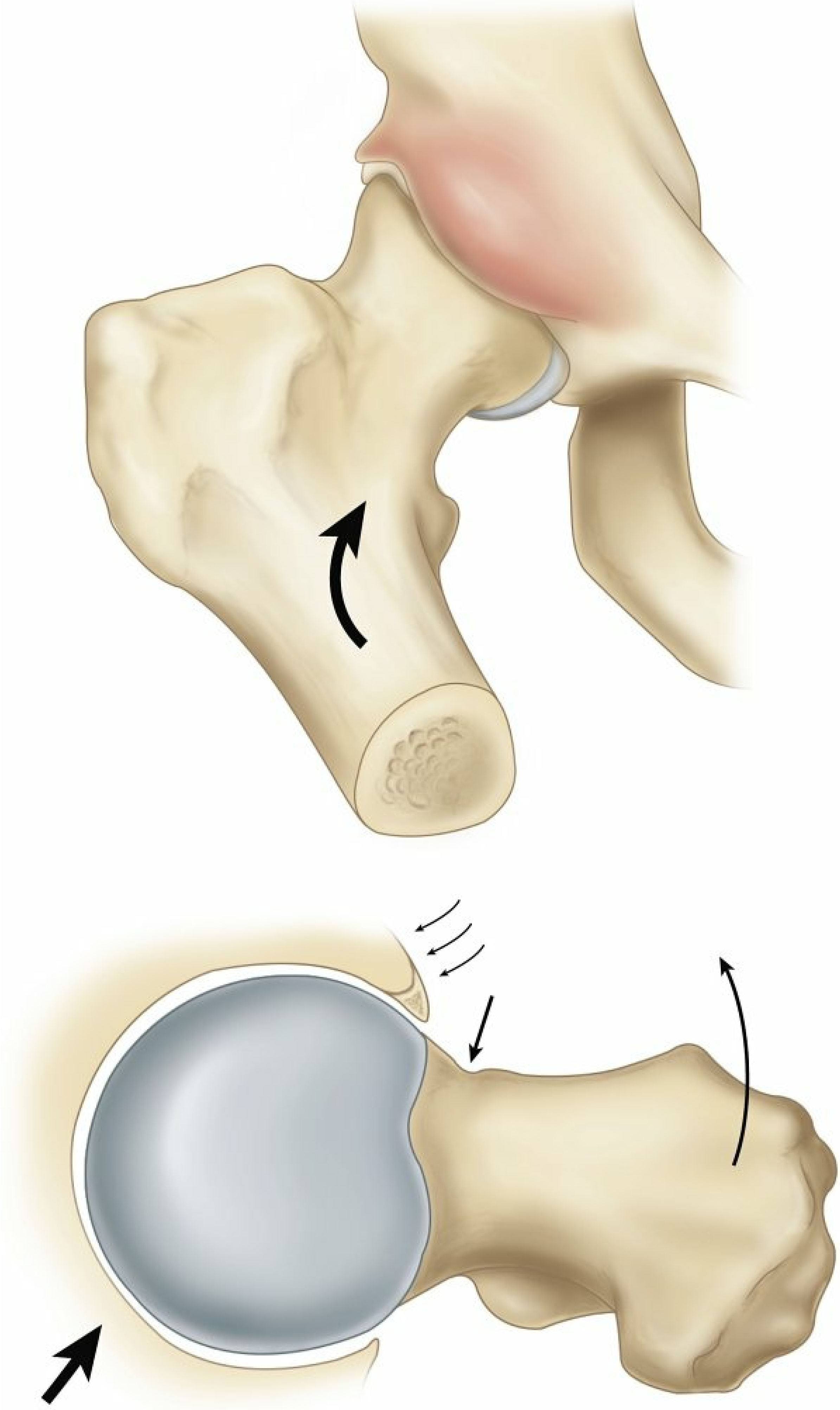


FIG. 5.3 Pincer-type impingement: an acetabular side disorder in which a prominent

anterosuperior acetabular rim *(three curved arrows)* impinges on the femoral neck (*thin straight arrow*) during flexion, leading to labral injury.

- Significant limitation of hip internal rotation tested at 90 degrees due to mechanical block
- Impingement can result in labral tears (pincer) and shearing delamination of the acetabular cartilage (cam).

Treatment of FAI

- **Surgical treatment varies according to patient anatomy.**
- **Labrum should be repaired when possible**; results appear to be superior to those of labral débridement.
- **Surgical hip dislocation (Ganz trochanteric osteotomy)**
  - Allows excellent exposure of proximal femur and acetabulum
  - Permits treatment of severe deformities
  - Preserves femoral head blood supply
  - Allows for repair of soft tissues (labrum and chondral flap tears)
  - Complications are rare (<5%) but include trochanteric nonunion and heterotopic bone formation.
  - Anterior Z-capsulotomy preserves posterior vessels to femoral neck and minimizes risk for osteonecrosis.
- **Hip arthroscopy**
  - See Chapter 4, Sports Medicine, for discussion.
- **Periacetabular osteotomy**
  - Less common procedure for FAI but may be used to address a retroverted socket

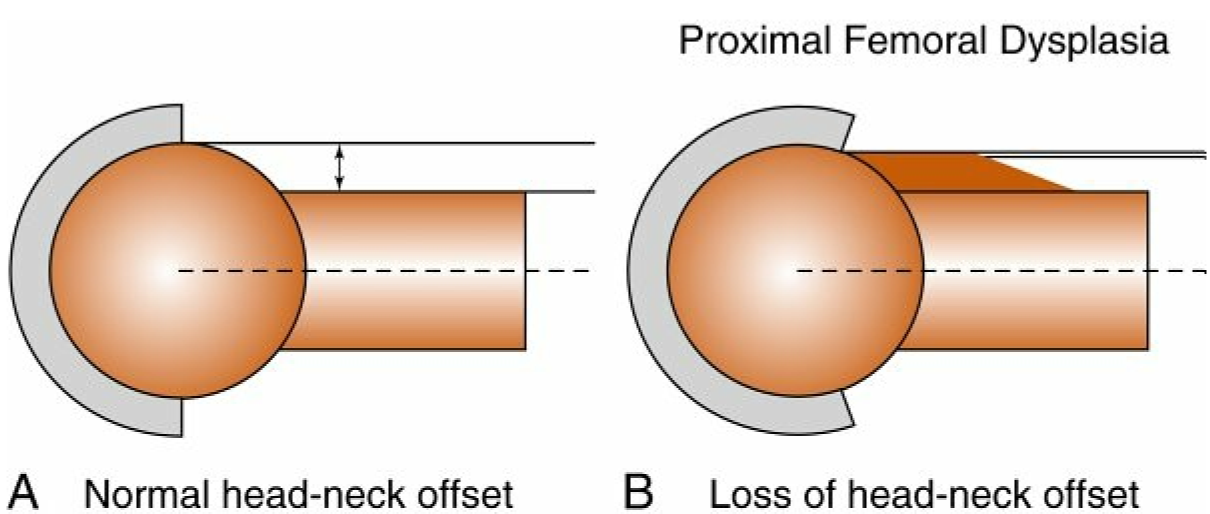


FIG. 5.4 (A) Diagram demonstrating normal head-neck offset. Offset is measured using lines parallel to the line defining the femoral head center and neck midline. (B) In femoral neck dysplasia, the offset between the femoral head and neck is significantly reduced. A reduced head-neck offset increases the risk for neck impingement upon the acetabular rim.

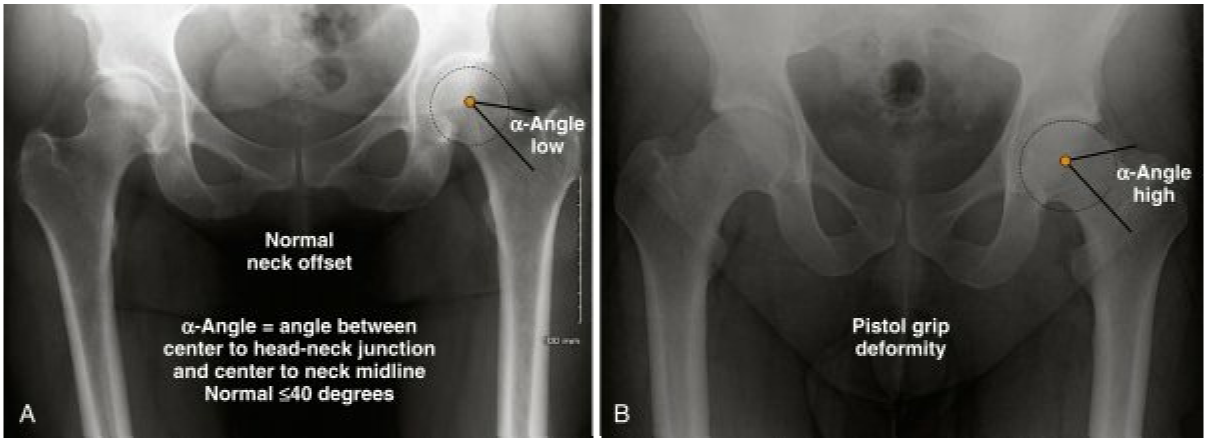


FIG. 5.5 (A) AP radiograph measuring α-angle. The α-angle is a method to evaluate head-neck dysplasia. The α-angle is formed between the lines of femoral head center and neck midline, and femoral head center and head-neck junction. Normal α-angle is typically 40 degrees or less. (B) AP radiograph measuring α-angle in a dysplastic proximal femur. α-Angle is increased.

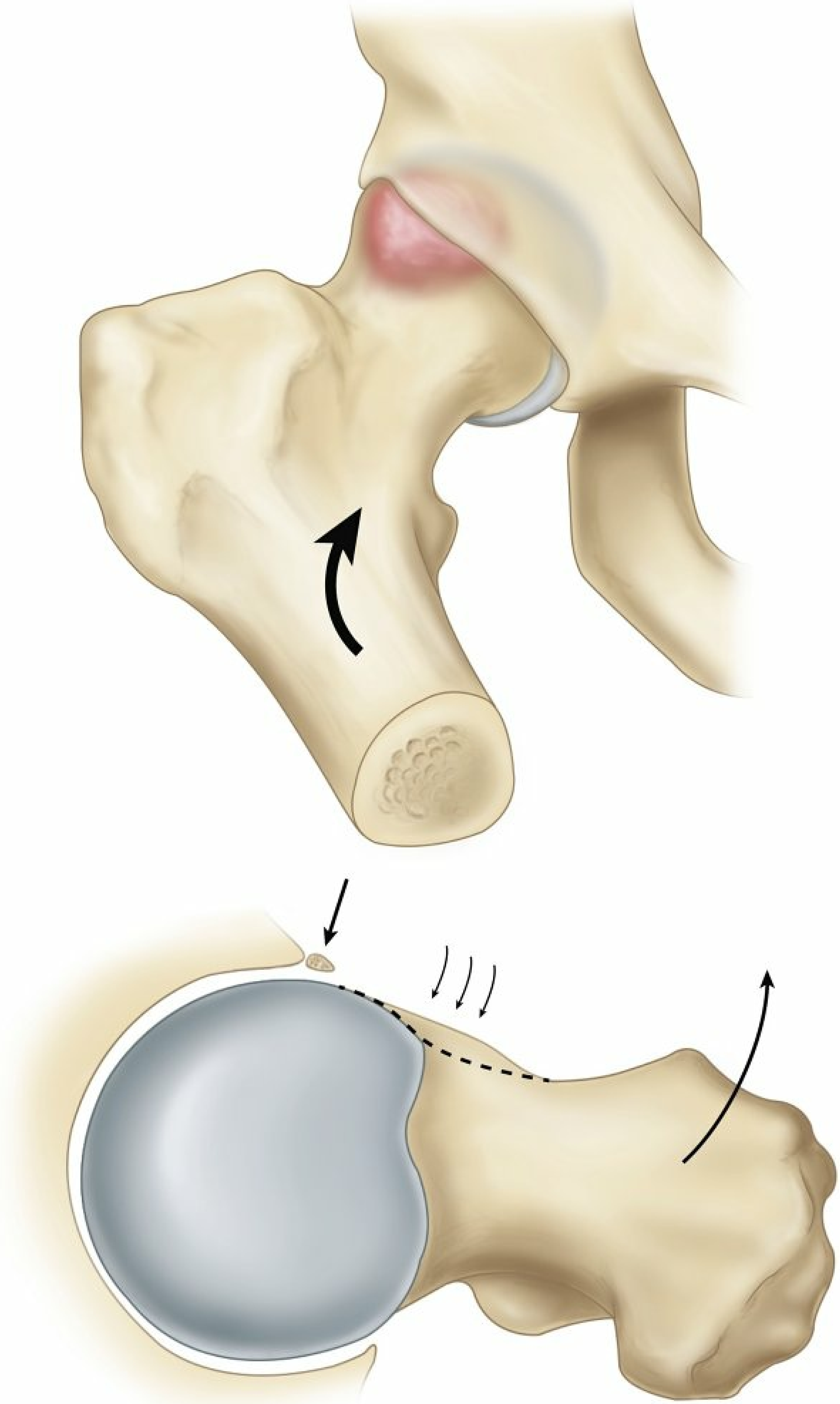


FIG. 5.6 Cam-type impingement: a femoral side disorder in which an aspherical femoral head

(three curved arrows) causes impingement of the neck against the anterior edge of the acetabulum *(straight arrow)* during flexion, resulting in labral injury and chondral delamination.

Section 3 Osteonecrosis of the Hip

Occurrence

- **Incidence not precisely known**
- **No comprehensive information on number of asymptomatic cases**
- **More common in males**
- **Typically affects patients in late 30s or early 40s**

Etiology (see Chapter 1, Basic Sciences)

- **Hypercoagulable states may explain many** *idiopathic* cases of osteonecrosis of the hip.
- **In all cases, end-stage result is vascular occlusion in the juxtaarticular sinusoids adjacent to joint.**

Clinical Presentation

- **Initial pain with sit to stand, stairs, inclines, and impact loading**
- **Pain location tends to be most noticeable in anterior hip.**
- **Can be acute in onset (acute infarct phenomenon), which can mimic an acute injury**

Imaging

- **Radiography initial study**
  - Pelvis, AP, and lateral radiographs
  - If osteonecrosis detected, contralateral hip must be imaged
    - 50% of osteonecrosis cases have bilateral involvement.
- **MRI is the standard imaging modality when radiographic findings are negative and osteonecrosis is suspected.**

Staging (Table 5.1)

- **Modified Ficat system (incorporates MRI information)**

Treatment

- **Nonsurgical**

- Bisphosphonate treatment may decrease risk for head collapse, although this issue is controversial and potential serious adverse effects are associated with these medications.

- **Surgical treatment**
  - Surgical treatment depends on these major variables
    - Head collapse (i.e., crescent sign)
    - Age
    - Extent of head involvement (by osteonecrosis)
      - Described as *volume* head involvement
      - Volume head involvement equals percentage of head involved on AP image multiplied by percentage of head involved on lateral image (e.g., 50% × 50% = 25% volume head involvement).
      - A—small lesion: less than 15% head involvement
      - B—medium lesion: 15% to 30% head involvement
      - C—large lesion: greater than 30% head involvement
  - Younger patient with no crescent sign
    - Common treatments
      - Core decompression
        - Treatment principles
          - Core decompression relieves pressure buildup within the femoral head by the inflammatory process.
          - Pressure relief translates to pain relief.
          - Stimulates a healing response
            - Bone and vascular neogenesis
        - Indications
          - No crescent sign
          - Patients on long-term steroid therapy have poor results with core decompression.
          - Small head lesion (A lesion)
            - Patients with medium and large head lesions

frequently experience femoral head collapse.

- Vascularized fibular strut (Fig. 5.7)
    - Treatment principles
        - Surgical removal of necrotic segment
        - Large core hole is needed.
        - Vascularized fibular strut is placed up against subchondral plate of femoral head to prevent collapse.
        - Particulate autogenous bone grafting of adjacent resected bone
    - Indications
        - Medium (B) and large (C) lesions
        - No crescent sign (preferred)
            - Reasonable success with crescent sign and minimal head collapse
- Less common treatments
    - Curettage of necrotic bone and bone grafting through femoral neck trap door
    - Rotational proximal femoral osteotomy
        - It must be possible to rotate osteonecrotic segment out of weight-bearing zone and maintain good hip function.

Table 5.1

Modified Ficat Staging System for Osteonecrosis of the Hip

Stage	MRI	Bone Scan	Radiographs	Patient Status
0	Positive	Positive	Negative	Asymptomatic
1	Positive	Positive	Negative	Symptomatic
2	Positive	Positive	Positive—no crescent	Symptomatic
3	Positive	Positive	Positive—crescent	Symptomatic
4	Positive	Positive	Positive—head flattening, DJD	Symptomatic

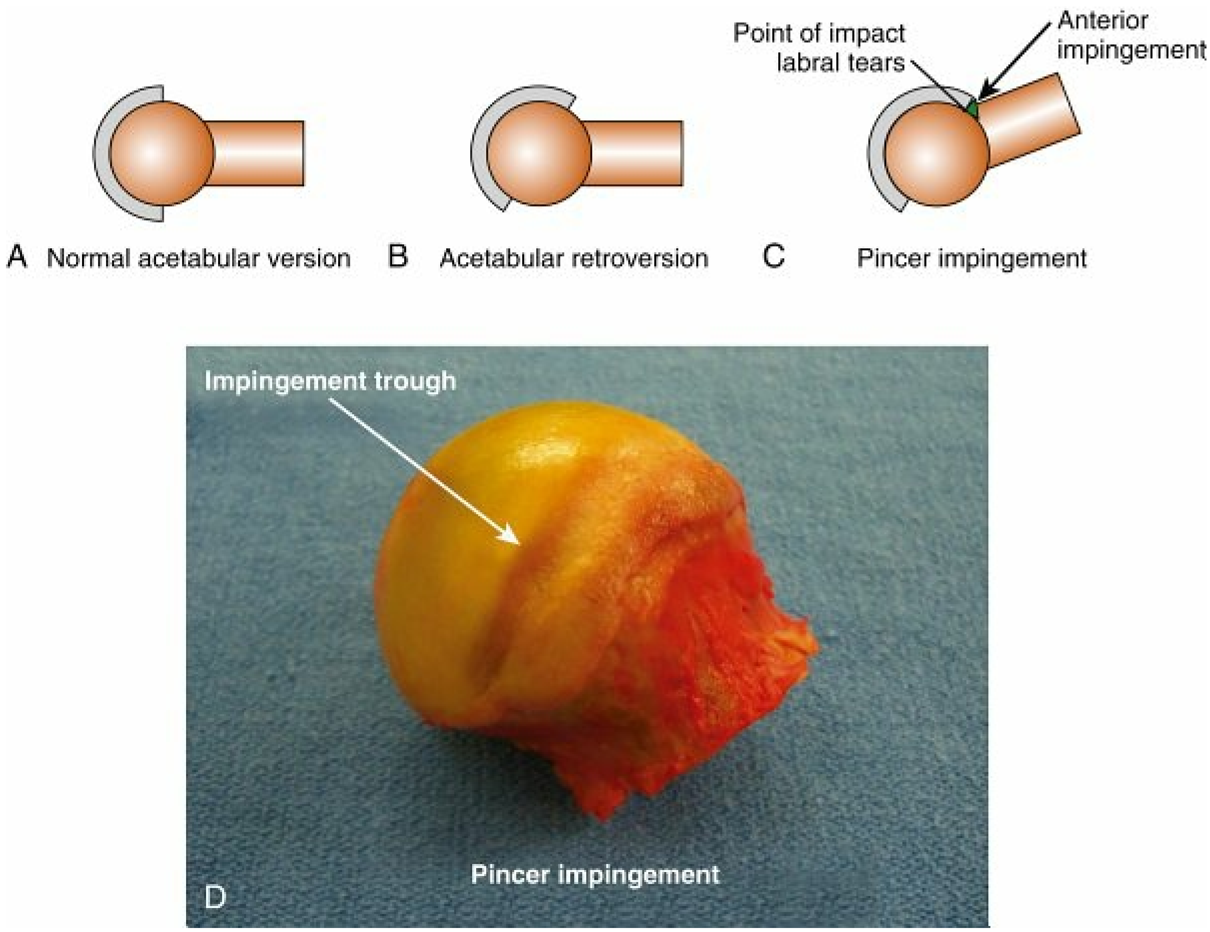


FIG. 5.7 Pincer-type femoral acetabular impingement. (A) Diagram showing normal acetabulum and proximal femur. (B) Diagram depicting acetabular retroversion. Retroverted acetabulum limits functional hip flexion. (C) Mechanics of pincer impingement. In hip flexion, femoral neck abuts acetabular rim. Typical result is localized damage to the labrum. (D) Ex vivo demonstration of pincer impingement. In this case, repetitive pincer impingement created a bony indentation trough on the femoral head at the site of flexion impingement.

- □ Patient 40 years or older with medium (B) or large (C) lesion
  - Best option is total hip replacement.
  - Medium to large lesions prone to collapse
- □ Patient older than 40 years with small (A) lesion
  - Best option is core decompression.

        - Core decompression relatively contraindicated if on chronic corticosteroid treatment
        - Result of vascularized fibular graft less predictable in older population
    - Presence of crescent sign (impending subchondral collapse) or worse
        - **THA is recommended treatment regardless of age**
        - Cementless cup and stem
        - Advances in bearing technology has improved durability in young patients
        - Good pain relief and function

Transient Osteoporosis of the Hip

- **Uncommon cause of groin pain and inability to bear weight**
- **Commonly affects pregnant women or patients in their fifth decade of life**
- **Radiographs may appear normal or show only subtle osteopenia in the head and neck.**
- **MRI appearance is similar to that in bone marrow edema, with diffusely increased signal in the head and neck on T2-weighted images.**
- **Spontaneous recovery may take several months and often resolves in the pregnant patient early in the postpartum period.**
- **Protected weight bearing to protect against stress fracture**
- **Surgical intervention rarely indicated**

Section 4 Treatment of Hip Arthritis

Nonoperative

- **Activity modification**
  - Reduction of impact-loading exercises
  - Reduction of weight
  - Avoidance of stairs, inclines, squatting
  - Physical therapy
- **Nonnarcotic medications**
  - NSAIDs
  - Evidence does not support the use of glucosamine sulfate.
- **Joint injections**
  - Corticosteroid—antiinflammatory treatment
  - Hyaluronate
    - Backbone of proteoglycan chain of articular cartilage
    - No strong evidence to support use in the hip
    - Not approved by FDA for hip use in United States
- **Assist device (cane or crutch)**
  - Opposite hand of affected hip

Operative

- **Arthroscopy**
  - **Limited indications in patients with radiographic evidence of arthritis**
  - Preoperative joint space narrowing is negative predictor of a good clinical outcome.
- **THA**
  - See Section 5, Total Hip Arthroplasty.
- **Hip fusion**
  - Less frequently used as THA technology advances
  - Classic indications
    - Very young male laborer
    - *Unilateral* hip arthritis
  - Energy expenditure
    - Approximately 30% increase in energy output during ambulation
  - Contralateral arthritis
    - Abnormal gait causes arthritis in these adjacent joints in 60% of patients.
      - Lumbar spine

            - Contralateral hip
            - Ipsilateral knee
        - Symptoms of pain typically start within 25 years of hip fusion.
    - Hip fusion technique
        - Preservation of abductor complex.
            - Many fusions are taken down for disabling pain in adjacent joints.
            - Selection of fusion technique that allows successful conversion to THA.
            - Greater trochanteric osteotomy with lateral plate fixation is preferred technique.
            - Care must be taken not to injure superior gluteal nerve, which innervates abductor complex.
        - Fusion position
            - 20–25 degrees of flexion
            - *Neutral abduction*
                - Increased back and knee pain when fusion is in abduction
            - Neutral or slight external rotation of 10 degrees
    - Fusion conversion to THA
        - Indications
            - Disabling back pain—most common
            - Disabling ipsilateral knee pain with instability
                - Excess knee stress will cause knee ligament stretch-out if fusion position is incorrect.
            - Disabling contralateral hip pain
    - Function after conversion to THA
        - **Hip function and clinical results directly related to integrity of abductor complex**
            - Preoperative electromyogram of gluteus medius may be helpful.
        - When hip abductor complex nonfunctional
            - Severe lurching gait results
            - Very high risk for instability; may require *constrained* acetabular component
- **Resection arthroplasty**
    - Indications
        - Incurable infection
            - Patients are most often immunocompromised.
            - Recurrent periprosthetic THA infection
            - Failed hip fusion with infection

- Chronic destructive septic arthritis
- Noncompliant patient with recurrent THA dislocation
- Nonambulator
  - Intractable pain from arthritis
  - Hip fracture with open decubitus ulcers
  - Significant contracture interfering with hygiene and posture
- Failed hip fusion in patient with prior major trauma to hip and/or pelvis
  - Soft tissue loss to hip region precludes successful placement of THA.
  - Neurologic injury to extremity precludes successful function of THA.

▪ **Hemiarthroplasty**

- Not routinely used in the treatment of arthritis and is relegated to specific limited role
  - Fracture treatment in low-demand elderly patient
    - Best indication—displaced subcapital hip fracture with little or no prior history of symptomatic hip arthritis
    - Patient not able to comply with standard THA precautions (dementia)
    - High risk for dislocation (Parkinson disease)
- Advantages
  - Reduced surgical time
  - Stability
    - Maximizes head-neck ratio.
    - Large-diameter ball requires more distance to travel before dislocation.
    - Suction fit provided by labrum (may be negated if labrum and capsule resected)

- Disadvantages
    - Groin pain in active individuals
    - **Increased risk for need for conversion to THA in active individual due to acetabular erosion**
    - Protrusio deformity may result, particularly if osteoporosis present (Fig. 5.8)

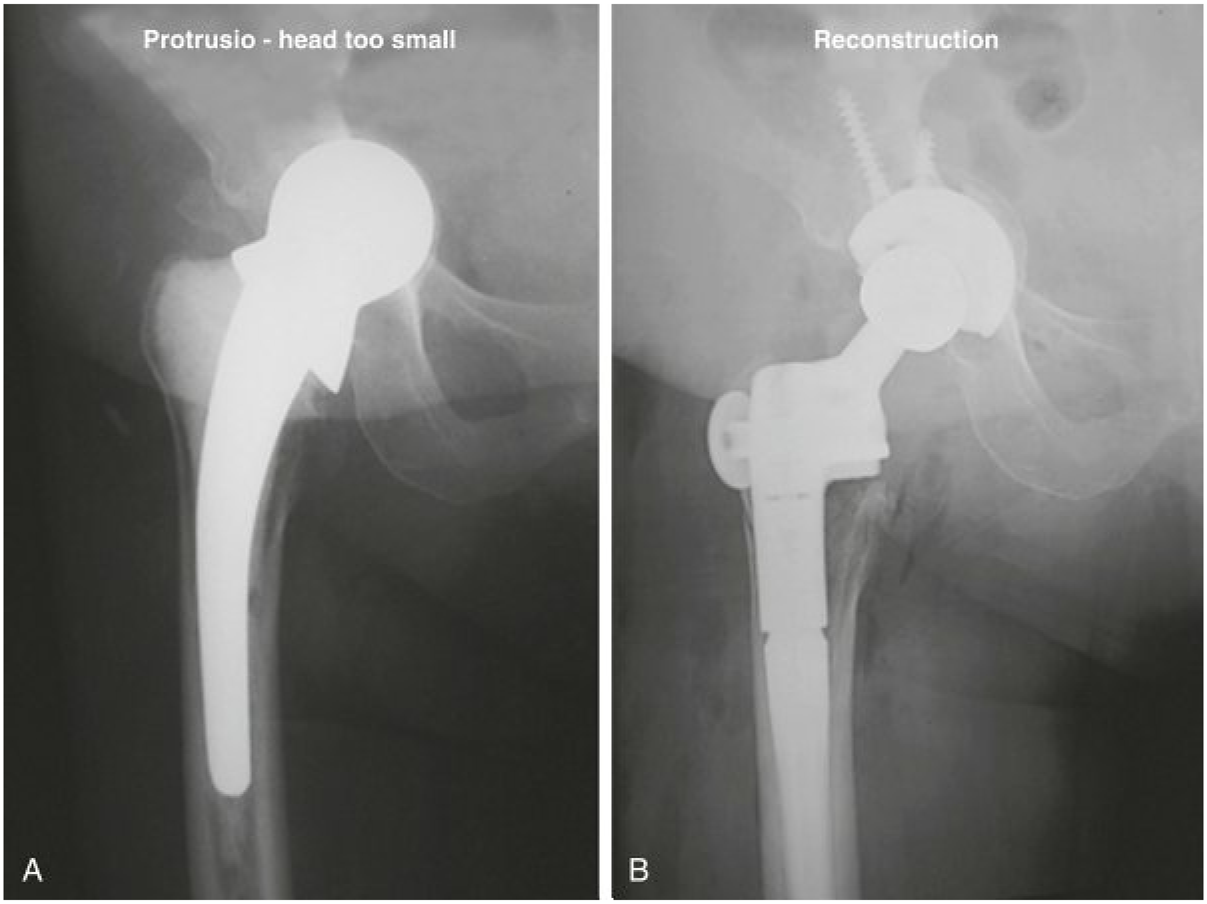


FIG. 5.8 Protrusio deformity. (A) AP radiograph demonstrating protrusio deformity of cemented hip hemiarthroplasty. This patient suffers from osteoporosis. (B) Conversion to THA. Hip successfully reconstructed with protrusio revision cup with screws. Bone graft is placed into protrusio deformity.

Section 5 Total Hip Arthroplasty

Indications

- **Debilitating pain affecting activities of daily living**
- **Pain not well controlled by conservative measures**
- **Patient medically fit for surgery**
- **No active infection—anywhere**

Surgical Approaches

- **The most common surgical approaches for THA are listed in** Table 5.2.

Templating

- **Templating for THA can help achieve appropriate restoration of biomechanics and avoid complications.**
- **Standard radiograph with a known magnification and calibration marker should be used.**
- **Goal is to optimize limb length and femoral offset (** Fig. 5.9).

Implant Fixation

- **Methods of fixation**
  - Cement
    - Polymethylmethacrylate (PMMA)
  - Cementless
    - Biologic fixation—bone growth into the prosthesis secures implant.
    - Two methods
      - Bone *ingrowth*—porous coating
      - Bone *ongrowth*—grit coating
    - Cup
      - Porous-coated cementless cup is preferred choice.
      - Porous-coated hemispheric cementless cups have reliable long-term results.
    - Stem
      - Both cementless and cemented fixation methods are acceptable techniques in primary THA.
      - Cementless stem indications

- High–activity-level patient (cement would cyclically fatigue over time)
- Young male patient (higher loading stress would cause cement cracks at stress points)
- **Cement fixation**
  - Microinterlock with endosteal bone
  - Cement fatigues with cyclic loading.
    - Fatigue starts at stress points within the cement mantle.
    - A *mantle defect* is an area where the prosthesis touches bone. This is an area of significant stress concentration (Fig. 5.10).
  - Cemented cups fail at a higher rate than cemented stems.
    - Acetabular cup is positioned at an angle (i.e., theta [Θ] angle) relative to longitudinal axis of leg. This creates shear and tension forces at cement-bone interface.
    - **Cement is strongest in *compression* and weaker in tension.**
    - Cemented stems fail at a lower rate than cups because stems have primarily a compression force.
- **Cemented stem failure**
  - Young, active patients are thought to have increased risk for failure over time.

Table 5.2

Most Common Surgical Approaches for THA.

Approach	Muscular Interval	Internervous Interval	Structures at Risk	PROS	CON
Anterior (Smith-Petersen)	Superficial: sartorius and tensor fascia latae Deep: rectus and gluteus medius	Femoral nerve and superior gluteal nerve	Lateral femoral cutaneous nerve Ascending branch of the lateral femoral circumflex artery	Stability Rapid recovery	I I A
Anterolateral approach (Watson-Jones)	Tensor fascia latae and gluteus medius	None	Branch of the superior gluteal nerve	Stability	I I
Lateral approach (Hardinge)	Splitting of the gluteus medius and sometimes vastus lateralis	None	Superior gluteal artery and nerve	Stability Better exposure of femur than with anterior and anterolateral approaches	I F
Posterior or posterolateral (Southern)	Splitting of the gluteus maximus Tenotomies of the external rotators	None	Sciatic nerve	Extensile approach Quick recovery Low rate of complications	Sligl c r

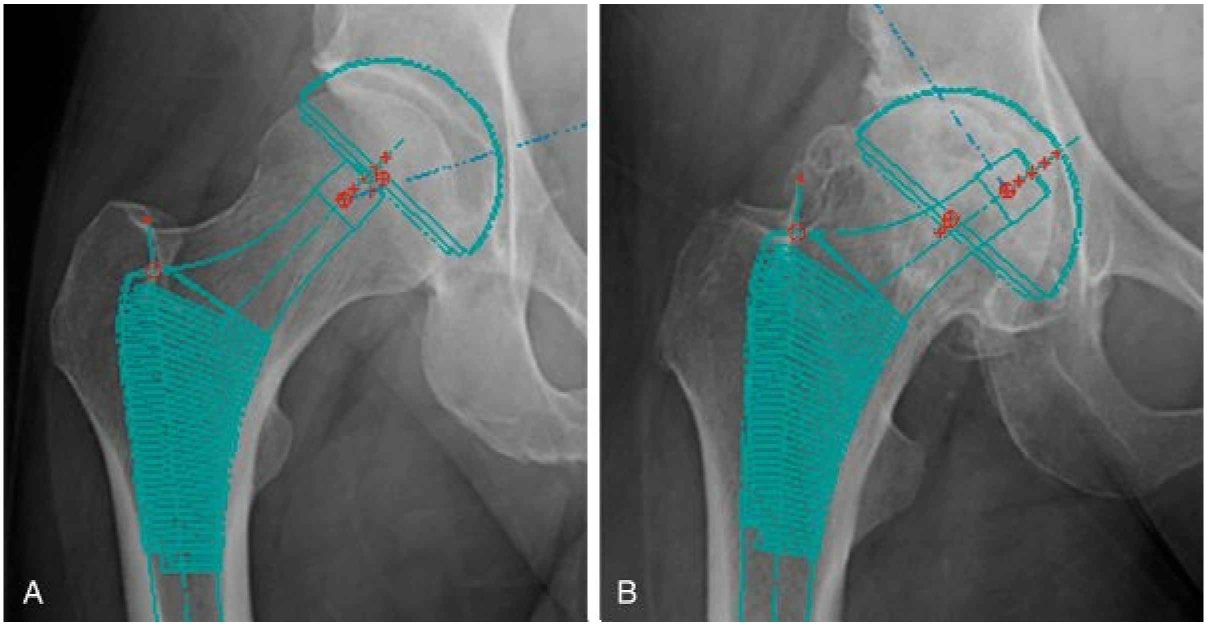


FIG. 5.9 (A) If the hip is inserted as templated, the expected outcome would be decreased leg length and offset in relation to the native hip. (B) In comparison, the patient in this radiograph would have increased leg length and offset.

- International registry data have demonstrated good survivorship with many cemented stem designs.

- **Cement technique—tips for success**
  - Porosity reduction during mixing
    - Decreased porosity reduces stress points in cement.
    - Vacuum mixing—most common method to reduce cement porosity
  - *Pressurization* of cement before component insertion
    - Enhances cement interdigitation with bone
  - *Pulsatile lavage* of bone before cementing
    - Clean, dry bone allows better cement interdigitation.
  - *Stem centralization* with distal stem centralizer
    - Maintains uniform cement mantle (i.e., no mantle defects)
  - *Stiff stem* lessens bending stress on cement mantle.
    - Cobalt chromium and stainless steel stems have performed better than titanium.
- **Biologic fixation**
  - Bone ingrowth (Fig. 5.11)
    - Prosthesis is fabricated with metal pores into metallic alloy. Bone grows into the porous structure, stabilizing the prosthesis to bone.
    - Successful bone ingrowth is based on the following factors:
      - Optimal pore size
        - Between 50 and 200 μm
      - Pore depth (i.e., deeper distance into metal) must be sufficient to allow for fixation strength.
        - Bone will not grow in deeper than 150

μm from the surface of the porous metal

- Optimal metal porosity
    - Porosity of 40%–80% appears to work.
    - Increased porosity is preferential for bone ingrowth but reduces mechanical properties.
- Minimize gap distance between prosthesis and bone.
    - Gaps between metal and bone must be less than 50 μm.
    - Bone will not grow across anything wider.
- Minimal implant micromotion
    - **Implant must have an *initial rigid fixation* for bone to grow into prosthesis.**
        - Bone fixation required with less than 50 μm micromotion
        - Fibrous fixation occurs with greater than 150 μm micromotion.
        - Fibrous encapsulation will result from macromotion.

FIG. 5.10 Lateral radiograph of cemented femoral stem with mantle defect. Note distal stem tip touching bone.

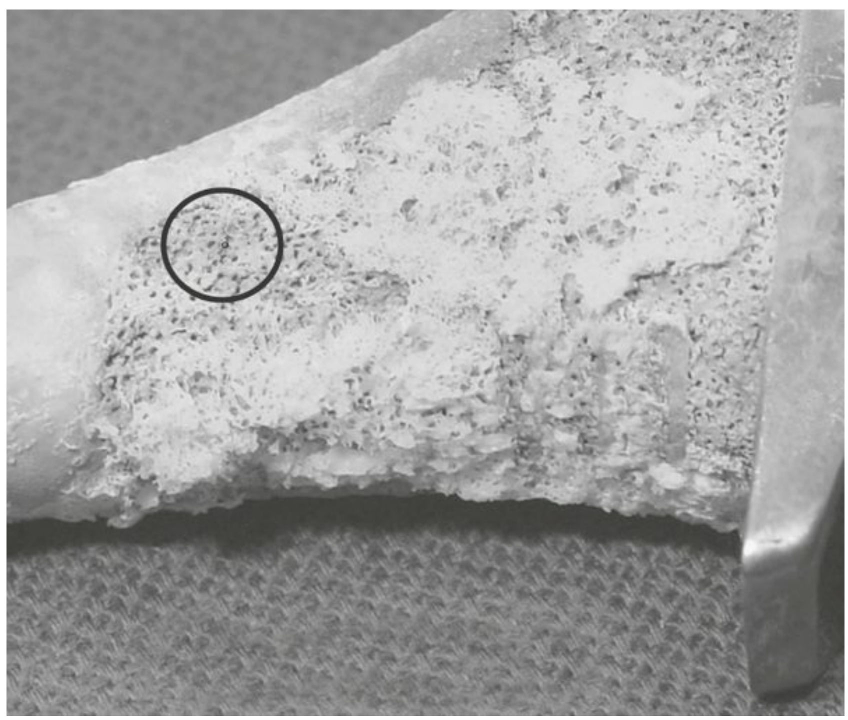


FIG. 5.11 Ex vivo retrieval of bone ingrowth femoral stem. Note metallic pores *(circle)* that allow bone to grow into prosthesis and osteointegrate.

- Cortical contact with bone
    - Cancellous bone is not weight bearing

- Implants must be placed upon cortical bone to allow physiologic load transfer to weight-bearing regions of bone.
- Shear and torsional strength stronger when implant is adjacent to cortical bone as opposed to cancellous bone
- Viable bone
  - Prior irradiation to pelvis and hip increases risk for aseptic loosening of bone ingrowth/ongrowth implants, and cement fixation may be considered.

▪ **Initial rigid fixation for cementless hip implants**
  - Initial rigid implant fixation to host bone is required for long-term osteointegration. Two techniques are used: *press fit* technique and *line-to-line* technique.
  - Press fit technique (Fig. 5.12)
    - Bone is prepared such that a slightly oversized implant (relative to bone contour) is wedged into position.
      - Femoral stem typically has a gradual taper design to allow press fit into bone. Stem is typically 0.5 to 1 mm larger.
      - Acetabular cup is a hemispheric design. Cup is typically 1 mm larger. Press fit is against the acetabular rim. Screws are *not* required.
    - Complications
      - Fracture is the most common complication.
        - The main reason for fracture is *underreaming.*
      - Acetabular fracture
        - If cup is stable, screws should be added.
        - If cup is unstable, cup is removed and fracture stabilized. Cup is reinserted with screws.
      - Femur fracture
        - Femur fractures are typically *proximal* in the calcar and due to wedge splitting of bone.
        - Calcar facture should be visualized to ensure it does not propagate distally.
        - Stem is removed and calcar fracture

typically stabilized with cerclage wires or cables. Stem is reinserted. If stem is unstable, then revision stem is inserted to obtain fixation distally in diaphysis.

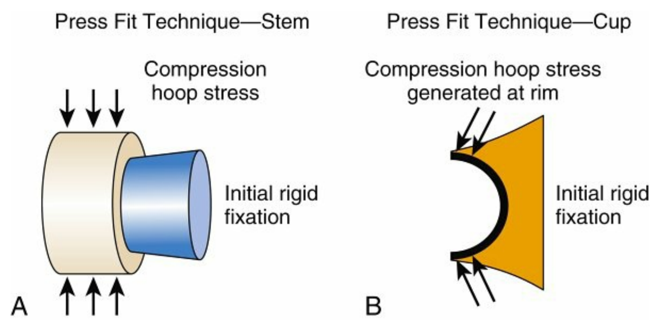


FIG. 5.12 Diagram of press fit technique for cementless hip fixation. (A) The canal of the femur is prepared with serial reaming and/or broaching to achieve desired implant size (remembering that cortical contact is preferred). An implant of slightly larger size is impacted into position. The stem usually has a gradual wedge taper. The wedging effect generates compression hoop stresses that hold the implant still to allow bone to grow into the implant interface. (B) The acetabulum is prepared with serial hemispheric reamers to achieve desired implant size (reaming to cortical margin of acetabular rim). An implant of slightly larger size is impacted into position. The wedge effect occurs at the rim of the acetabulum. The compression hoop stress generated at the rim holds the implant still to allow bone to grow into the implant interface.

□ Line-to-line technique

- Bone is prepared such that contour of bone is same size as implant.
    - Femoral stem has an extensive porous coating that provides an initial frictional fit. The rough surface provides enough resistance to motion that the implant is stable once impacted into final position. The frictional fit is also known as scratch fit or interference fit.
    - Acetabular cup is placed into position. Cup is a hemispheric design. Cup is secured with multiple screws placed into bone.

- Complication
  - Fracture is complication seen with femoral stem insertion; fracture typically occurs at distal stem tip.
    - The force required to insert a straight stem into a bowed femur with a frictional fit can exceed the strength of the bone. The area of stress concentration is at the stem tip because of the modulus mismatch (bone/implant proximal vs. hollow bone distal).

Bone Ongrowth Fixation

- **Description**
  - Prosthetic surface is prepared by blasting of the surface with an abrasive grit material. Nickname is *grit blast fixation.*
  - Grit blasting process creates microdivots—no pores, just divots. Divot diameter approximately the same size as pore hole for a porous-coated implant.
  - Bone grows *onto* rough surface, stabilizing prosthesis.
  - Surface roughness (R_a) (Fig. 5.13)
  - R_a is defined as average peak to valley on the surface of the implant.
  - Implant roughness determines strength of biologic fixation.
    - Linear relation of R_a to fixation strength
- **Technique**
  - Initial rigid fixation of implant is always a *press fit* technique.
  - Femoral stem design is typically a high-angle, double-wedge taper (wedge in both coronal and sagittal planes) (Fig. 5.14).
  - Grit surface is extensile. Fixation strength with grit blast fixation is significantly lower than that with porous coating, and therefore the area of surface coating is greater.
  - There are very few cups designed with bone ongrowth surface coating.
- **Complication**
  - Aseptic loosening
    - Stem settling occurs when initial rigid fixation is not good enough to allow osteointegration.

Hydroxyapatite

- **Hydroxyapatite may be used as surface coating on implants designed for** cementless fixation.

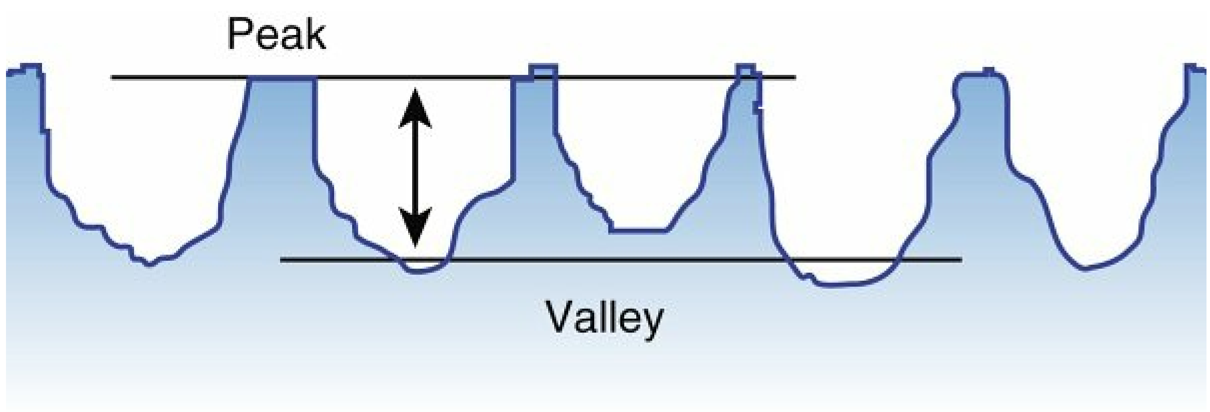


FIG. 5.13 Surface roughness (R_a) of bone ongrowth prosthesis. R_a is defined as the average peak to valley on the surface of the implant. The value is typically expressed in micrometers (μm).

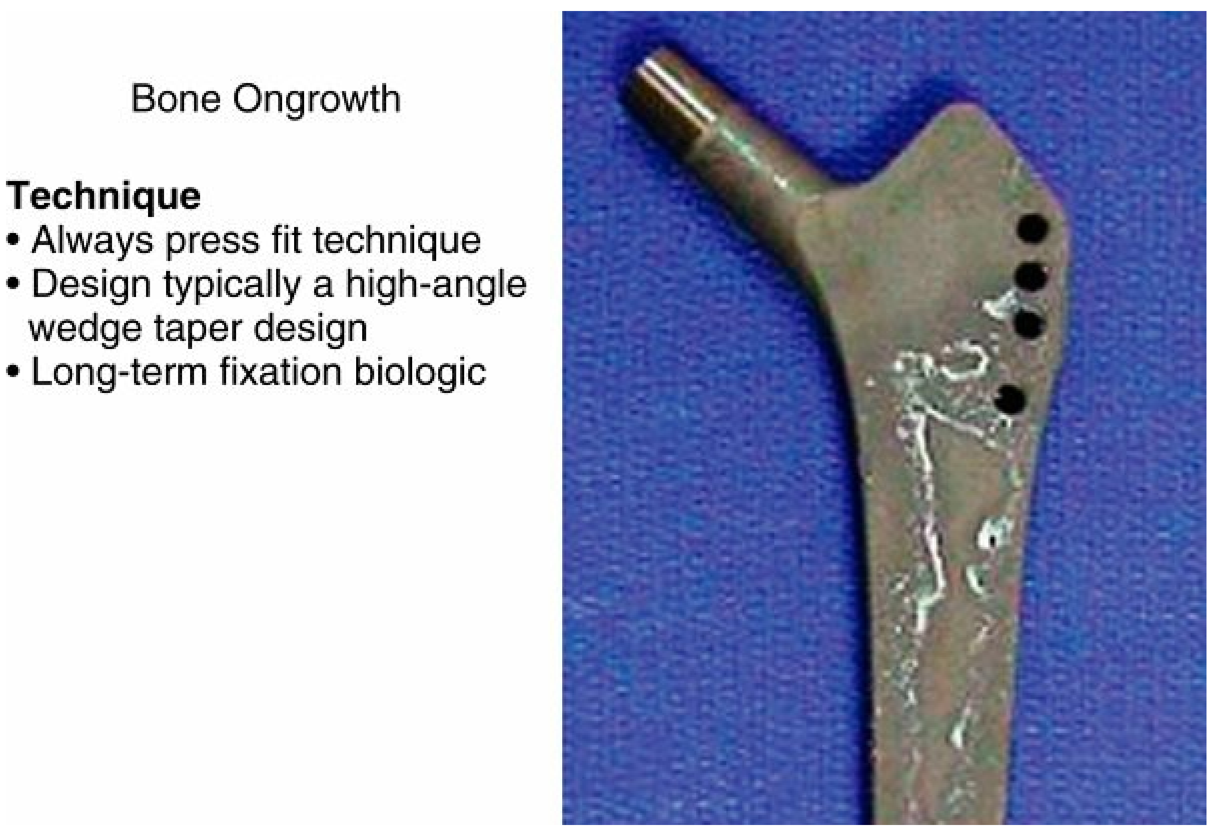


FIG. 5.14 Retrieval photograph of bone ongrowth stem. The stem has a sharp angle wedge design in two planes. The edges of the implant are sharp to provide rotational stability. Note the rather scant amount of bone on the surface of this prosthesis. Implant was found biologically stable at the time of removal.

- **Formula is Ca** $_{10}(PO_4)_6\ (OH)_2$.
- *Osteoconductive* only
- **Effect—allows more rapid closure of gaps between bone and prosthesis**
  - ◻ Bidirectional closure of space between prosthesis and bone
  - ◻ Osteoblasts adhere to hydroxyapatite surface during implantation and then grow toward bone.
  - ◻ **Clinically shortens time to biologic fixation**
- **Success requires**
  - ◻ High crystallinity—amorphous areas of hydroxyapatite will dissolve.
  - ◻ Optimal thickness—a thick coating will crack and shear off.
    - Thickness less than 50–70 μm preferred
  - ◻ Surface roughness
    - Higher implant R_a provides increased metal-hydroxyapatite interface fracture toughness.

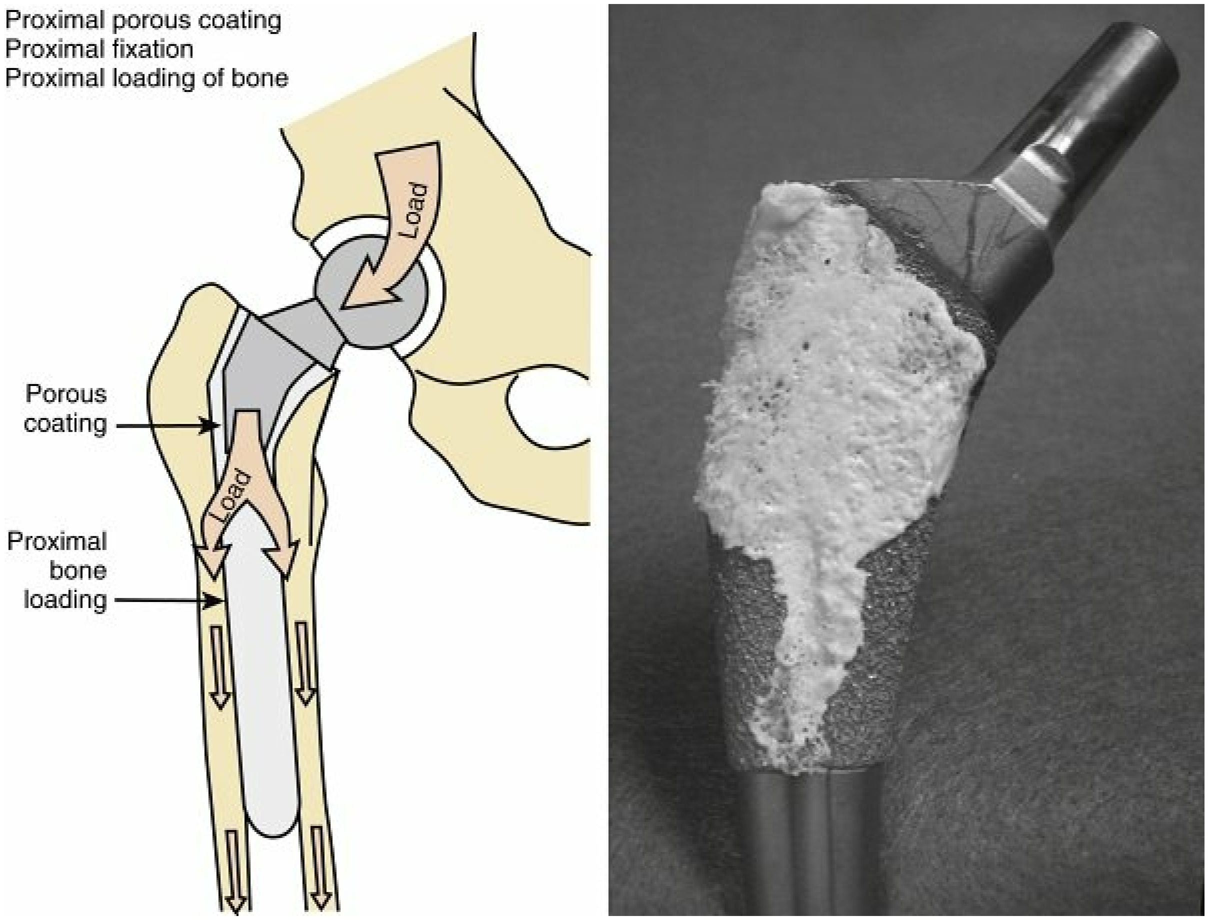


FIG. 5.15 Diagram and retrieval photograph of proximal bone loading in a proximal porous-coated implant. With proximal porous coating, loading forces are transferred through the porous coating into the metaphysis and proximal diaphysis. This helps maintain proximal bone density.

Femoral Stem Loading

- **Proximal porous coating (** Fig. 5.15)
  - Mechanical load is transferred to metaphysis and proximal diaphysis. This is termed *proximal bone loading.*
  - Proximal bone density is better maintained with proximal porous-coated implants.
- **Extensive porous coating (** Fig. 5.16)
  - More of the mechanical load bypasses the proximal femur because porous ingrowth is present throughout the diaphysis. This is termed *distal bone loading.*
  - In a well-fixed extensively porous-coated femoral stem there will be endosteal consolidation of bone near the end of the stem. This is called a *spot weld* (Fig. 5.17).
- **Cemented stem**
  - In a well-fixed cemented stem, the mechanical load is distributed throughout the cement mantle. As with an extensively porous-coated stem, more of the load bypasses the proximal femur. A cemented femoral stem is considered *distal bone loading.*

Femoral Stress Shielding

- **Description**
  - **Proximal femoral bone density loss observed over time in the presence of a solidly fixed implant**; typically applies to cementless implants
- **Etiology**
  - *Stem stiffness* is main factor.
    - **Problem is modulus mismatch between stem and femoral cortex.**
- **Factors affecting stem stiffness**
  - Stem diameter is most important.
    - Stem stiffness approximates *radius* ^{4} of stem.
    - Larger-diameter stems are exponentially stiffer.
  - Metallurgy
    - Co-Cr (cobalt-chrome) alloy is stiffer than titanium alloy.
  - Stem geometry
    - More stiff
      - Solid and round stems
    - Less stiff
      - Hollow stems, slots, flutes, taper designs
- **Typical scenario creating stress shielding**
  - Large-diameter stem, of 16 mm or greater
  - Co-Cr alloy stem
  - Round, solid, cylindrical stem shaft
  - Extensive porous coating
  - Distal bone loading

Femoral Stem Breakage (Fig. 5.18)

- Failure mode is ***cantilever bending.***
  - Seen with smaller-diameter stems (cemented or cementless)
- **Clinical scenario**
  - Stem is fixed distally and loose on top.
  - Loading of stem creates cyclic bending stress.
  - Fracture occurs generally in middle portions where stems taper and become thin.

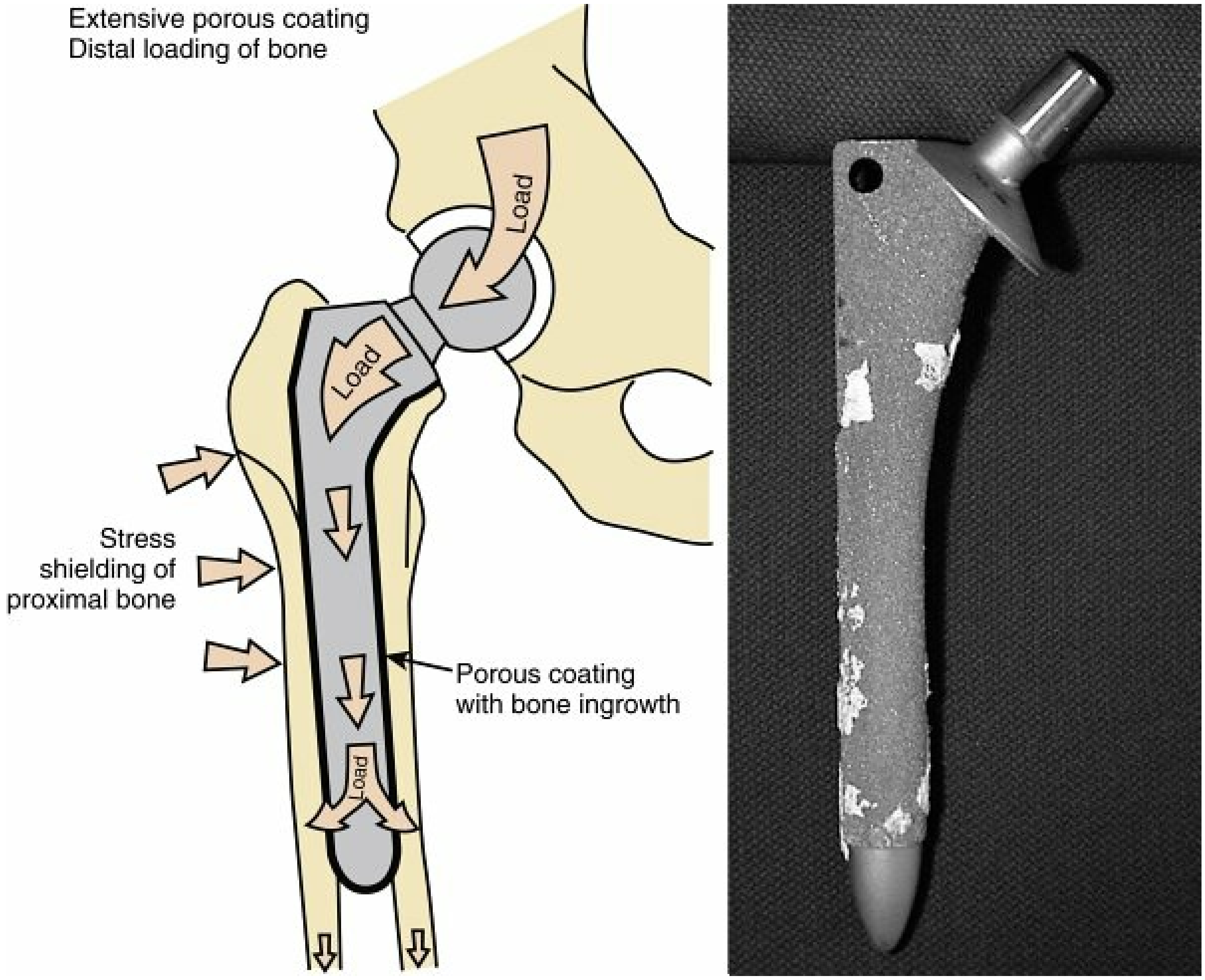


FIG. 5.16 Diagram and retrieval photograph of distal bone loading in an extensively porous-coated prosthesis. With extensive porous coating, a majority of bone ingrowth occurs in the femoral diaphysis. Loading forces are transferred through the porous coating into the more distal diaphysis. As a result, bone density in the proximal femur is reduced because it does not experience as much load.

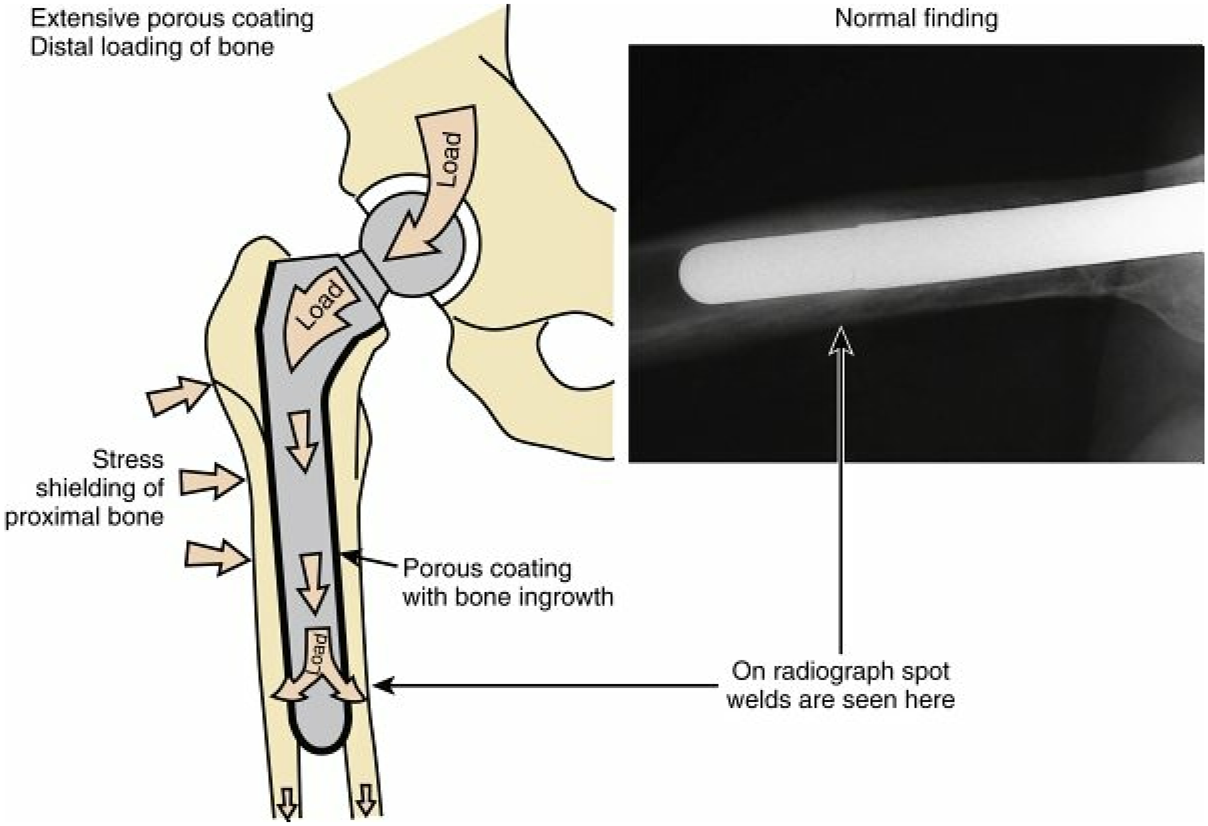


FIG. 5.17 Diagram and radiograph of spot weld. A spot weld indicates stable osteointegration of an extensively porous-coated implant. In contrast, a bony pedestal is bone accumulation within the medullary canal below the tip of a mechanically loose stem. The bony pedestal seeks to keep the stem from sinking farther down the medullary canal.

FIG. 5.18 Photograph of stems retrieved because of stem fracture. Stem on the left was cemented. Stem on the right was cementless. Both stems have narrow diameters, and both fractured in the typical region—the transition to the narrow part of the stem.

Section 6 Revision THA

Presentation

- ***Start-up pain* is the most common initial presentation of loosening.**
    - Groin pain indicates a loose acetabular cup.
    - Thigh pain indicates a loose femoral stem.
- **Infection must always be ruled out as a cause of pain.**
- **Anterior iliopsoas impingement and tendinitis may be the cause of groin pain in THA when a prominent or malpositioned cup is present and no other causes can be found.**

Acetabular Side (Fig. 5.19)

- **Identification of bone defects in acetabulum and pelvis**
    - *Cavitary deficiency* is a loss of cancellous bone without compromise of main structural bone support.
    - ***Segmental deficiency* is loss of main bony support structures.**
        - Acetabular rim
        - Acetabular column
        - Medial wall
    - Combined deficiencies
- **Well-fixed cementless implant with osteolytic defect**
    - Can be treated with débridement, bone grafting, and bearing component exchange without revision of the cup.
        - Contraindications to this approach are a poorly positioned cup, poor implant design, an ongrowth fixation surface, or damaged locking mechanism.
- **Significance of bone defects**
    - Major segmental bone deficiencies require a reconstruction cage, structural bone graft, or modular porous metal augments.
    - A structural bone graft (a graft that reconstructs a segmental defect) alone without a cage has a high loosening rate.
- **Fixation revision of acetabulum (** Table 5.3)
    - Cementless porous biologic fixation is preferred.
        - A cemented cup with impaction bone grafting is used more frequently outside of North America.
    - **Hemispheric porous cup with screws is most common solution.**
        - Must have at least two-thirds of rim and a reasonable initial press fit to work
        - Requires at least 50% contact with host acetabular bone

- Recommended cup replacement is to re-create the native center of rotation.
  - Cup placement should be inferior and medial (i.e., low and in).
  - Lowest joint reactive forces
  - Cup placement superior and lateral (i.e., up and out) is not recommended.
    - Highest joint reactive forces
    - Higher wear and component loosening
- Filling of cavitary deficiencies with particulate bone graft.
- Acetabular porous metal wedge augmentation is an acceptable adjuvant to hemispheric cup to achieve stability and fixation when necessary.

□ Reconstruction cage (Fig. 5.20)

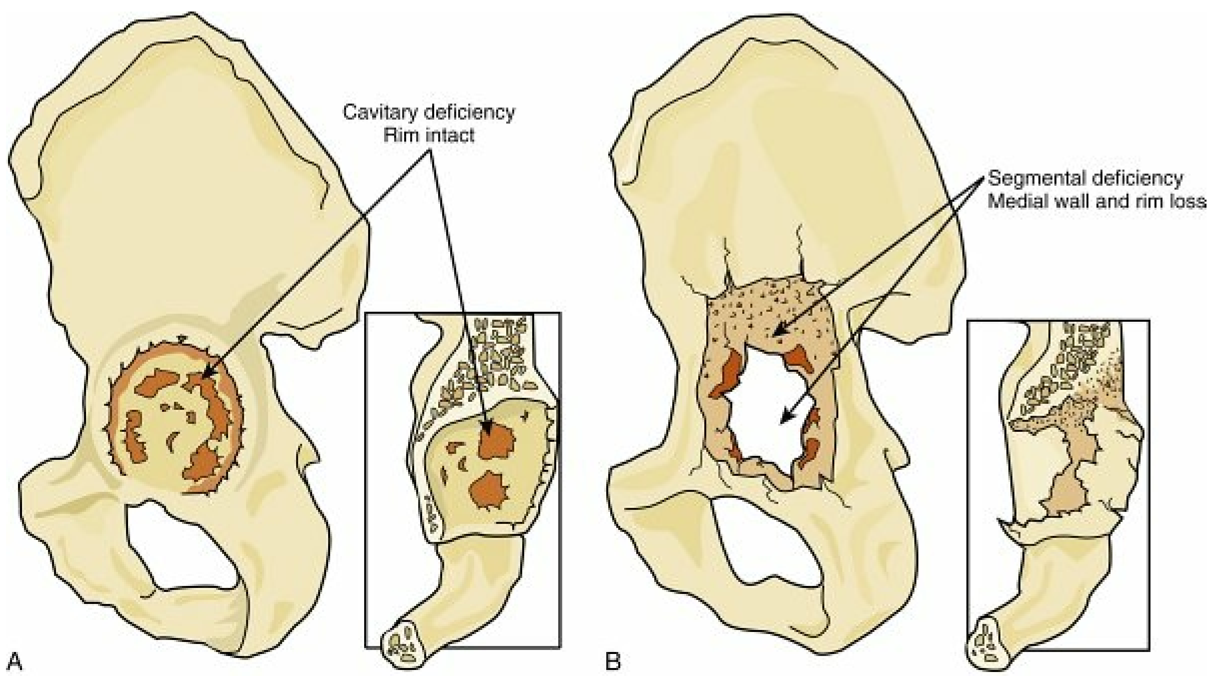


FIG. 5.19 Diagrams of pelvis demonstrating cavitary and segmental deficiency. (A) Cavitary deficiency. Bone loss involves cancellous bone. Main support structures are intact. (B) Segmental deficiency. In this diagram there is structural loss of the medial wall and superior acetabular rim. Segmental defects are more difficult to reconstruct.

Table 5.3

Reconstruction Options for Acetabular Revision.

Acetabular Revision Option	Clinical Pearls
Hemispheric porous-coated cup	May be used in conjunction with adjunct techniques of bone grafting; screw fixation recommended
Highly porous metal cup	Appears to be effective in achieving biologic fixation in cases of severe bone defects; augments may be used for structural support; cup-cage construct can be used to offload cup.
Antiprotrusio cage	Useful in cases of severe bone defects or pelvic discontinuity; spans areas of healthy host bone and accommodates bone grafting deep to the cage; relies on mechanical fixation alone
Customized triflange implant	Requires several weeks or a month to obtain implant; serves as a good salvage option in cases of catastrophic bone loss and discontinuity; may achieve biologic fixation

Modified from Taylor ED, Browne JA: Reconstruction options for acetabular revision, *World J Orthop* 3:95–100, 2012, Fig. 1.

- Used when segmental bone deficiencies prevent initial rigid fixation of a hemispheric porous cup in desired position.
- Bone graft
  - Cage placement is against acetabulum and pelvis. Bone graft is placed behind cage.
    - Particulate graft preferred
    - Bulk support allograft when needed
- Acetabular cup insertion
  - Acetabular cup is cemented into reconstruction cage.
- Mid- to long-term failure rates using this technique are significant because of mechanical loosening and/or breakage of the cage as a result of lack of biologic fixation. Many surgeons have abandoned this technique in favor of porous metal augments, cup-cage constructs, and custom triflange cups.

□ Modular porous metal construct (Fig. 5.21)

- Increasingly being used for cases of severe bone loss
- May allow achievement of mechanical stability and osseointegration when less than 50% host bone contact is available for a hemispherical implant.
- Can help facilitate restoration of the hip center of rotation by

filling superior defects
  - Different highly porous metal options available, including tantalum (75% porous by volume).
  - Intraoperative flexibility to match defects
  - Revision cup may be combined with a cage in a so-called cup-cage construct to improve initial stability and fixation
- □ Custom triflange cup (Fig. 5.22)
  - Severe cases of bone loss where defect-matching techniques are limited
  - Decision to use is made preoperatively as this cup is custom made for each patient on the basis of a CT scan.
    - Requires several weeks to manufacture
- □ Acetabular screw placement (Fig. 5.23)
  - *Posterior-superior* quadrant is the safe zone for acetabular screw placement. This is preferred zone for screw placement.
  - ***Anterior-superior* quadrant is considered the zone of death.** Screws and/or drill that penetrate too far risk laceration of the external iliac artery and veins.
  - If a major vessel injury occurs during screw placement, the hip wound should be immediately packed tight. Without closure of the hip wound, an anterior pelvic incision is made to gain proximal control of the bleeding artery. Repair of the bleeding source is then addressed.

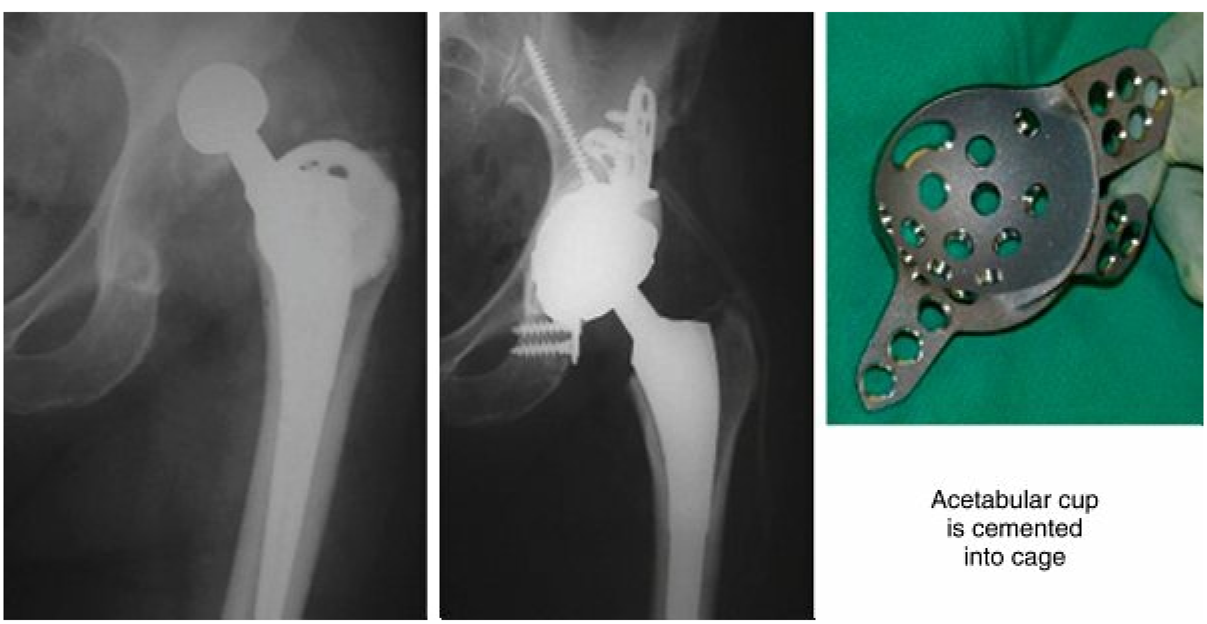


FIG. 5.20 Reconstruction cage for segmental acetabular deficiency. *Left,* Displaced acetabular cup. Note segmental bone loss of posterior acetabulum. *Center,* Pelvic reconstruction with a triflange cage. The cage is secured to bone with screws. Acetabular cup is cemented into the cage. *Right,* Triflange cage before insertion.

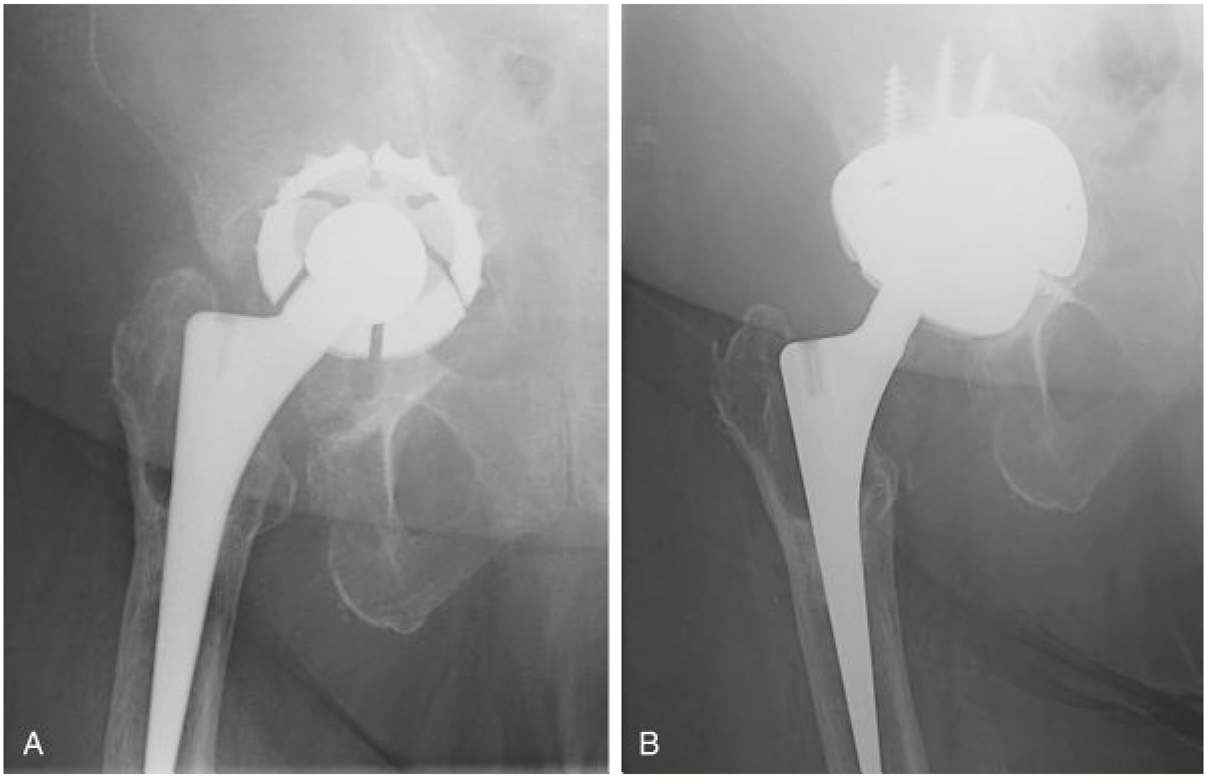


FIG. 5.21 (A) Preoperative radiograph showing failed acetabular component with large medial defect and intact rim. (B) Postoperative radiograph demonstrating the revision acetabular construct using tantalum augments as "footings" to support cup.
From Taylor ED, Browne JA: Reconstruction options for acetabular revision, *World J Orthop* 3:95–100, 2012, Fig. 1.

- Pelvic discontinuity
  - Defined as separation of the superior aspect of the pelvis from the inferior aspect by fracture and/or osteolysis
  - Treatment/options
    - Acute discontinuity may be treated like a fracture with an attempt made to get the discontinuity to heal. Posterior pelvic reconstruction plate to ilium and ischium, followed by hemispheric cup, jumbo cup, or highly porous metal component with augmentation, may be used.
    - **Chronic discontinuity represents a nonunion, and the discontinuity is unlikely to heal.** Use of a cup-cage construct, custom triflange cup, or a distraction technique with augments is preferred.

Femoral Side (Fig. 5.24)

- **Identification of bone defects in femur**
  - *Cavitary deficiency* is loss of endosteal bone. Cortical tube remains intact.
    - Endosteal ectasia is a form of cavitary deficiency in which the

outer cortex has increased in diameter as a result of mechanical irritation by a loose femoral stem.

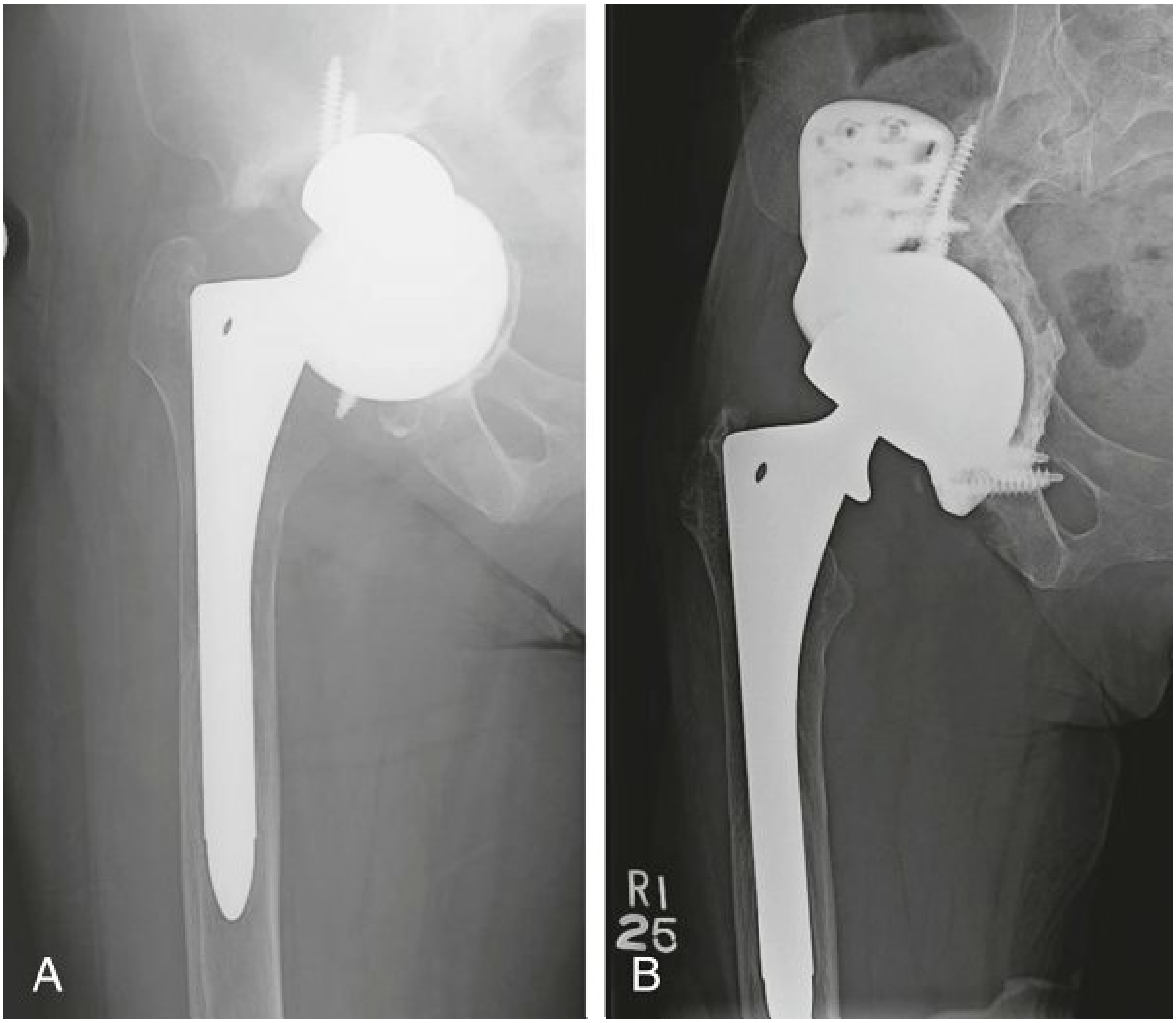


FIG. 5.22 (A) Preoperative radiography demonstrating failed revision acetabular component with massive bone loss and pelvic discontinuity. (B) Postoperative radiographs showing custom triflange cup reconstruction.

From Taylor ED, Browne JA: Reconstruction options for acetabular revision, *World J Orthop* 3:95–100, 2012, Fig. 1.

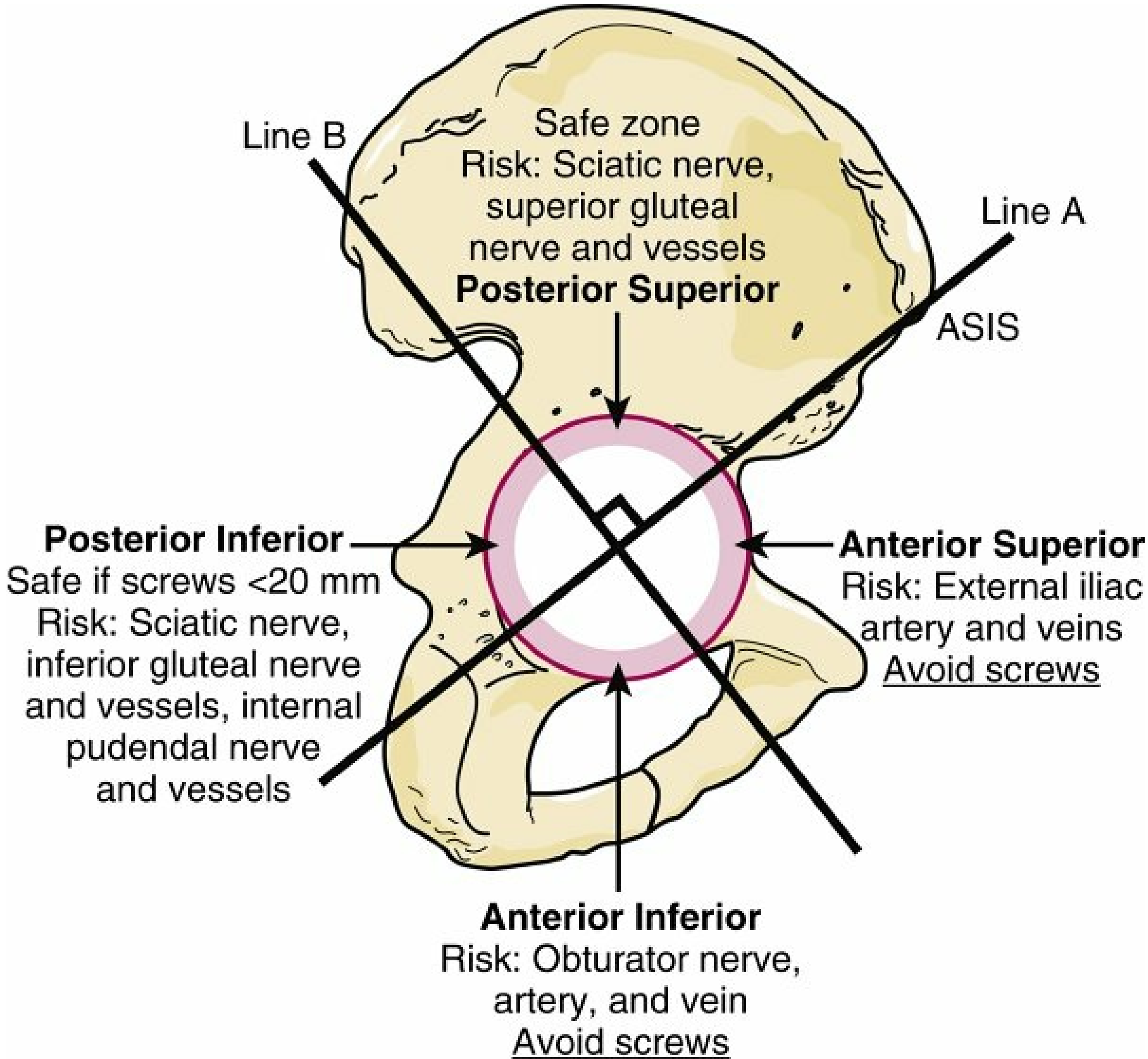


FIG. 5.23 Diagram showing four quadrants for acetabular screw placement. *Line A* is formed by drawing a line from the anterior superior iliac spine (ASIS) to the center of the acetabular socket. *Line B* is then drawn perpendicular to line A, also passing through center of socket.

- □ ***Segmental deficiency*** **is a loss of part of the cortical tube in the form of either holes in or complete loss of a portion of the proximal femur.**
- □ Combined deficiencies

▪ **Significance of bone defects**

- □ Revision femoral stem must bypass the most distal defect.
  - • New implant must bypass most distal cortical defect by a minimum of *two cortical diameters*. Otherwise there is an increased risk for fracture at the tip of the stem.
    - • The revision stem must prevent bending movements from passing through the region of the cortical hole, which is a weak point.
- □ Extensive metadiaphyseal bone loss and a nonsupportive diaphysis (Paprosky type IV classification) require a femoral replacement endoprosthesis or an allograft-prosthetic composite.

▪ **Fixation revision of femur**

- □ Cementless porous biologic fixation is preferred.

- Cemented revision stems without impaction bone grafting have high failure rates at intermediate term and limited indications in the revision setting.

□ **Extensively porous-coated cylindrical long-stem prosthesis**

- Monoblock stem typically made of Co-Cr
- Achieves fixation in the diaphysis
- Longer stems may be bowed, and engagement of the stem in the canal will dictate anteversion.
- Stem should bypass defects and be long enough to achieve initial rigid fixation.
- Extensively grit-blasted stem with splines also an accepted solution
- Minimum of 4 cm of diaphyseal bone required
- **Becoming less popular due to technical difficulty in use, risk for fracture, and thigh pain with large stiff implants**

□ **Tapered fluted implant**

- Monoblock or modular stem made of more flexible titanium with a roughened surface
- Achieves stability in the diaphysis
- Taper design provides axial stability, and flutes provide rotational control.
- Modular junctions allow for freedom in component anteversion and leg length but may increase the risk of breakage.
- May obtain adequate stability and fixation with less than 4 cm of diaphyseal bone
- **Becoming more popular due to ease of use and ability to restore biomechanics through modularity**

□ **Cemented revision stem**

- High intermediate-term failure rate
- Reasonable consideration in patients with irradiated bone
- Acceptable for use in very elderly or very low-demand patient when immediate full weight bearing is needed

□ **Impaction grafting technique**

- Acceptable revision technique with greater popularity outside North America
- Surgical technique
  - Distal cement restrictor placed into diaphysis
  - Particulate allograft bone (fresh frozen bone recommended) impacted into endosteal canal. Bone is impacted around a femoral stem trial
  - Polished tapered stem cemented into impacted allograft bone

- Polished tapered stem allowed to settle slightly within cement. Mechanical load forces are transmitted as compression forces upon allograft bone.
- Allograft heals to endosteal bone.
- Cement stays interdigitated with allograft.
- Endosteal bone is restored.

- Indications

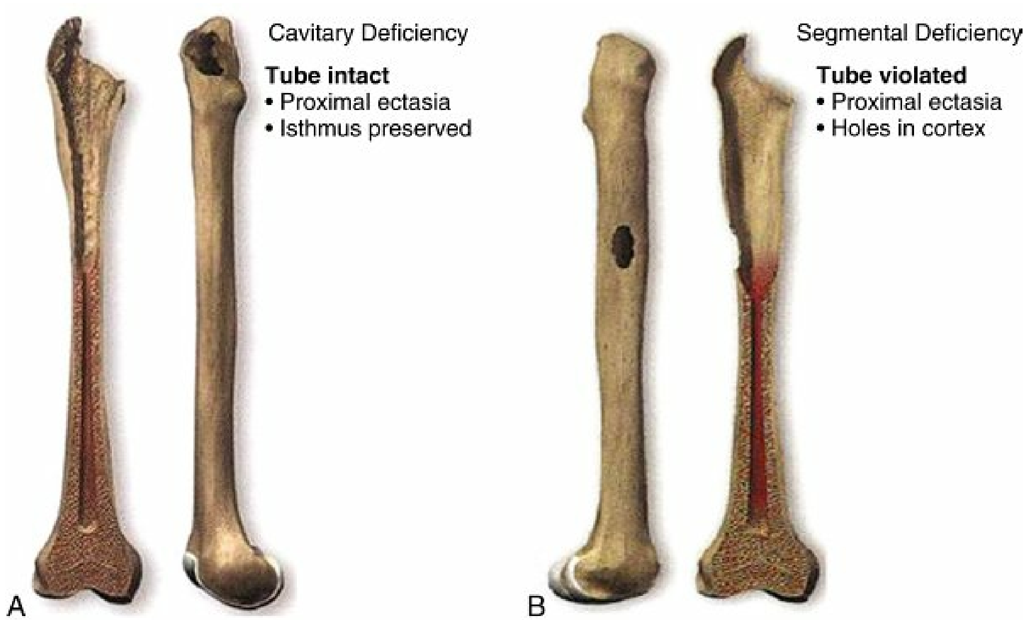


FIG. 5.24 Diagrams of proximal femur demonstrating cavitary and segmental deficiencies. (A) Cavitary deficiency. Bone loss involves cancellous bone and endosteal cortical bone within the femur. The outer cortical tube remains intact. The overall strength of the tube is diminished. (B) Segmental deficiency. In this diagram the segmental defect is the hole in the diaphysis. A proximal cortical ectasia is also present (cavitary defect).

- Used to reconstitute cortical bone when there is significant cortical ectasia
- Cortical tube must be intact. Small cortical defects can be covered with an external mesh or allograft strut.
- Bone must not be devascularized during process of covering hole

- Complications
  - Most common complications are fracture and subsidence.
  - Choice of allograft and morcelization technique are important factors affecting success.

□ **Segmental bone deficiency of femur**

- Cortical holes are reinforced with allograft cortical struts secured with cerclage cables (or wires).

- Proximal cortical deficiencies may be restored with modular metallic endoprosthetic segments (proximal femur replacement) or with a bulk support allograft.
- Proximal allograft technique (allograft-prosthesis composite, or APC)
    - Revision stem cemented into proximal allograft
    - Allograft connected to host femur with a step cut or through an intussusception (telescoping) technique.
- Allograft held to native femur with cables, plate, and/or allograft cortical strut.

Section 7 Articular Bearings and Corrosion in Tha

Introduction

- **Ceramic on highly crosslinked polyethylene (HCLPE) has become the most popular bearing option in North America.**
- **Rates of osteolysis have fallen dramatically with the widespread adoption of HCLPE.**
- **Concerns about trunnion corrosion have reduced the use of Co-Cr femoral heads in favor of ceramic heads.**
- **Although polyethylene (PE) wear debris has historically been the main culprit of osteolysis, metal debris from metal-on-metal bearings and trunnion corrosion may have been a more common reason for osteolysis in the past decade.**

Polyethylene

- **Ultra-high-molecular-weight polyethylene (UHMWPE) was introduced in the 1960s by Sir John Charnley.**
- **HCLPE was introduced in the late 1990s to reduce wear and osteolysis.**
  - Cross-linking of poly chains made by irradiation of PE.
  - **Disadvantage of HCLPE is reduction in mechanical properties** and can lead to catastrophic failure of the implant
- **Sequence of events in irradiation of PE (** Fig. 5.25)
  - Irradiation of PE ruptures PE bond, creating free radicals.
  - Free radicals can rebond via two different pathways.
    - In presence of oxygen (i.e., air), free radicals can bond with oxygen, resulting in PE chain scission. This is termed *oxidized* PE. **Irradiation of PE must be done in an inert environment** (i.e., with no oxygen).
    - In absence of oxygen, the free radical bonds with an adjacent chain to create a cross-link. This is termed *cross-linked* PE.
- **Dose of irradiation**
  - Requires high-dose irradiation, 5–15 Mrad (10 Mrad = 100 kGy)
  - The higher the dose of irradiation, the greater number of free radicals generated.
  - Problem—residual free radicals after cross-linking do remain. This is an oxidation risk.
- **Free radical elimination**
  - Postirradiation thermal treatment of the polymer is required to reduce remaining free radicals to ensure the oxidative stability of joint implants in the long term.

- Annealing—heating below the melting point—preserves mechanical properties but does not completely eliminate free radicals.

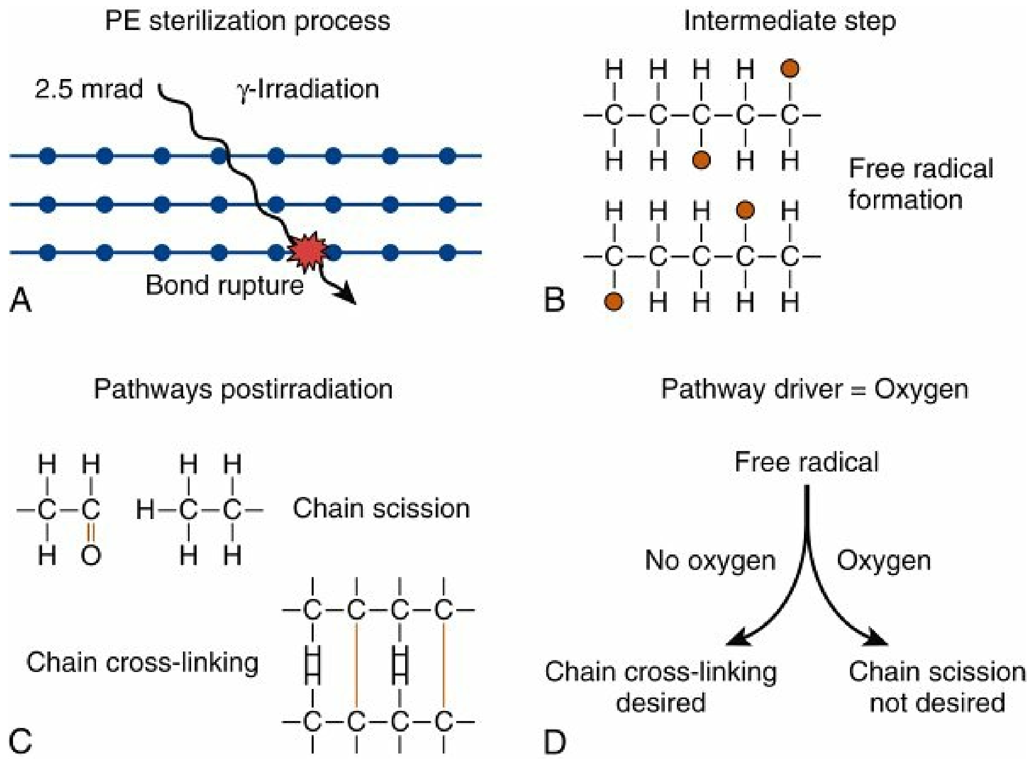


FIG. 5.25 Diagram depicting PE irradiation process. Irradiation of PE causes bond rupture (A), which creates free radicals (B). Free radicals can combine with oxygen to create an oxidized form of PE, which results in chair scission; in the absence of oxygen, the PE chains can form cross-links (C). The presence or absence of oxygen determines the pathway the PE free radicals will take (D). Cross-linking is the desired pathway.

Table 5.4

Comparison of Melted Versus Annealed HCLPE First-Generation Properties.

Irradiated and Melted	Irradiated and Annealed
Low crystallinity (<50%)	Good crystallinity (>55%)
Low strength (<40 MPa)	Good strength (>45 MPa)
No oxidation potential	Potential for oxidation
Potential for macroscopic failure	Potential for osteolysis

- Melting—heating above the melting point—decreases mechanical properties owing to loss of crystallinity but eliminates free radicals.

□ Vitamin E, an antioxidant, may be added to PE as another method to stabilize free radicals

- **Several different methods to produce HCLPE exist (** Table 5.4)
    - ▫ Each process attempts to decrease number of free radicals, improve oxidation resistance, and minimize adverse mechanical properties
- **PE microstructure**
    - ▫ PE in a manufactured implant exists in two forms (i.e., phases; Fig. 5.26).
        - Crystalline phase
            - Provides mechanical strength to PE
        - Amorphous phase
            - Only amorphous regions of PE cross-link.
- **PE properties—crystallinity**
    - ▫ Optimum crystallinity 45%–65%
    - ▫ Decreased crystallinity (<45%)
        - Decreases mechanical properties
        - PE more prone to macroscopic failure (i.e., cracks)
    - ▫ Increased crystallinity (>65%)
        - The large crystalline phase leaves a very small amorphous phase.

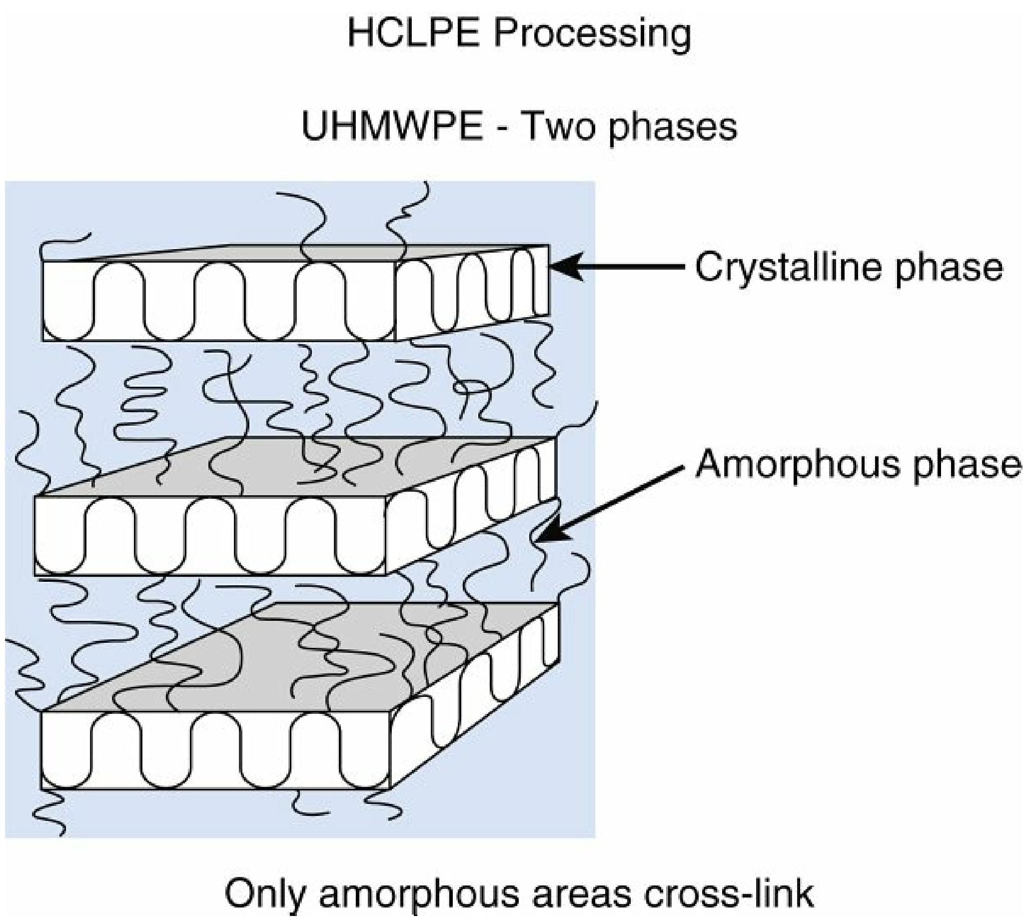


FIG. 5.26 Diagram of ultra-high-molecular-weight polyethylene phases. The UHMWPE in an implant exists in two forms (phases): the crystalline phase and the amorphous phase. The crystalline phase provides the mechanical properties to the PE. When the PE is irradiated, only the amorphous areas cross-link.

- The greatly reduced amorphous region is more susceptible to chain scission oxidation.
  - Creates significant increase in particulate debris

- **PE sterilization process—three methods:**
  - Ethylene oxide gas
  - Gas plasma spray (peroxide)
  - Low-dose irradiation (generally between 2.5 and 4.5 Mrad)
- **PE implant manufacturing process—four methods:**
  - Ram bar extrusion (Fig. 5.27)—machine component
  - Sheet molding—machine component
  - Compression molding—machine component
  - Direct compression molding—no machining (implant made directly from mold)—best wear of four techniques
  - Calcium stearate used in the manufacturing process has been shown to cause problems with PE and should be avoided
- **Methods to store and maintain the PE implant in an oxygen-free environment**
  - Vacuum packaging
  - Oxygen-free gas packaging: uses argon or nitrogen
  - Oxygen that diffuses back into PE product can lead to on-the-shelf oxidation.
- **HCLPE—clinical performance**
  - Clinical studies demonstrate reduction in wear rates and the incidence of osteolysis compared to standard UHMWPE implants at 10+ years of follow-up.
  - Low wear rate of HCLPE appears to be independent of head diameter, with significant reductions in wear seen even with large head size.

Polyethylene Wear and Osteolysis

- **PE wear comes from two sources.**
  - *Bearing wear*—head-cup articulation
  - *Backside wear*—occurs when the PE insert rubs against the metal shell, creating PE debris. This occurs because the PE locking mechanism does not completely inhibit PE micromotion against the metal shell. The more backside micromotion allowed, the more PE debris generated.

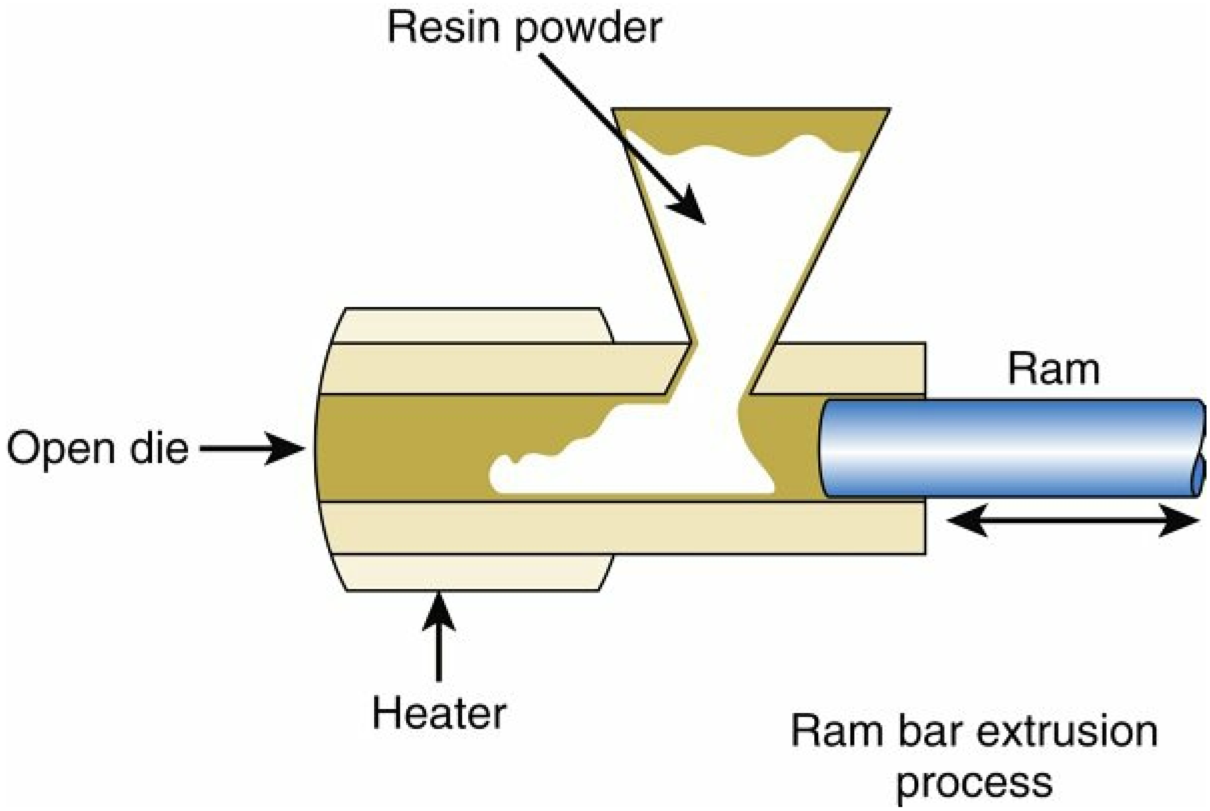


FIG. 5.27 Diagram of ram bar extrusion process. PE powder is poured into the chamber. The chamber is heated, and the bar of melted PE is pushed out the end of the die. Calcium stearate is added to the PE power to prevent it from sticking to the surfaces of the die.

- *Submicron*-sized particles shed by the PE bearing are responsible for eliciting the osteolysis reaction.
  - Billions of particles are generated
    - Osteolysis more likely when the number of PE particles exceeds 10 billion particles per gram of tissue
- *Adhesive* bearing wear is the most important process that generates submicron-sized PE particles.
  - Types of PE bearing wear
    - Adhesive wear (Figs. 5.28 and 5.29)—most important mechanism in osteolysis process
    - Abrasive wear—rough femoral head surface causes mechanical scratching of PE surface with loss of PE material (*cheese grater* effect).
    - Third-body particles—particles within joint space get between head and PE cup, causing abrasion. These particles cause PE to be removed from cup surface. Third-body particle sources include:
      - Cement debris
      - Metal debris shed from cup or stem
      - Metal debris from metal corrosion at modular metal-metal interfaces (i.e., modular junctions)
      - Hydroxyapatite debris shed from implant surfaces

- Abrasive material introduced at time of prosthetic joint implantation (i.e., metal debris from drill bit)

Osteolysis Process

- **Phagocytosis of submicron-sized PE particles by macrophage**; macrophage becomes activated
- **Additional macrophage recruitment via cytokines released by activated macrophage**
- **Release of osteolytic factors (cytokines) by the activated macrophage; these factors include**
  - TNF-α—IL-1β
  - Transforming growth factor (TGF)-β—IL-6
  - Platelet-derived growth factor (PDGF)—receptor activator of nuclear factor κB ligand (RANKL)
- **Bone resorption mediated via RANKL**

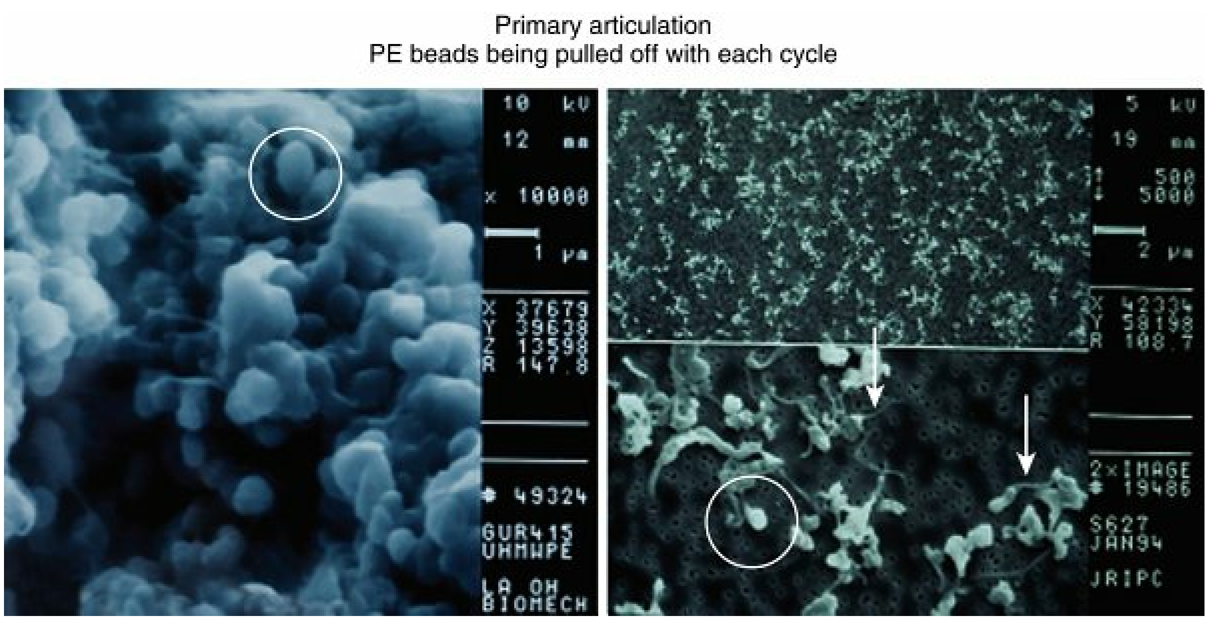


FIG. 5.28 Scanning electron microscope photographs demonstrating adhesive wear in a PE cup bearing. *Left,* Surface profile of a PE cup. Note submicron-sized beads that are melted together. *Top right,* PE particles collected after a bearing simulator test. *Bottom right,* Magnified view reveals that the particles collected *(circle)* are actually the beads pulled off the surface of the cup. *Arrows* point to the tails on the beads, indicating that the beads are individually pulled off as the femoral head moves against the PE cup.

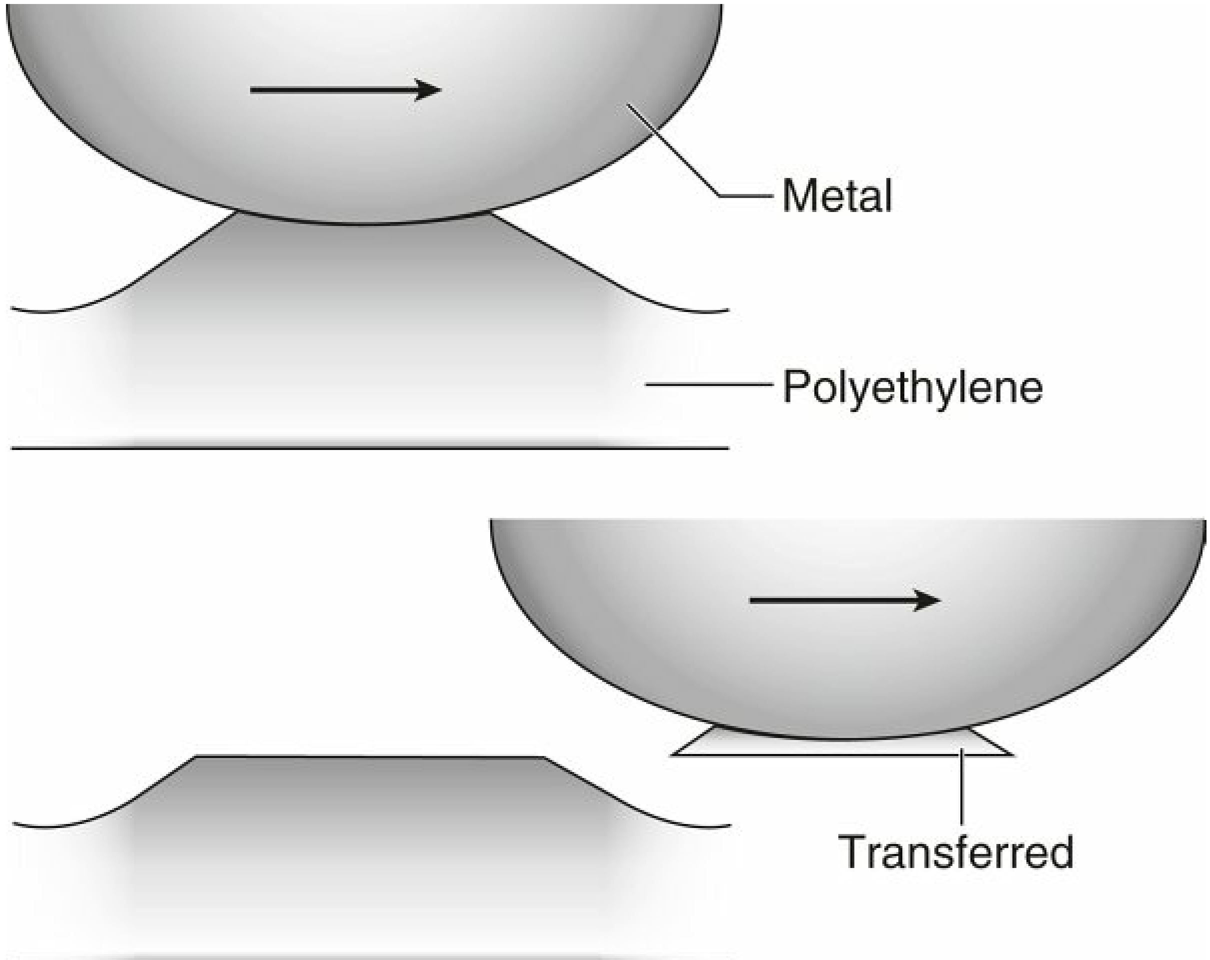


FIG. 5.29 Adhesive wear occurs when the atomic forces occurring between the two opposing surfaces are stronger than the inherent strength of either material. In THA, adhesive wear causes small portions of the PE surface to adhere and transfer to the opposing metal femoral head. This process leads to wear particle generation and the creation of pits and voids in the PE.

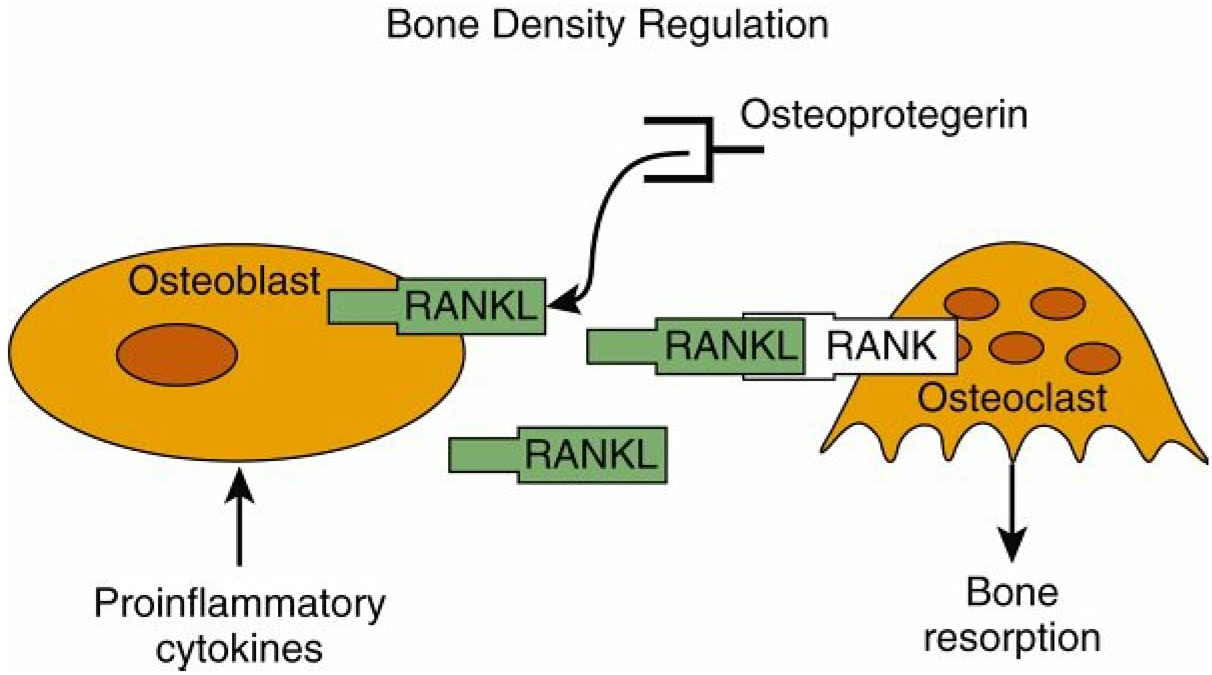


FIG. 5.30 Diagrammatic representation of osteolysis-induced resorption of bone. Proinflammatory cytokines released by the activated macrophage reach the osteoblast, which in turn upregulates the production of RANKL. RANKL is produced on the surface of the osteoblast but is also released by the osteoblast in a soluble form. RANKL attaches to RANK receptor on the osteoclast surface. This attachment induces osteoclastogenesis, resulting in bone resorption. RANKL is blocked by osteoprotegerin (expressed by osteoblasts and many other cell lines). The RANKL/osteoprotegerin ratio in the bone microenvironment determines overall bone homeostasis.

- **Mechanism of bone resorption mediated by osteoblast/RANKL (** Fig. 5.30)
  - RANKL is produced by the osteoblast.
  - RANKL attaches to RANK receptor on **osteoclast**, which activates bone resorption process.
  - Osteoprotegerin, produced by many cell lines, blocks RANKL and mitigates bone resorption.
- **The only cell that resorbs bone is the osteoclast.**

Osteolysis Around THA Prosthesis—Effective Joint Space

- **Intraarticular generation by PE particles elicits an inflammatory response that results in a hydrostatic pressure buildup within the joint.**
- **PE particles are then disseminated throughout the effective joint space (** Fig. 5.31).
  - *Effective joint space* is defined as any contiguous area around the joint where the implant touches bone and includes the area around the cup, stem, and screws.

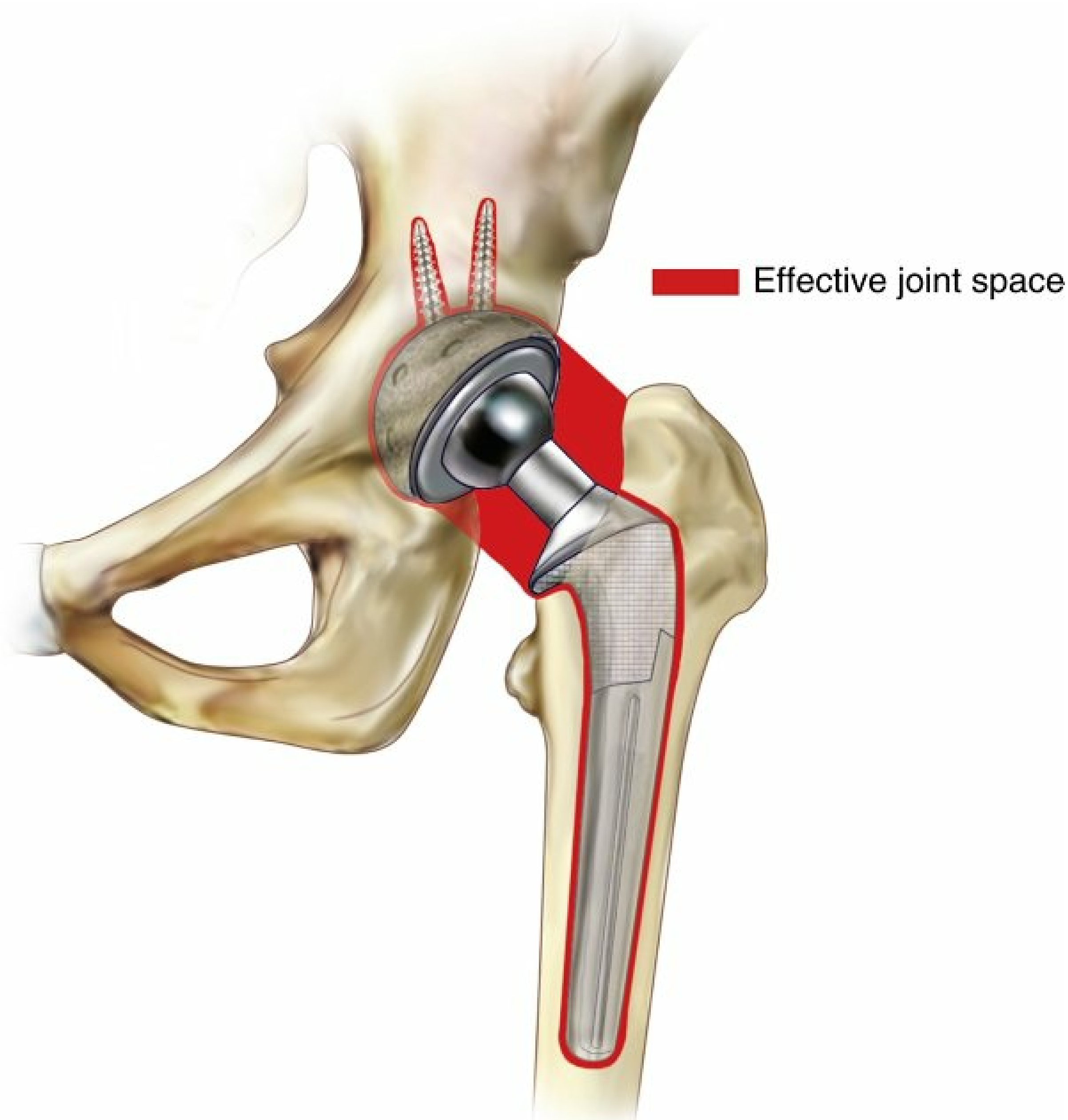


FIG. 5.31 Effective joint space and osteolysis. Diagram of THA depicts area of effective joint space. The effective joint space includes any area where the prosthesis touches bone. PE particulate debris can be pumped anywhere within the effective joint space if there is a path for PE particles to be pumped.

- **Osteolysis can occur anywhere within the effective joint space (** Fig. 5.32).
- **Areas well sealed by biologic integration inhibit particle dissemination.**

Particle Debris Formation—Linear Versus Volumetric Wear

- **Volumetric wear is the main determinant of the number of PE particles generated.**
- **Volumetric wear is directly related to the square of the radius of the head (** Fig. 5.33).
- **The wear track generated** *approximates* a cylinder. The volume of a cylinder, and hence the amount of PE debris generated, is formulated as follows:

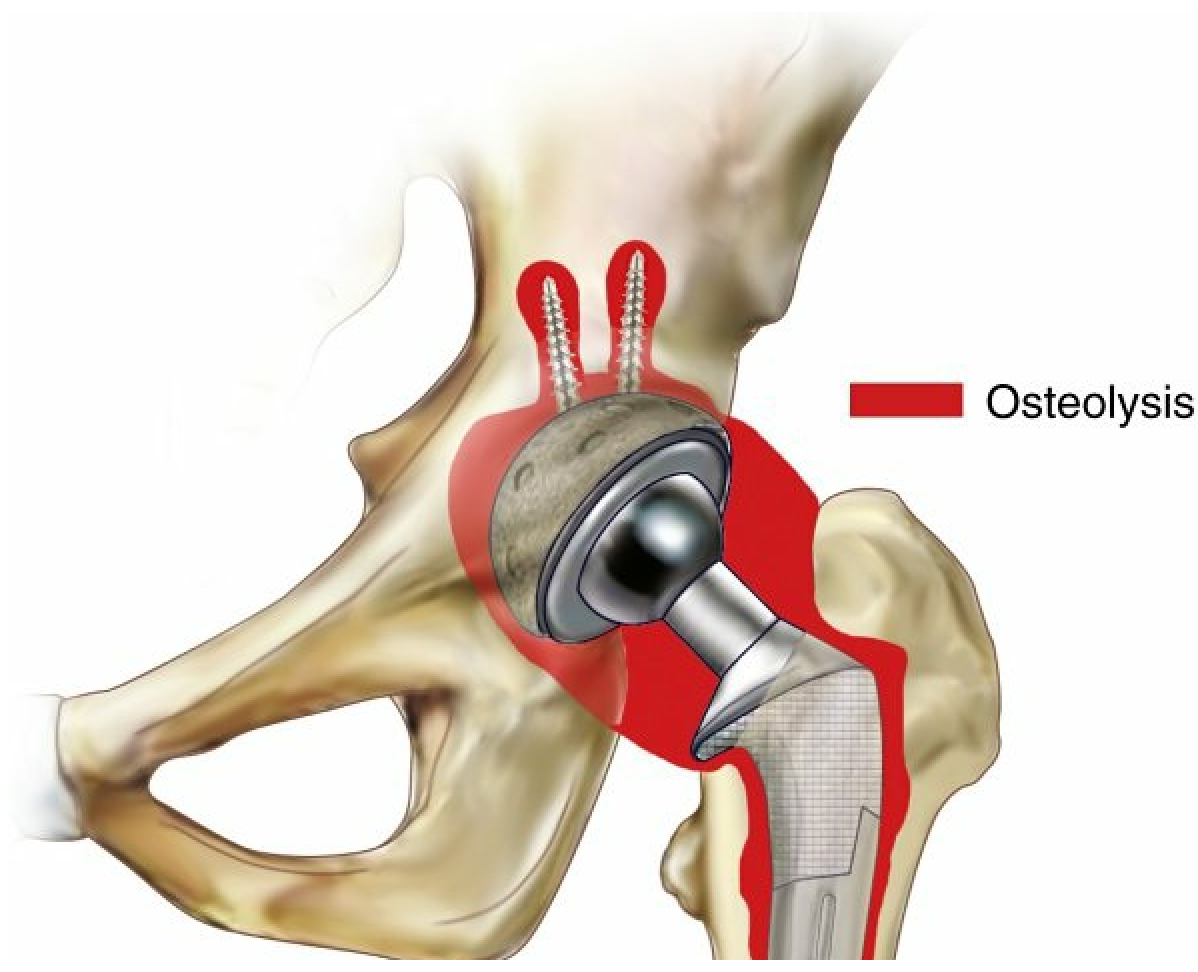
$$V = 3.14\, r^2 w$$

where V is the volumetric wear of the PE cup, r is the radius of the femoral head, and w is the linear head wear (i.e., the distance the head has penetrated into the cup).

- **Linear wear rates in excess of 0.1 mm/yr are associated with osteolysis (the so-called osteolysis threshold).**
- **Avoiding excessive wear was the main reason for use of smaller-diameter femoral heads with traditional polyethylene liners.**
- **With HCLPE, wear rates remain low and well below the osteolytic threshold for even large-diameter femoral heads (>36 mm).**

Osteolysis—Radiographic Findings in THA

- **Endosteal scalloping in femoral endosteal canal is hallmark finding (** Fig. 5.34).



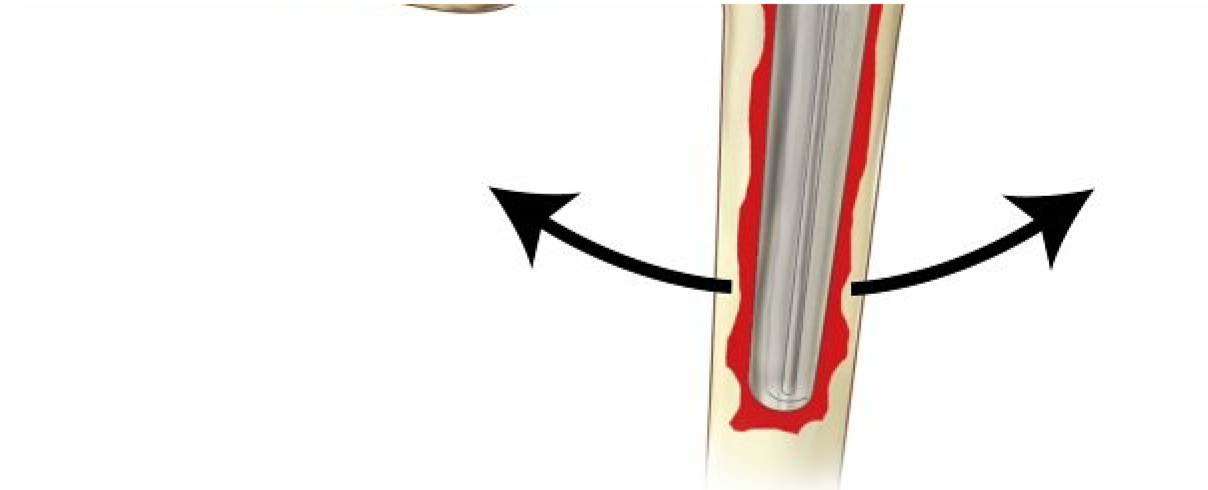


FIG. 5.32 Diagram shows osteolysis around a THA prosthesis. Because fluid (and PE particles) will move in path of least resistance, prosthetic design influences where osteolysis is likely to occur.

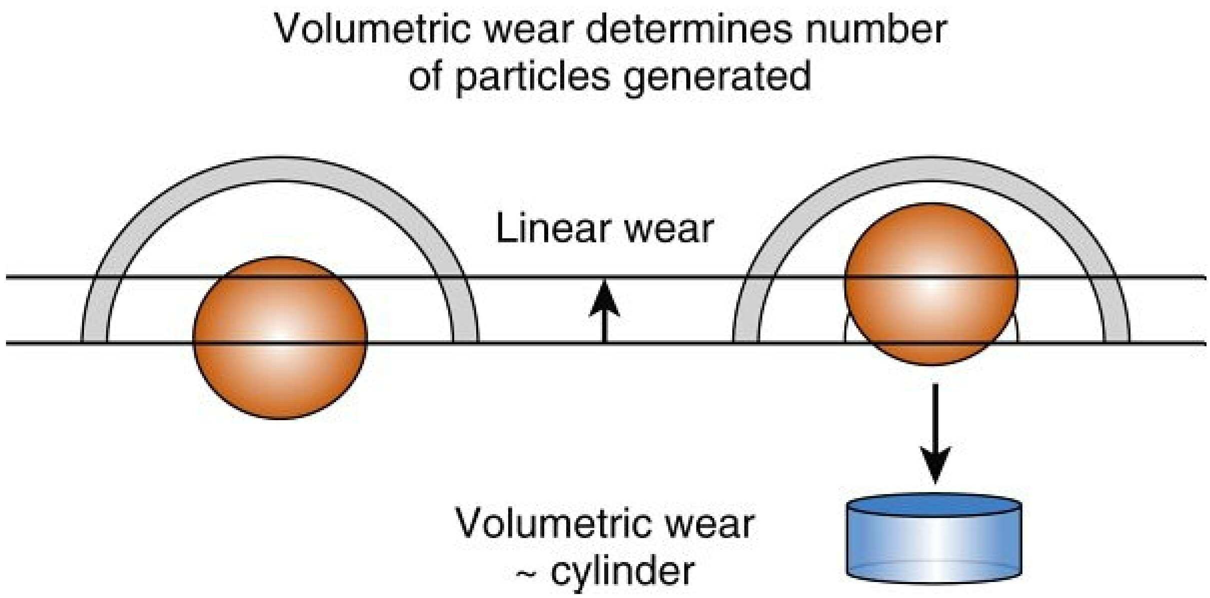


FIG. 5.33 Diagram of PE wear in THA. As the head wears through the PE cup, a wear track is generated. Liner wear is measured where the femoral head has penetrated into the PE cup. The wear track generated approximates a cylinder.

- **Round lytic lesions behind acetabular cup with screw holes is common finding.**
- **Round lytic lesion surrounding acetabular screw is also a typical finding.**
- **Osteolytic lesions develop later in prosthetic life cycle (usually starting after 10 years). Osteolytic lesions spotted within the first 2–3 years of the prosthetic life cycle are most likely a result of infection or corrosion. Osteolytic lesions due to polyethylene wear have rarely been reported with modern HCLPE liners.**

Treatment of Polyethylene Wear

- **Modular bearing change**
  - □ Indications
    - • Symptomatic patient with PE wear

- **Symptoms may be due to painful effusion or microfracture through osteolytic defect.**

FIG. 5.34 Lateral radiograph of femoral stem demonstrating osteolysis in THA. The classic finding is endosteal scalloping of the femoral cortex.

- Significant linear PE wear associated with progressive radiographic osteolysis with concern for impending catastrophic failure
- Recurrent instability and/or mechanical symptoms of subluxation
- Implants must be well fixed to bone (loose implants should be revised) and adequately positioned.

□ Complications

- Most common postoperative complication is dislocation.
    - Patients generally feel well and fail to allow adequate soft tissue healing.
    - Not revising poorly positioned implants increases

the risk of impingement and instability

- ◻ Technique
  - Both liner and head must be exchanged.
  - Bone grafting osteolytic lesions behind cup with particulate graft through cup holes or small iliac trap door
- ◻ Cementing of PE bearing into fixed porous cup
  - Indicated when there is a damaged/worn locking mechanism or replacement PE bearing is not available
  - Technique requirements
    - Optimization of PE cup position to avoid neck impingement
      - Reduces chance of hip instability
    - Deep seating of PE liner into metal cup
      - Maximizes surface contact with cement and minimizes risk of debonding of PE cup from cement
    - Roughening of back side of PE liner insert
      - Increases surface area for bonding with cement
    - Roughening of inside surface of metal cup shell
      - Also increases surface area for bonding with cement
    - Close matching of PE liner to metal shell is *not important*

Bearing Lubrication

- ▪ **Boundary lubrication**
  - ◻ Asperities (surface rough points) on each surface make contact with each other—always.
  - ◻ Boundary lubricant (i.e., synovial fluid) separates surfaces just enough to prevent severe wear.
  - ◻ Typical for hard-on-soft bearings.
- ▪ **Fluid-film (or hydrodynamic) lubrication**
  - ◻ Asperities on each surface are small (i.e., highly polished surfaces) and do not make contact.
  - ◻ Fluid-film lubrication *always* requires angular velocity.
    - Ball must be moving at significant speed.
  - ◻ Factors affecting fluid-film state:
    - Radial clearance (Fig. 5.35)
      - Radial clearance is defined as radius of cup minus radius of head.

- Radial clearance defines contact area of bearing.
  - Best radial clearance (value depends on biomaterial used) provides polar contact with high conformity. This value provides best bearing wear rate.
- R_a
  - The smoother the bearing surfaces, the better the chance for fluid film lubrication.
  - Supersmooth surfaces are used for hard-on-hard THA alternative bearings.
  - Hard-on-hard bearings—surface roughness
    - Metal (Co-Cr)—R_a 0.01 μm
    - Ceramics—R_a 0.006 μm
- The greater the head radius, the better the chance for fluid film lubrication.
- Bearing size
- Sphericity
- Bearing material

Metal and Ceramic on PE

- **Ceramic femoral heads are being increasingly used due to concern with trunnion corrosion with metal femoral heads.**
- **Hard-on-soft bearing couples**
  - Alumina ceramic on PE—good

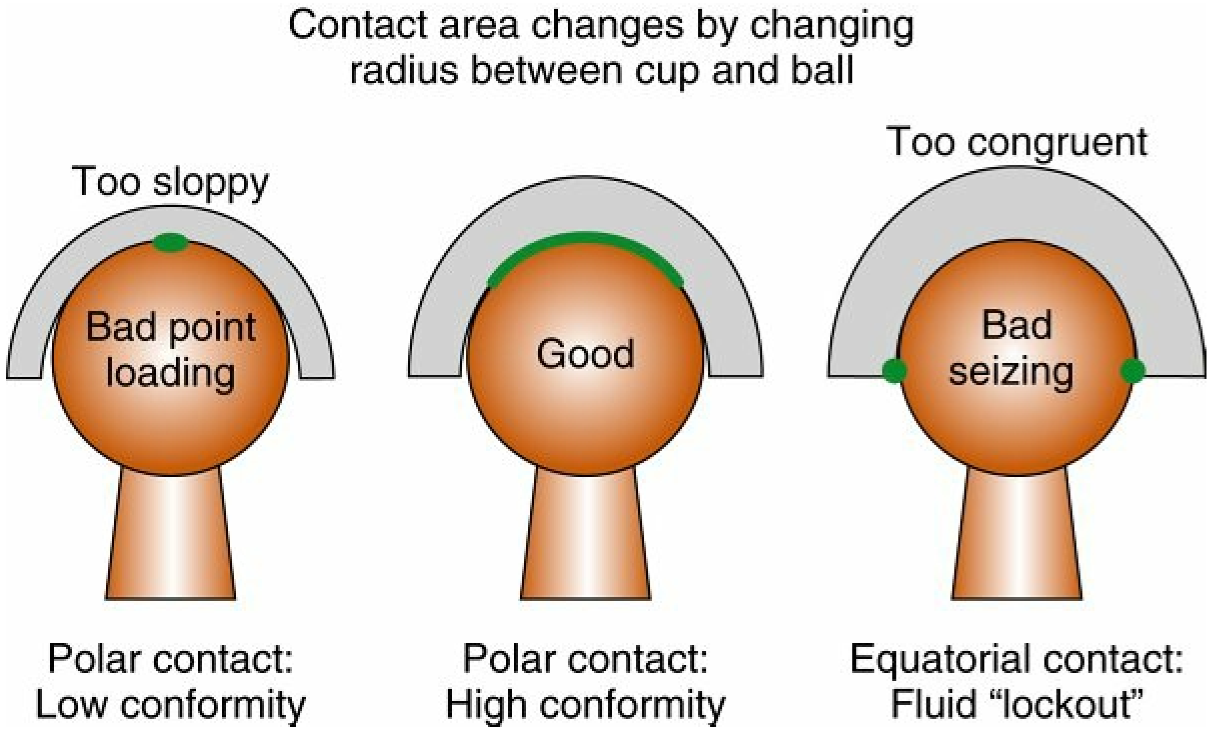


FIG. 5.35 Diagram showing effect of radial clearance and surface contact area of alternative hard-on-hard THA bearing. *Left,* A relatively high radial clearance. With a high radial clearance, hip loading is concentrated in a small polar contact region. This is disadvantageous and causes higher wear rates. *Right,* A relatively low radial clearance. With a low radial clearance, fluid is not allowed effective ingress into and egress out of the bearing region. This creates a fluid lockout state, which causes high friction and wear. *Center,* Ideal radial clearance, which allows adequate fluid flow within the bearing but also provides optimum surface contact area for best wear.

- □ Co-Cr alloy on PE—good
- □ Zirconia ceramic on PE—not good
  - Zirconia ceramic in vivo undergoes phase transformation. This means surface architecture changes over time, making the surface more rough.
  - Yttrium-stabilized tetragonal crystal phase changes to monoclinic crystal phase.
  - Monoclinic phase has increased surface roughness—increased PE wear
- ▪ **Stainless steel on PE—fair**
- □ Titanium alloy on PE—avoid
  - Titanium alloy head is easily scratched (Fig. 5.36).
    - Results in increased abrasive wear
    - Causes rapid PE wear
- ▪ **Factors affecting wear**
  - □ Sphericity of head
  - □ Surface roughness of head
    - Co-Cr head (Fig. 5.37)
      - Carbide asperities stick up and cause scratching.
    - Ceramic head (Fig. 5.38)

- Residual pits on surface create roughness.
- Metal smearing—ceramic heads (Fig. 5.39)
  - *Metal smearing* is transfer of metal to surface of ceramic head (ceramic head is not scratched)
  - Source of metal smear is hip subluxation with subsequent metal transfer from acetabular cup.
  - There is increased surface roughness in metal smear region.
  - Increased roughness causes increased wear.

Metal on Metal

- **High rates of early failure and revision have led to very low use of the metal-on-metal (MOM) bearing couple**
- **Despite poor clinical results, metal-on-metal bearings were felt to have theoretical benefits.**
  - Very small particles generated
    - 0.015- to 0.12-μm (i.e., nanometer-sized) particles
  - Very low linear wear
  - Very low volumetric wear

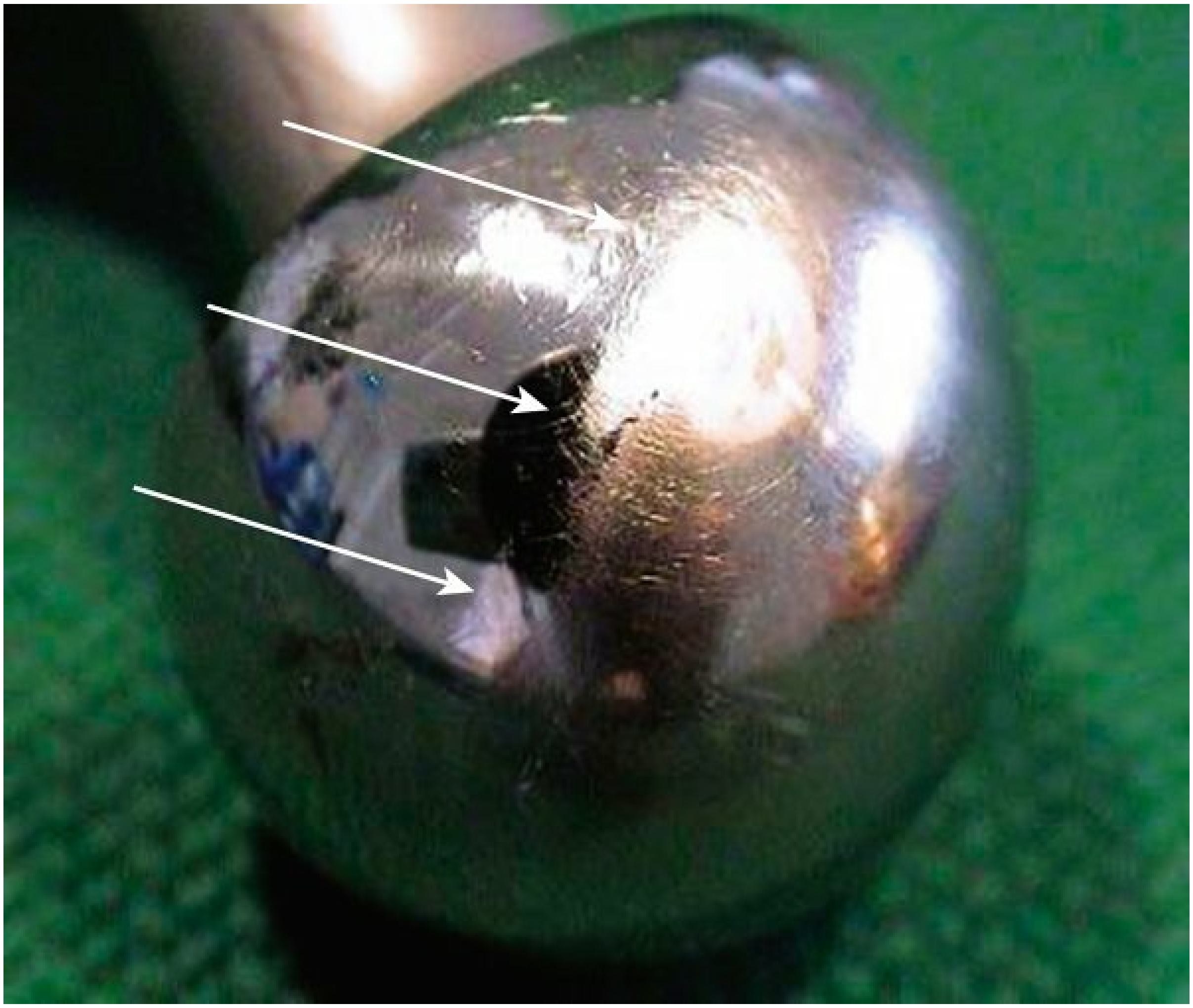


FIG. 5.36 A retrieved cemented femoral stem with nonmodular titanium femoral head. *Arrows* point to hemisphere of abrasive wear. This area articulates with the PE cup. It has become scratched by third-body particles that have entered the joint-bearing region. This roughened surface greatly increases PE wear.

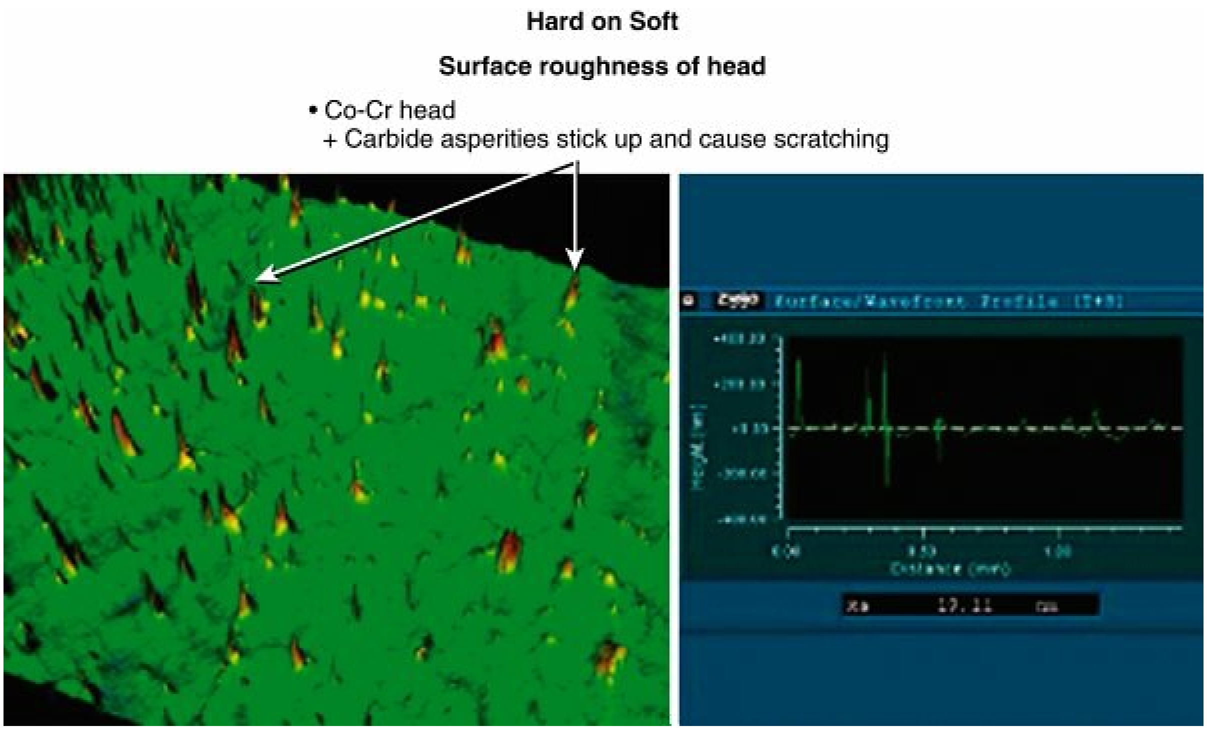


FIG. 5.37 Scanning photomicrograph of cobalt-chrome (Co-Cr) alloy head. The sharp peaks emanating from the surface are carbide asperities that protrude from the surface. (Courtesy Ian Clarke, PhD, and Donaldson Arthritis Research Foundation.)

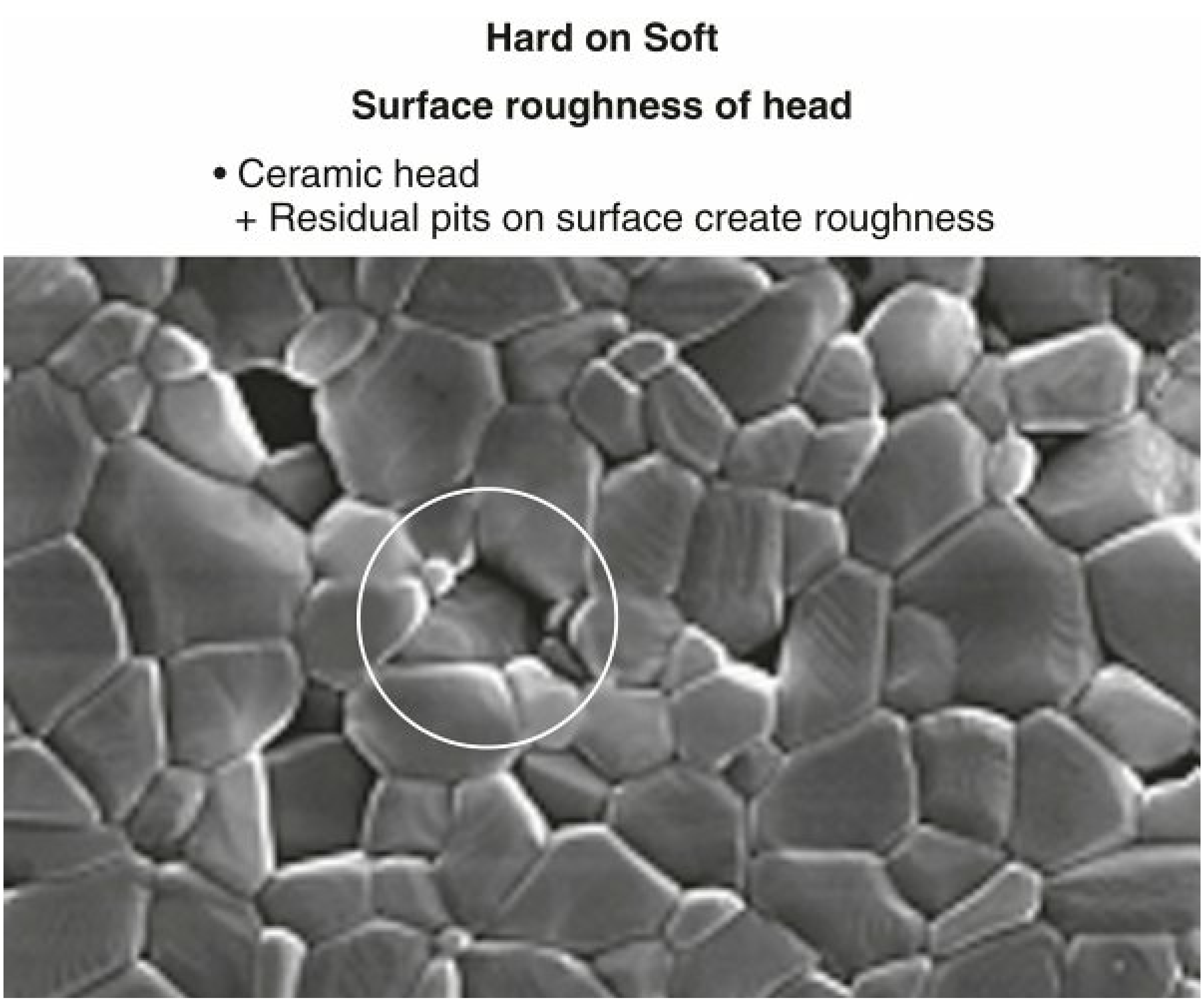


FIG. 5.38 Scanning micrograph of surface of a ceramic head. Note residual pits *(circle)* on surface. These small areas create the roughness of a ceramic surface.

- However, absolute number of particles generated is significantly greater than with comparable PE bearing.
- Run-in wear
  - Described mainly for metal-on-metal bearing
  - Run-in wear is the higher wear rate seen within the first 1 million cycles (≈1 year of high activity).
  - Etiology—in vivo polishing of the two new round bearing surfaces
    - Polishes out high points
      - Areas out of round

FIG. 5.39 Photograph of a retrieved ceramic head demonstrating metal smear. With repetitive hip subluxation, metal from the acetabular cup is transferred to the ceramic head. The greater the smear area, the higher the rate of PE wear.

      - Areas of prominent carbide asperities
    - Very small changes occur in diameters with polishing.
  - After run-in wear, the wear rate reduces to a lower, steady-state rate.

- **Metal-on-metal debris response**
  - Very small (nanometer-sized) particles can dissolve to generate cobalt and low-valence (Cr^{3+}) chromium ions.
  - With normal bearing wear, cobalt and chromium levels are detectable in urine and blood.
  - Serum and urine levels correlate to bearing wear rate.
    - High blood levels of cobalt and chromium (after run-in phrase) correlate to abnormal bearing wear.
      - Usually a result of repetitive subclinical subluxation and poor prosthetic mating
  - Biologic response to wear debris
    - Metal debris from metal-on-metal bearing processed by the *T lymphocyte*
    - Inflammatory response may lead to benign inflammatory mass (pseudotumor) or soft tissue necrosis.
    - Adverse local soft tissue response (ALTR) has been reported to occur in between 0% and 6.5% of cases following MOM THA.
      - Likely related to continued debris formation at a high rate in susceptible patients with a predisposition
  - **Patients with malpositioned implants (particularly a cup abduction angle >55 degrees) often have increased wear.**
  - Edge wear (maximum area of wear crosses over edge of cup) leads to large increase in local contact pressures and breakdown of boundary lubrication (Fig. 5.40).
  - Cup position does not explain all failures.
    - Ultimate response may be pseudotumor formation (mass or cystic fluid collection).
      - May be more common in patients with high serum cobalt and chromium levels, but correlation is weak
      - No cut-off values for metal ion levels have been identified although levels above 5-7 ppb are concerning
  - ALTR/pseudotumor response—clinical presentation
    - Pain and ache in hip common, although may be clinically silent
    - **Standard evaluation for painful MOM THA includes evaluation of serum cobalt and chromium levels as well as cross-sectional imaging (in addition to standard evaluation for infection)**.
      - MRI with metal artifact reduction sequence

(MARS) shows pseudotumor (Fig. 5.41); ultrasound may also be used although less common.

- Osteolysis may be seen around implants on plain radiographs.
- Tissues show inflammatory mass, primarily of lymphocytes.
    - Pathologic finding known as ***aseptic lymphocyte-dominated vasculitis-associated lesion*** **(ALVAL)**
    - Grading systems have been developed to determine the severity of ALVAL
    - Regional tissues around the hip show necrosis thought to be secondary to cobalt and chrome toxicity.

- Major concern is for destruction of abductors
    - Revision surgery often recommended to avoid progressive soft tissue damage
    - Abductor loss is very difficult to treat, so avoidance is paramount.

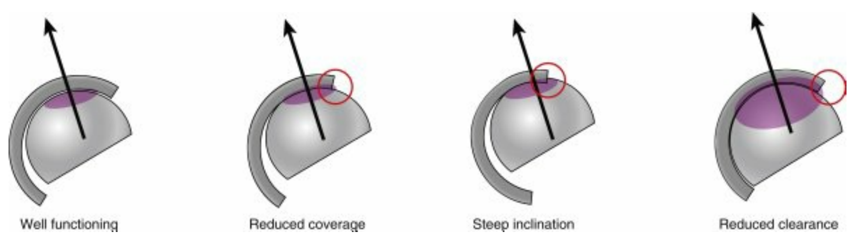


FIG. 5.40 Edge wear occurs when the maximum area of wear crosses over the edge of the cup and has been associated with increased wear rates in metal-on-metal bearings. Potential causes of edge wear (*circles*) are shown; they include reduced coverage of the head from a cup that is less than a hemisphere, a cup that is excessively vertical, and reduced clearance between the head and the cup.

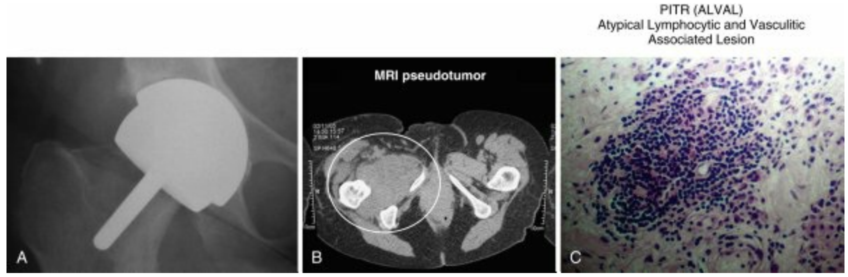


FIG. 5.41 Case example of pseudotumor following metal-metal resurfacing arthroplasty. (A) Radiograph of total articular resurfacing (TAR) implant with osteolysis in superior cup region and around superior femoral neck region. (B) MRI of local hip region showing large mass that extends into pelvis *(circle)*. (C) At surgery, the large inflammatory mass shows aggregates of T cells surrounding vascular structures. Special staining would also reveal metal debris particles in these regions. *PITR,* Particulate-induced T-lymphocyte response.

- **High rate of complications have been reported for revision THA in the setting of a failed MOM bearing and ALTR, with high rates of dislocation and infection**.

□ ALTR/pseudotumor response—treatment
- Removal of MOM bearing
- Revision of loose implants
  - Titanium alloy implants should be used for revision.
- Radical soft tissue débridement
  - Debulking of toxic tissues
- Ceramic-on-PE bearing should be used (not a Co-Cr head)
  - Revision ceramic femoral head should have a metal taper adapter sleeve

▪ **Specific patients in whom MOM bearing should be avoided:**

□ A woman of childbearing age
- Metal ions do cross placenta.

□ Patient in renal failure
- Metal ions no longer eliminated

▪ **Cancer risk with MOM bearings**

□ To date, there has been no increased risk for cancer in comparison with standardized populations.

□ However, with high bearing–wear scenarios, the local tissues are subject to potential metaplasia/dysplasia from metal ions.

Hip Resurfacing

▪ **Advantages**

- Preservation of proximal femur bone stock in young patients
  - Better stability than with standard THA with smaller-diameter femoral heads
  - Theoretically easier to revise to THA
- **Disadvantages**
  - Larger exposure required
  - Requires use of a MOM bearing
- **Relative contraindications**
  - Coxa vara—increased risk for neck fracture
    - Vertical shear force on neck
  - Female of childbearing age
  - Renal failure
  - Loss of bone stock, small anatomy, poor hip mechanics
  - Metal hypersensitivity
- **Complications**
  - Most common early complication (within first 3 years) is femoral neck fracture (1%–4%).
    - Risk factors: notching of the neck, female gender, poor bone quality, varus implant position, small components, disruption of blood flow to femoral head
  - Higher incidence of groin pain has been reported than for THA.
  - Abnormal soft tissue reactions secondary to metal-on-metal bearing

Ceramic-on-Ceramic Bearing

- **First-generation alumina—high head fracture rate (up to 13.4%)—reasons:**
  - More related to neck impingement (Fig. 5.42)
    - Adverse head/neck ratio
    - Ceramic heads with thick skirts
  - Poor manufacturing technique
  - Low ceramic density
  - Coarse microstructure
- **Third-generation alumina results in lower fracture rate.**
  - Improved manufacturing technique
  - Hot isostatic pressed technique
  - High ceramic density
  - Finer microstructure
  - Skirt elimination results in better head/neck ratio.
- **Advantages**
  - Lowest wear
    - Generally less wear (both linear and volumetric) than metal-on-metal

        - Fewer particles generated than with metal-on-metal
    - □ Bioinert debris
        - No ionization of particles
        - No cancer risk
        - No dysplasia/metaplasia effects on local soft tissues
- ▪ **Disadvantage**
    - □ Head size limitation
        - Ceramic socket must be placed within a metal acetabular shell. Also, ceramic socket must have a minimum thickness to limit fracture. These factors limit ultimate ceramic head size.
        - Stability is less than large-diameter metal-on-metal bearing.
        - Fluid film mechanics less optimal with smaller head radius.
    - □ Head length limitation
        - No skirts allowed
        - Can potentially limit hip offset, leading to hip impingement and instability
    - □ **Hip squeaking**
        - Psychologically affects patients with daily audible squeak
        - Etiology—perfect storm consisting of:
            - Implant malpositioning
            - Lever range wear
            - Stripe line formation, which creates an arcuate rough area on head and disrupts lubrication
            - Implant resonance—vibratory resonance created by lever range over rough region is amplified by prosthetic construct, which may be audible in ear frequency range.

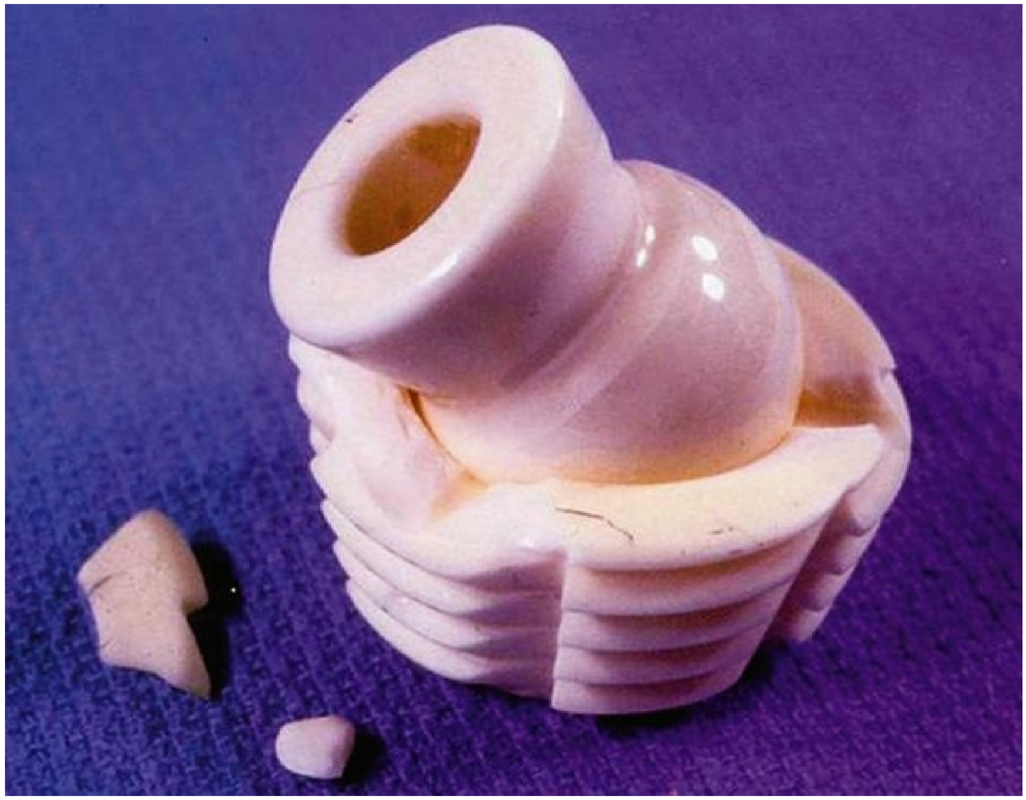


FIG. 5.42 Photograph of retrieved first-generation ceramic-on-ceramic THA. Note very thick neck, which was required for strength in first-generation systems. The enlarged neck adversely reduced head/neck ratio. Also note acetabular fracture resulting from neck impingement.

- Disruption in lubrication will lead to squeaking in all hard-on-hard bearings.
- Treatment is revision of the cup to PE bearing with head change (head is damaged by squeak).

□ Fracture

- The Achilles heel of this material when used for hip bearing
- Fracture is due to low toughness of material.
- Fracture treatment:
    - Typically replace with another ceramic-on-ceramic bearing
    - After fracture, microscopic shards of ceramic remain and are severely abrasive.
    - If a PE bearing is placed after ceramic bearing fracture, there will be rapid PE wear (HCLPE is better in this scenario than traditional polyethylene).

□ Stripe line

- Primarily described on ceramic-on-ceramic bearings, but similar effect can occur on metal-on-metal bearings
- Defined as an area of roughness created on the head and cup as a result of repetitive subclinical subluxation; hip is in lever range (Fig. 5.43)

- Head change
  - Any ceramic head placed on a used femoral neck must have an internal titanium adapter sleeve (Fig. 5.44).
  - A used femoral neck is roughened by wear and corrosion.
  - A new ceramic head (without a metal jacket) placed on a roughened neck can fracture with repetitive hip loading. High points on roughened neck cause a *burst fracture.*

Dual-Mobility Components

- **A small-diameter femoral head articulates with an outer polyethylene liner (forming a large diameter bipolar femoral head construct), which in turn articulates with a metal acetabular shell.**
- **Design affords greater impingement-free range of motion (ROM) and a larger head-neck ratio, resulting in increased jump distance and a reduced likelihood of dislocation.**
- **Low dislocation rates in primary and revision THA have been reported.**
- **Concerns include potential for excessive wear of polyethylene liner and the unique complication of intraprosthetic dislocation (dislocation of the inner head from the outer ball), which requires open reduction.**

Trunnion Corrosion

- **There has been increasing attention on the potential for metal ion release from the modular junction between the head and stem.**
  - Corrosion seen on majority of retrievals for failed metal-on-metal hip replacements
  - Large-diameter femoral heads, larger femoral component offsets, and varus stems increase the mechanical stress on the trunnion (toggle effect), although the importance of this increase in trunnion corrosion is unclear.
  - Process has been associated with ALTR and pseudotumor formation (similar in pathology to MOM THA failures).
  - Has been reported in metal on PE bearings
  - Has been reported with smaller-diameter heads (28 mm) in addition to larger-diameter implants

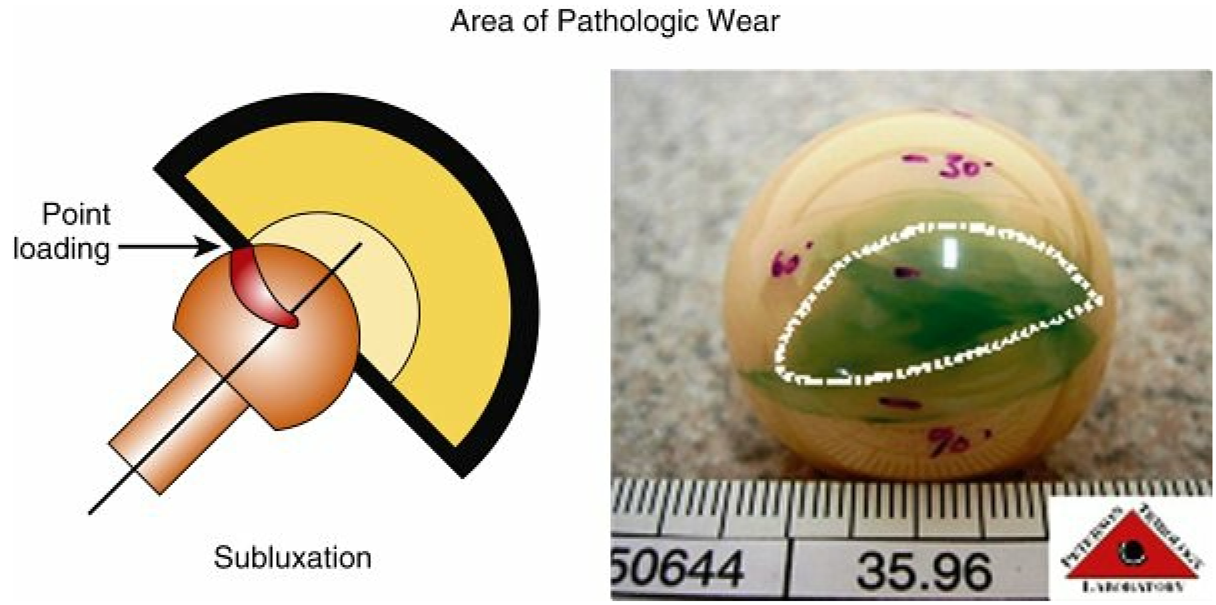


FIG. 5.43 *Left,* Diagram depicting stripe line. With repetitive subclinical subluxation, the prosthetic head rotates upon the edge of cup bearing. This is a high-contact-stress scenario that roughens the articular surface of the femoral head. *Right,* Slide attempts to show stripe line, which is highlighted on the ball. Stripe line detection requires microscopic review.

FIG. 5.44 Photograph of internal metal jacket in ceramic head. This internal metal sleeve protects the head from burst fracture when placed on to a used femoral neck that has been roughened by use.

- **Corrosion (trunnionosis)**
  - □ Gradual destruction of metal by reaction with environment (oxidation)
  - □ *Passivation*—formation of protective oxide coat
  - □ ***Fretting corrosion*** **(or mechanically assisted crevice corrosion)**
    - Small cyclic motion (<100 μm) between two surfaces (**any modular junction**)
    - Disrupts protective oxide layer
  - □ *Crevice corrosion*
    - Crevices create local conditions that increase oxidation
- **Clinical scenario for trunnion corrosion**
  - □ Diagnosis of exclusion (high index of suspicion)
  - □ Workup includes metal ion levels and MRI (similar to that for MOM THA)
  - □ **Concern when metal ions more than 1 ppb in metal on polyethylene articulation**
  - □ Revision to ceramic head with titanium sleeve adapter
  - □ Stem revision not required in absence of gross catastrophic damage

- **Trunnion corrosion responsible for increased use of ceramic heads in primary THA (Co-Cr should be eliminated if titanium stem is used)**

Section 8 Periprosthetic THA Fracture

Time of Fracture

- **Intraoperative or early postoperative**
  - Relates to surgical technique, implant design, and quality of host bone
- **Late**
  - Associated with low-level trauma plus concomitant risk factors
    - Osteolysis
    - Stem loosening with bone abrasion
    - Segmental bone defect (i.e., hole in bone)
  - Most late fractures occur at stem tip.
    - This is area of greatest modulus mismatch.
      - Bone and stem—stiff
      - Hollow bone distal—flexible

Intraoperative Fracture

- **Highest risk is with cementless implants**.
- **Acetabular fracture**
  - Most common reason for fracture is underreaming.
  - Underreaming of 2 mm or more associated with higher fracture risk
  - Cup may be left in place if stable, and additional screws used to enhance fixation.
  - An unstable cup needs to be revised and may require a posterior column plate.
- **Femoral fracture**
  - A longitudinal split in the calcar encountered during implantation of a tapered, proximally coated stem may be treated with stem removal, cabling, and reinsertion.
    - If this procedure does not result in a stable implant, a stem that bypasses the fracture and achieves diaphyseal fixation may be needed.

Early Postoperative Fracture

- **Acetabular fracture**
  - Overmedializing the cup can lead to fracture of the medial wall and intrapelvic migration of the acetabular component.
- **Femur fracture**
  - Often a result of unrecognized intraoperative fracture
  - Tapered wedge design
    - Associated with proximal femur fractures
  - Cylindrical, fully porous-coated stems
    - Associated with distal femoral cracks
  - Treatment
    - If implant is loose and unstable
    - Open reduction with internal fixation (ORIF) and component revision
    - If implant still maintains initial rigid fixation
    - Observation and limited weight bearing if just a small nondisplaced fracture
    - Prosthetic retention plus ORIF of fracture if there is significant fracture displacement or implant migration

Late Fracture

- **Treatment guided by the Vancouver classification (** Fig. 5.45)
  - Fractures in the trochanteric area (Vancouver A)
    - Fractures involving the greater trochanter (Vancouver A_G) can be treated nonoperatively if minimal displacement
      - ORIF considered for significant displacement or nonunion
      - ORIF *not* recommended in presence of massive osteolysis—inadequate bone for fixation and fracture healing
    - Fractures involving the lesser trochanter (Vancouver A_L) treated nonoperatively with protected weight bearing even if displaced
    - Fractures around or just distal to the stem (Vancouver B)
      - **If the stem is well fixed (Vancouver B1), treatment is with ORIF**.
        - Locking plate with unicortical screws and cables
        - Allograft struts with cables
      - **If the stem is loose with good bone stock remaining (Vancouver B2), implant must be revised**.
        - A broken cement mantle indicates a loose stem.

            - **Diaphysis-engaging cementless revision stem preferred** (fully porous-coated cylindrical or tapered fluted modular implant may be used)
            - Fracture fragments typically secured proximally around revision femoral implant with wires or cables
        - If the stem is loose and poor bone stock is present in the proximal femur (Vancouver B3), implant must be revised and bone stock augmented.
            - Allograft-prosthetic composite (young patients)
            - Proximal femoral replacement (elderly or low-demand patients)
    - Fractures well distal to femoral stem (Vancouver C)
        - Treated with ORIF using standard osteosynthesis techniques
        - Creation of a stress riser should be avoided, and the plate and femoral stem should be overlapped.

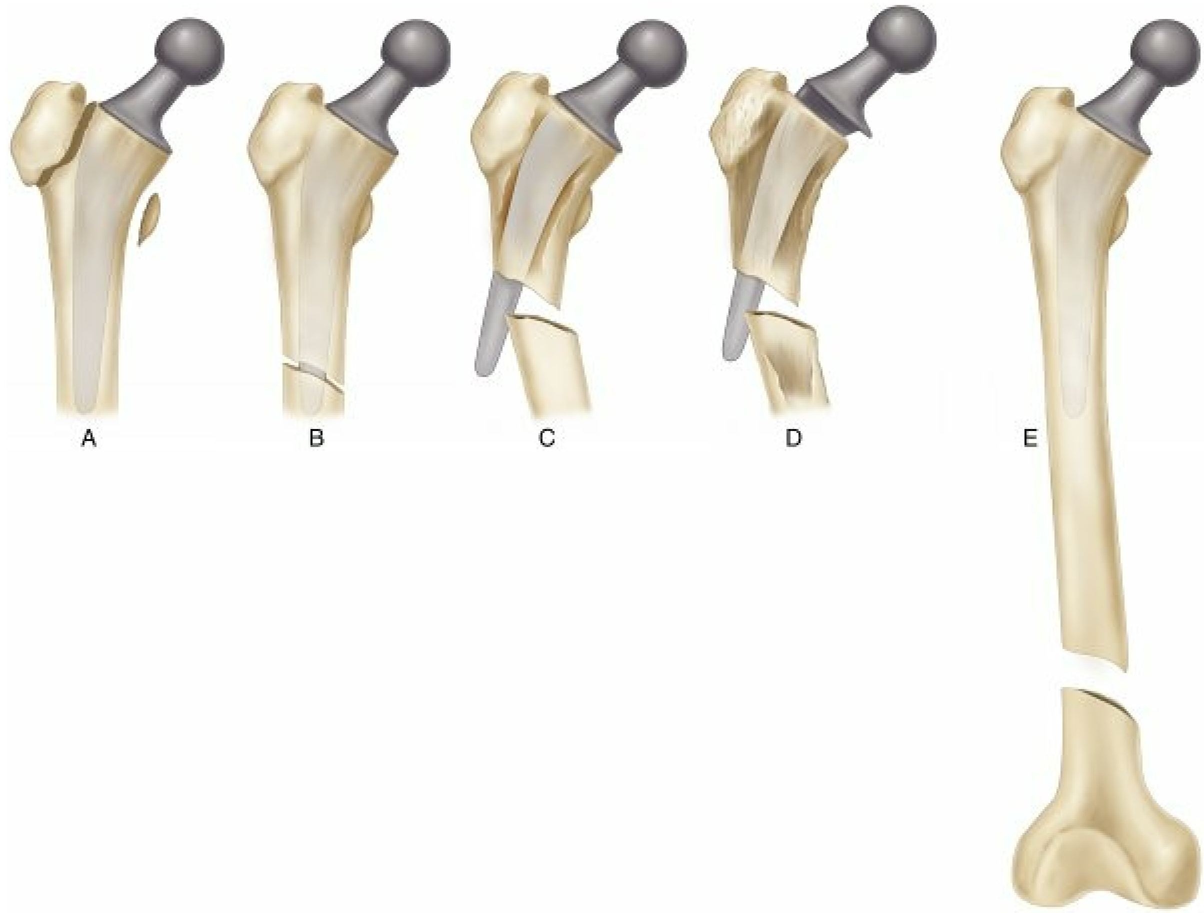


FIG. 5.45 Vancouver classification of periprosthetic hip fractures. Type A fractures (A) include greater and lesser trochanteric fractures. Type B fractures occur around or just below the implant and include B1 fractures with a well-fixed stem (B), B2 fractures around a loose stem (C), and B3 fractures around a loose stem with poor remaining bone stock (D). Type C fractures (E) occur well distal to the femoral prosthesis.

Section 9 THA—Miscellaneous

Nerve Injury

- **Involved nerves: 80% sciatic nerve, 20% femoral nerve**
- **Compression is most common pathologic mechanism of injury.**
  - Of patients who have a nerve injury after primary THA, only 35%–40% will have recovery to normal strength.
- **Sciatic nerve travels closest to acetabulum at the level of ischium.**
  - During surgery, the most common reason for sciatic nerve injury is errant retractor placement causing excess compression to nerve.
  - Peroneal nerve division is most often involved because this part of nerve is closest to acetabulum.
- **Risk factors for nerve injury**
  - Female gender
  - Posttraumatic arthritis
  - Revision surgery
  - Developmental dysplasia of the hip
    - **Risk for sciatic nerve palsy increases with leg lengthening of more than 3–5 cm**.
- **Postoperative functional footdrop**
  - Clinical scenario—patient sits in chair after surgery and experiences footdrop.
    - With hip flexed 90 degrees in chair, there is too much tension on sciatic nerve.
  - Treatment—patient returned to bed.
    - Hip placed in extension (bed flat)
    - Knee flexed on one or two pillows
    - This position provides least tension on sciatic nerve.
- **Postoperative hematoma**
  - A hip hematoma from anticoagulation can cause sciatic nerve palsy.
    - Compression is mechanism of injury.
  - **Treatment is immediate evacuation of hematoma**.

Anatomy

- **Medial femoral circumflex artery**
  - Located underneath quadratus femoris muscle or gluteus maximus tendon
  - Cutting deep to this area risks laceration to vessel.
    - Treatment is ligation/cauterization.

- Ascending branch of the lateral femoral circumflex artery
    - **At risk during direct anterior approach to THA and should be ligated**
    - Passes upward beneath tensor fasciae latae and is encountered in the space between tensor fasciae latae and sartorius
- Transverse acetabular ligament and obturator vessels
    - Transverse acetabular ligament extends between the two cotyloid pads at the inferior aspect of the acetabulum.
    - Errant retractor placement inferior to the ligament can damage obturator artery and vein.
    - Treatment is ligation/cauterization.

Specific Complications and Host Risk Factors

- **Sickle cell disease**
    - Associated with early prosthetic loosening
        - Mechanism is extended bone infarct disease.
        - Higher risk of periprosthetic joint infection.
- **Psoriatic arthritis**
    - Associated with higher periprosthetic infection rate
- **Ankylosing spondylitis**
    - Associated with higher risk for heterotopic ossification (HO)
    - Hip hyperextension due to fixed pelvic deformity can lead to a higher anterior dislocation rate.
- **Parkinson disease**
    - Higher dislocation rate
    - Higher perioperative mortality
    - Higher perioperative medical complications
    - Higher reoperation rate
- **Paget disease**
    - Increased blood loss
    - Good results may still be obtained with cementless fixation.
- **Dialysis**
    - Higher risk of infection and loosening
- **Fat emboli syndrome**
    - Occurs with femoral stem insertion
    - Fat and bone marrow emboli are pressurized into bloodstream.
    - Intraoperative hypotension, hypoxia, mental status changes, and petechial rash are hallmark findings.
    - Treatment is volume and respiratory support.

Venous Thrombosis

- **Activation of clotting cascade begins during surgery.**
  - Greatest risk for activation occurs during insertion of femoral component; applies to both cemented and cementless implants.
  - Mechanism for thrombogenesis
    - Femoral venous occlusion during preparation and insertion of femoral component
    - Typically, leg is twisted and mechanically levered during femoral stem preparation and insertion.

Heterotopic Ossification

- **Small amounts of clinically insignificant HO are common and likely present in a majority of patients undergoing THA.**
- **Risk factors: male gender, ankylosing spondylitis, hypertrophic subtype of arthritis, posttraumatic arthritis, head injury, and history of HO**
- **Prevention**
  - Careful handling of soft tissues
  - Prophylaxis with oral indomethacin or radiation therapy (700–800 Gy) within 24 hours prior to surgery or 72 hours after surgery
- **Treatment**
  - **No effective treatment in early postoperative period once the process has started**
  - Indication for surgical resection is significant loss of motion.
  - Process should appear mature and stable on serial radiographs before resection is undertaken.
  - Heterotopic bone may recur after operative resection.

Iliopsoas Impingement

- **Underrecognized cause of groin pain after THA**
- **Discomfort with resisted hip flexion and straight-leg raise**
- **Cross-table lateral radiograph or CT may show a retroverted cup or anterior overhang of the acetabular component.**
- **An injection may be used to confirm the diagnosis.**
- **Treatment is with release or resection of the iliopsoas tendon, alone or in combination with acetabular revision for an anterior overhanging component.**
  - Acetabular revision is more predictable for groin pain resolution in patients with 8 mm or more of anterior acetabular component prominence.

Implant Facts

- **THA biomaterials—Young's modulus relative values are shown in** Table 5.5.
- **THA bearing friction—relative values are listed in** Table 5.6.

Table 5.5

Biomaterials Use in Total Hip Arthroplasty—Relative Stiffness Ratings.

Implant Material	Young's Modulus (Material Stiffness)—Relative Value Rating
Alumina ceramic	Highest Young's modulus
Zirconia-reinforced alumina ceramic	↓
Zirconia ceramic	
Cobalt-chrome alloy	
Stainless steel	

Titanium alloy	
Cortical bone	
Cement (PMMA)	
Polyethylene (UHMWPE)	
Cancellous bone	
Tendon/ligament	
Cartilage	Lowest Young's modulus

Table 5.6

Bearing Friction Values for Biomaterials Use in Total Hip Arthroplasty.

Bearing Material	**Coefficient of Friction—Relative Value Rating**
Articular cartilage	Highest Young's modulus
Al_2O_3 on Al_2O_3 (alumina on alumina)	
Co-Cr alloy on Co-Cr alloy	
Metal on PE	
Ice on ice	
Steel on steel	Lowest Young's modulus

Section 10 THA—Joint Stability

Dislocation in THA frequently is a multifactorial issue. Treatment is patient specific, and the solution depends on the particular problem.

Incidence of THA Dislocation

- **Primary THA—typically 1%–2%**
- **Revision THA—typically 5%–7%**
- **Highest incidence of dislocation**
  - THA in the elderly patient (>80 years) for failed ORIF of femoral neck fracture—reasons:
    - Muscular weakness
    - Mental compromise
    - Loss of balance and coordination

Risk Factors for Dislocation

- **Female gender**
- **THA for osteonecrosis**
- **Posterolateral approach**
- **Smaller femoral head size**
- **Greater trochanter nonunion**
- **Revision THA**
- **Obesity**
- **Alcoholism**
- **Neuromuscular conditions**

Assessment

- **Assessment of a dislocating THA evaluates:**
  - Component design
  - Component alignment
  - Soft tissue tension
  - Soft tissue function
  - Spinopelvic alignment and postural pelvic positioning
- **Component design**
  - Prosthetic ROM consists of two parts, primary arc range (Fig. 5.46) and lever range (Fig. 5.47).
    - Primary arc range

- Primary arc range is controlled by the head/neck ratio (Fig. 5.48).
  - Ratio of head diameter to neck diameter is head/neck ratio.
  - Best stability is achieved by maximizing head/neck ratio (Fig. 5.49).
- Additions to acetabulum and/or femoral neck decrease primary arc range.
  - Neck skirt (also known as femoral head collar on femoral stem)
    - Decreases head/neck ratio
  - Acetabular hoods
    - Decrease primary arc range (Fig. 5.50)
  - Acetabular constrained cups
    - Markedly decrease primary arc range (Fig. 5.51)
    - Rule—constrained cups should be avoided as much as possible.

- Lever range
  - Range allowed as hip starts to lever out of socket
  - Lever range is controlled by head radius (Fig. 5.52).
  - A large head has higher excursion distance and is more stable.

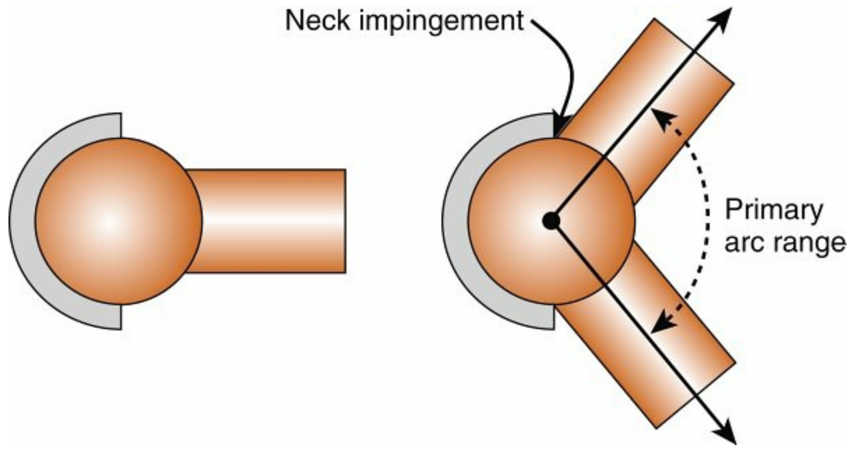


FIG. 5.46 Diagram demonstrating primary arc range in THA. At the end of hip range, neck impingement occurs, limiting motion. Primary arc range is the arc of motion allowed between the two ends of impingement.

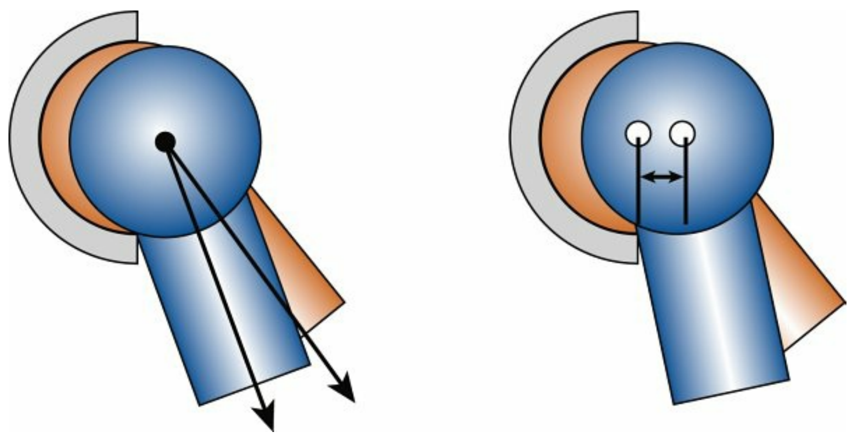


FIG. 5.47 Diagram demonstrating lever range and excursion distance. *Left,* Lever range. When the femoral neck impinges on the acetabular cup, it begins to lever out of the socket. The range of motion allowed before the hip dislocates is termed the *lever range*. *Right,* Excursion distance. As the hip begins to lever, the femoral head is lifted out of socket. The excursion distance is the distance the head must travel to dislocate. The excursion distance is equal to the radius of the femoral head

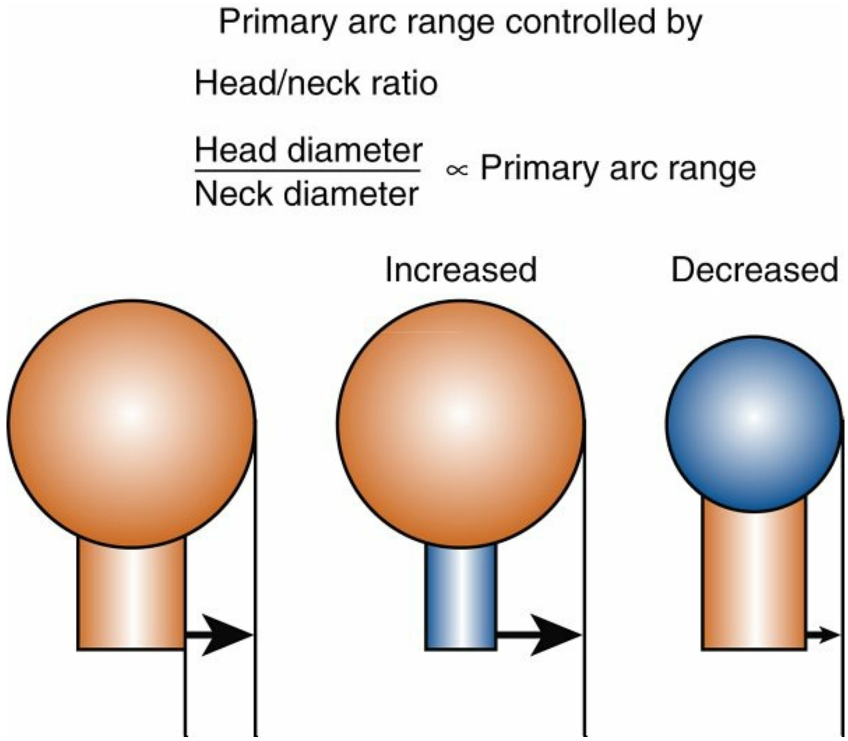


FIG. 5.48 Diagram demonstrating head-neck ratio. Diagram on *left* defines head diameter/neck diameter as head/neck ratio. *Center* diagram shows an increased head/neck ratio when, in this example, the femoral neck diameter is decreased. Diagram on *right* shows a decreased head/neck ratio when, in this example, the femoral head diameter is decreased.

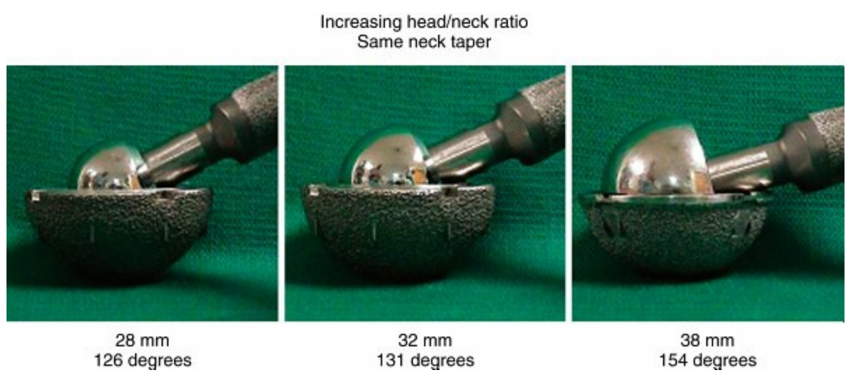


FIG. 5.49 Photographs showing how increasing head-neck ratio increases primary arc range. In this demonstration, the neck diameter remains constant. As the head diameter increases, the head-neck ratio increases, and primary arc range increases as well.

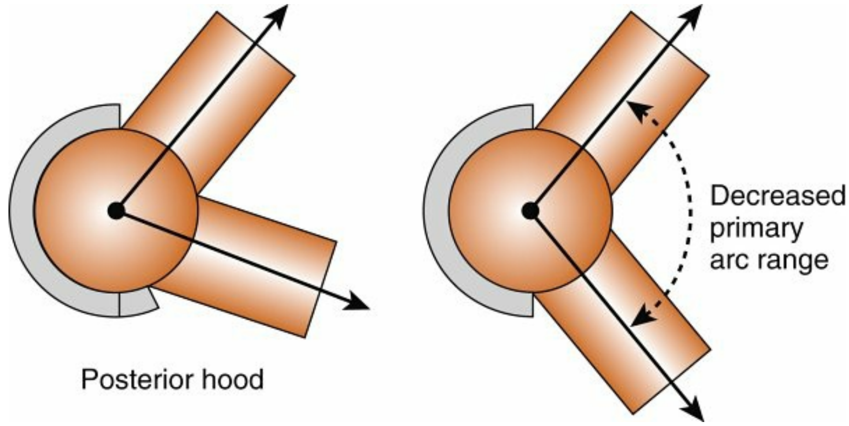


FIG. 5.50 Diagram showing the addition of an acetabular posterior hood. The addition of an acetabular hood significantly reduces primary arc range.

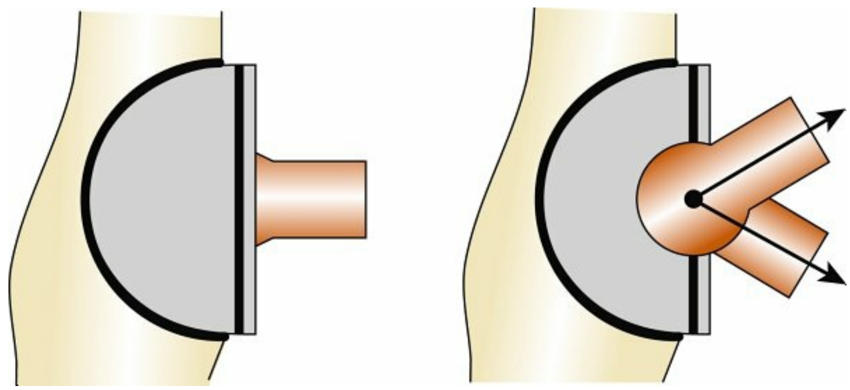


FIG. 5.51 Diagram of constrained acetabular cup. A constrained liner covers the femoral head past its equator. This keeps the ball from coming out of socket but has the adverse effect of severely restricting primary arc range.

- Most stable construct is a bipolar hemiarthroplasty (two pivot points).

□ Best range in THA
- High primary arc range
  - Maximized head/neck ratio
  - No additions to cup or neck
- High excursion distance
  - Large-diameter head

▪ **Component alignment**

□ Primary arc range must be centered within patient's functional hip range (Fig. 5.53).

□ Component malalignment does not decrease primary arc range.

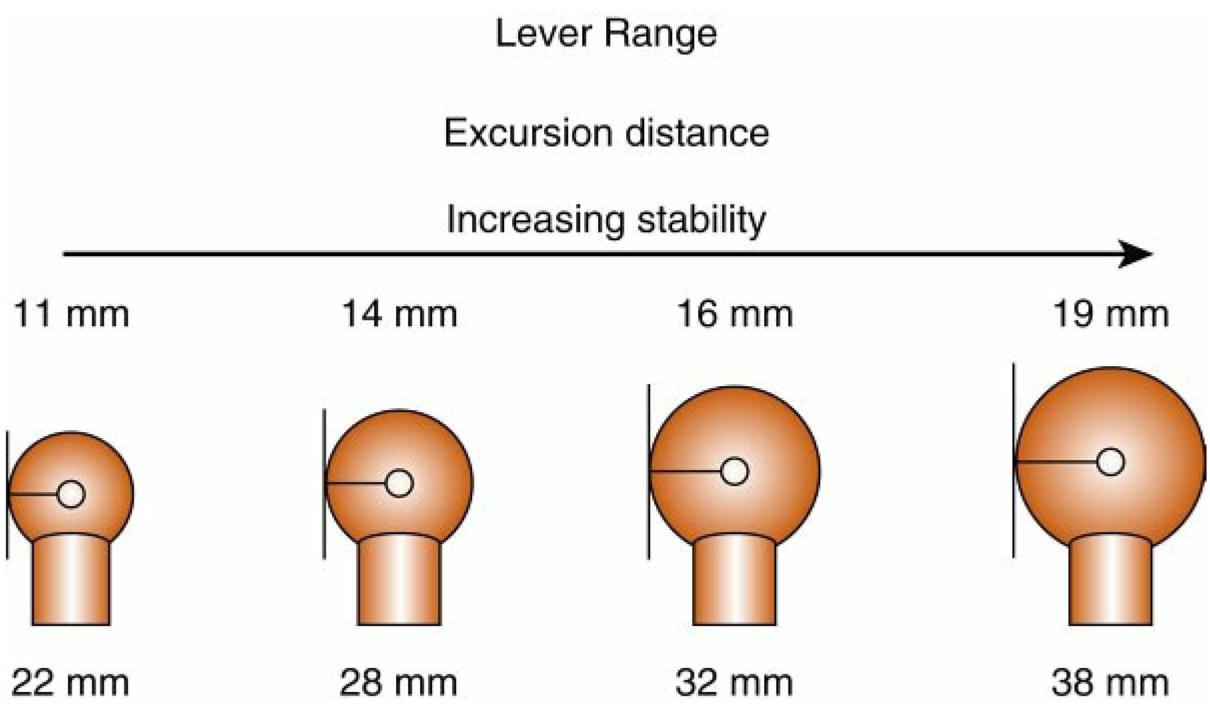


FIG. 5.52 Diagram demonstrating excursion distance and effect on hip stability. Excursion distance is equal to the radius of the femoral head. By increasing femoral head diameter, excursion distance is increased. This increases hip stability.

- Placement of components in a malaligned position results in a stable side and an unstable side of the functional hip range.
- Implant positioning in THA
  - Cup anteversion: 20–30 degrees (Fig. 5.54)
  - Cup theta (Θ) angle (also known as *coronal tilt*): 35–40 degrees (Fig. 5.55)
  - Stem anteversion: 10–15 degrees (Fig. 5.56)
- Cup malposition
  - Retroversion—risk is posterior dislocation.
  - Excess anteversion—risk is anterior dislocation.
  - High Θ-angle (vertical cup)—risk is posterior-superior dislocation.
  - Low θ-angle (horizontal cup)—risk is inferior dislocation.
- Stem malposition
  - Retroversion—risk is posterior dislocation.
  - Excess anteversion—risk is anterior dislocation.

- **Soft tissue tension**
  - **Abductor complex is key to hip stability**.
    - Consists primarily of gluteus medius and gluteus minimus muscles
    - Prosthetic implant design and positioning must maintain/restore proper abductor hip tension.
  - Restoration of abductor tension achieved by the following (Fig. 5.57):

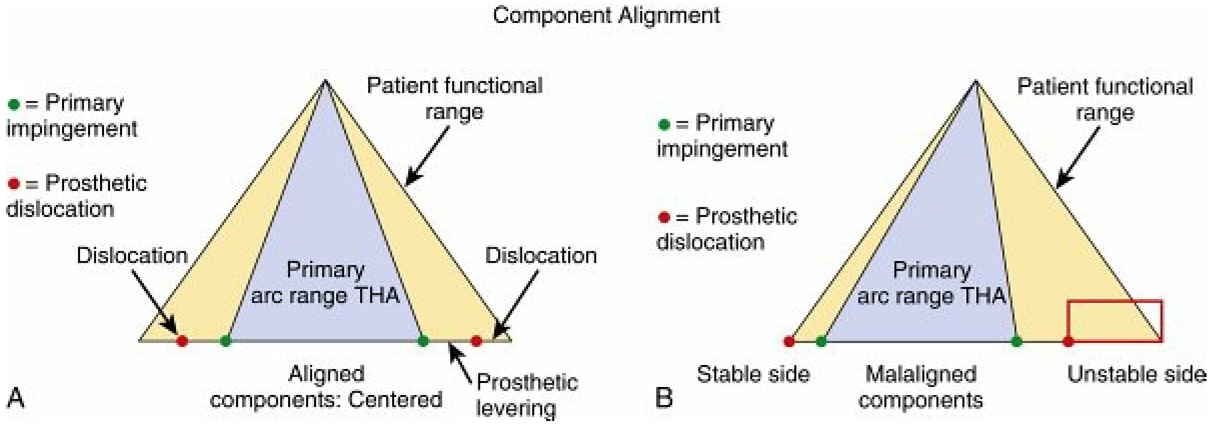


FIG. 5.53 Diagrammatic representation of component malposition showing its effect on hip stability. (A) Primary THA arc range centered within patient's functional hip range. Generally, THA arc range is less than patient's hip range because of smaller head size. (B) Component malalignment. Note that THA arc range has not changed. Instead, malposition allows the patient to exceed primary arc range and lever range. This in effect creates a stable side and an unstable side.

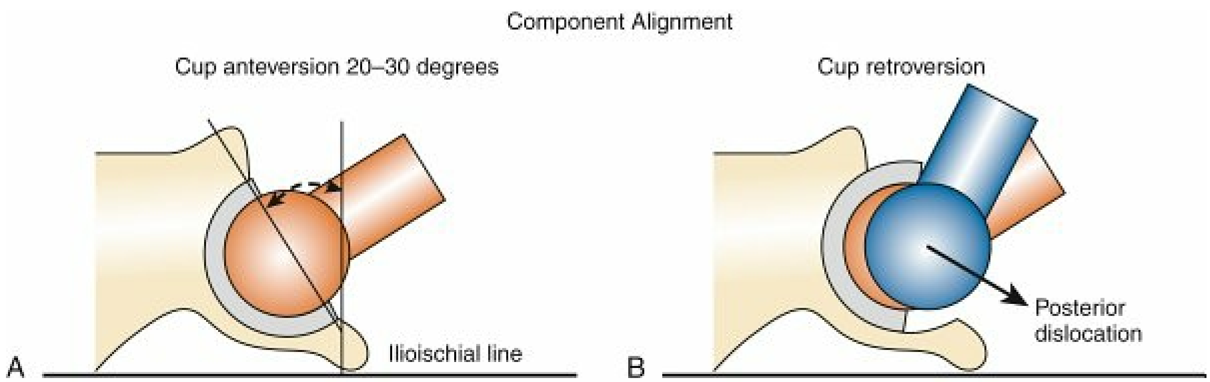


FIG. 5.54 Diagram of acetabular cup anteversion. (A) In this figure, cup anteversion is referenced relative to the ilioischial line. The cup should be placed at 20–30 degrees of anteversion. (B) With a retroverted cup, the femur impinges and levers in flexion, which can result in posterior hip dislocation.

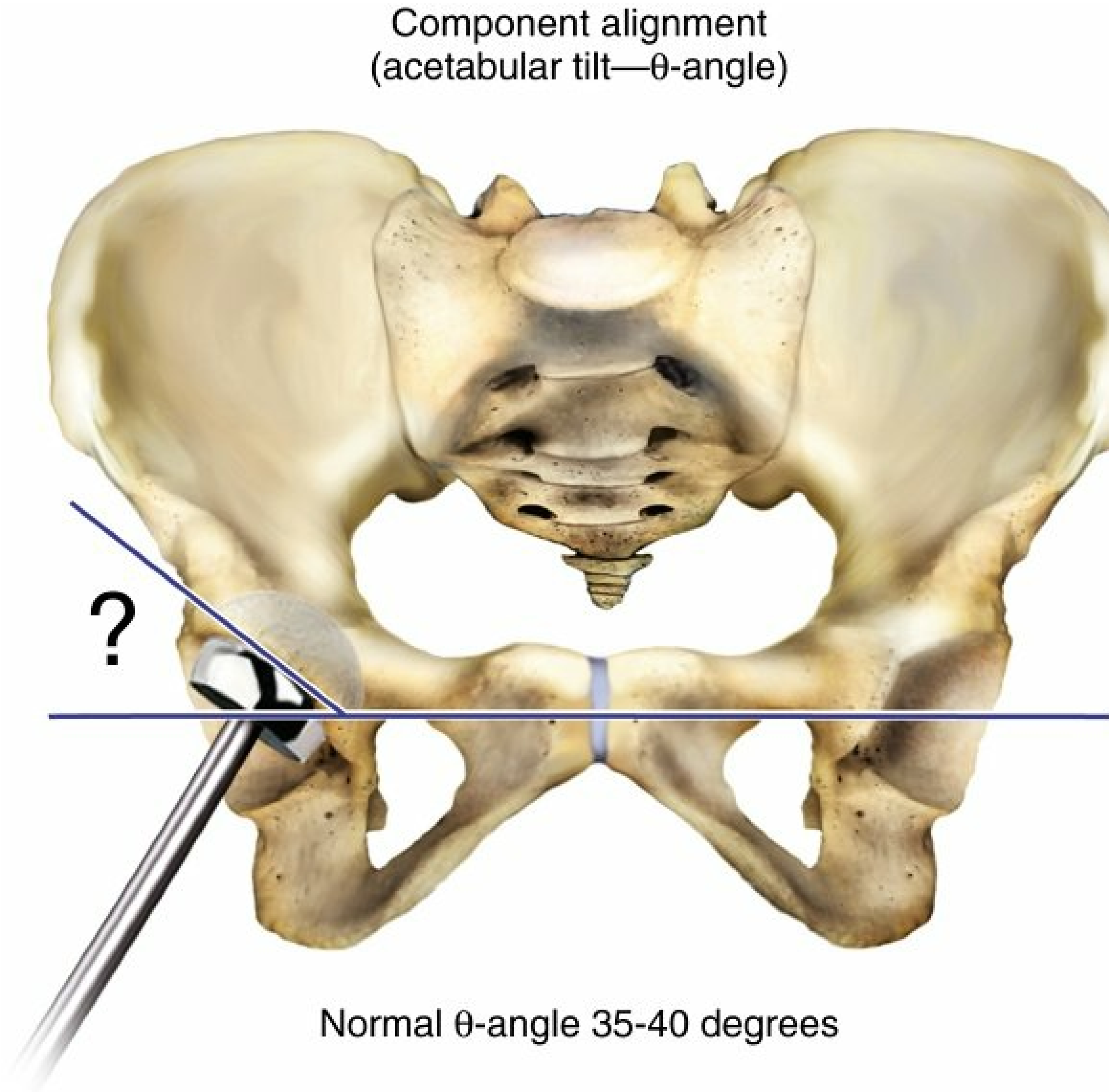


FIG. 5.55 Diagram of theta (Θ)-angle. In the coronal plane, the cup should be placed at a Θ-angle of 35–40 degrees. A low Θ-angle cup poses a risk for abduction impingement. A high Θ-angle cup increases risk for posterior-superior dislocation.

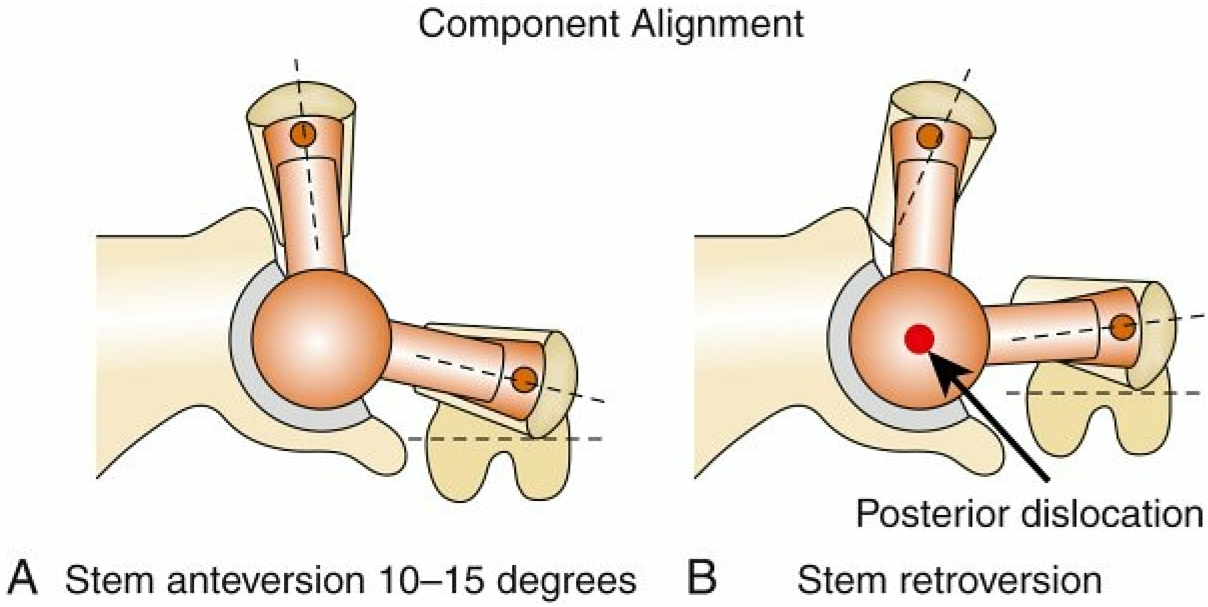


FIG. 5.56 Diagram of stem anteversion. (A) Normal stem anteversion of 10–15 degrees. This allows functional hip flexion without impingement. (B) Stem retroversion. With a retroverted stem, the proximal femur impinges early against pelvis. This can result in levering and posterior dislocation.

- Restored normal hip center of rotation
- Restored head offset
- Restored femoral neck length

□ Problems with reduced hip offset

- Weakened abductor complex
- Increased joint reaction force (decreased abductor lever arm)
- Presence of Trendelenburg sign

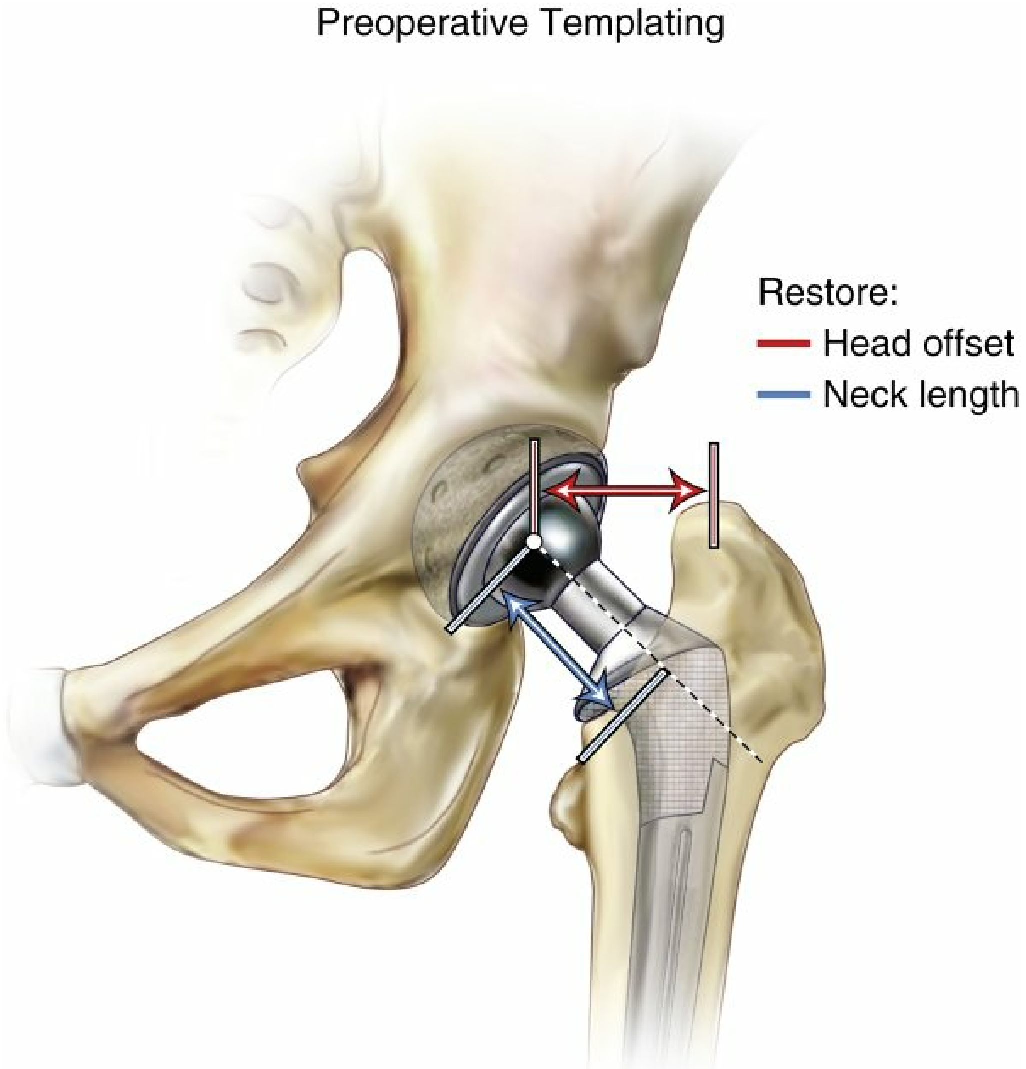


FIG. 5.57 Diagram demonstrating head offset and femoral neck length. Head offset is the distance from the hip head center to the lateral femur (either the greater trochanteric tip or a line that is centered within the femoral medullary canal). Femoral neck length is the distance from the femoral head center to the base of the femoral neck (usually the top of the lesser trochanter is used as the reference mark). Preoperative hip templating is used to make sure that the appropriate implant design and femoral neck osteotomy level are chosen to restore preoperative values.

- Gluteus medius lurch with walking
- Increased risk for dislocation

□ Problems with short neck length

- Short neck length occurs when a low neck cut is made, a short prosthetic neck length is used, or both.
- Shortens abductor muscle length, resulting in abductor weakness
- Decreases hip offset, which also weakens abductor complex
- Results in bony impingement of greater trochanter against pelvis during hip range (Fig. 5.58)
    - Causes pain
    - Allows hip levering and increases risk for dislocation

- Shortens leg length

- □ Problems with restoring neck length by using a long head
    - A short femoral neck cut can be compensated with an extra-long prosthetic neck length. However, a long neck length requires a skirt (Fig. 5.59).
        - A skirt decreases primary arc range.
        - Increases risk for dislocation
        - If the prosthetic neck-shaft angle is lower than that of native hip, the addition of neck length will excessively increase neck offset.
        - This can cause trochanter bursitis and chronic lateral hip pain (Fig. 5.60).
    - Narrow-offset femoral stem design
        - A femoral stem with an offset designed with a narrower angle than the native hip will reduce hip offset. This reduces abductor tension and increases risk for hip dislocation.
        - A narrow-offset stem can be compensated for by with a longer femoral head length (i.e., neck length). This creates two potential problems.
            - Addition of neck length to restore offset will excessively lengthen the leg.

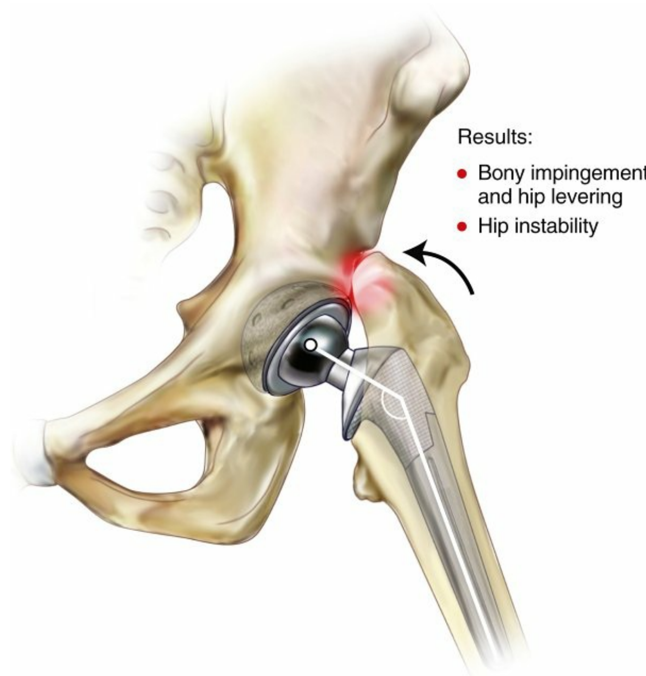


FIG. 5.58 Diagram showing effect of decreased neck length. A decreased neck length brings the proximal femur closer to the pelvis. As the hip is ranged *(arrow)*, the greater trochanter is more likely to abut the pelvis. This causes hip levering and increases risk for hip instability.

- Addition of a long neck requires a skirt, which decreases primary arc range and increases risk for dislocation.

□ Greater trochanteric escape (Fig. 5.61)

- Greater trochanteric escape occurs when the greater trochanter pulls away from the proximal femur.
  - Usually a result of failed trochanter fixation after revision THA
    - Can also occur from trauma (usually associated with osteolysis in greater trochanter)
    - Successful reattachment is difficult and often fails.
- Problems
  - Because the hip abductor complex attaches to the greater trochanter, trochanteric escape results in a loss of hip compression and increases risk for hip dislocation.
  - There is greater external and internal hip rotation because the greater trochanter no longer restricts rotation range. This also increases the risk for

dislocation because the hip can more easily approach and exceed lever range.

- The greater trochanter fragment can impinge between the hip and pelvis, causing hip levering.

- Treatment
  - Maximized head/neck ratio.
    - No neck skirts and no acetabular hoods
  - Resection of greater trochanter fragment to prevent impingement levering.
  - Constrained acetabular cup is last resort.

▪ **Soft tissue function**

□ The soft tissues about the hip are controlled by several body systems. All are integrated to provide hip stability. The three main factors controlling soft tissue function are:

- Central nervous system

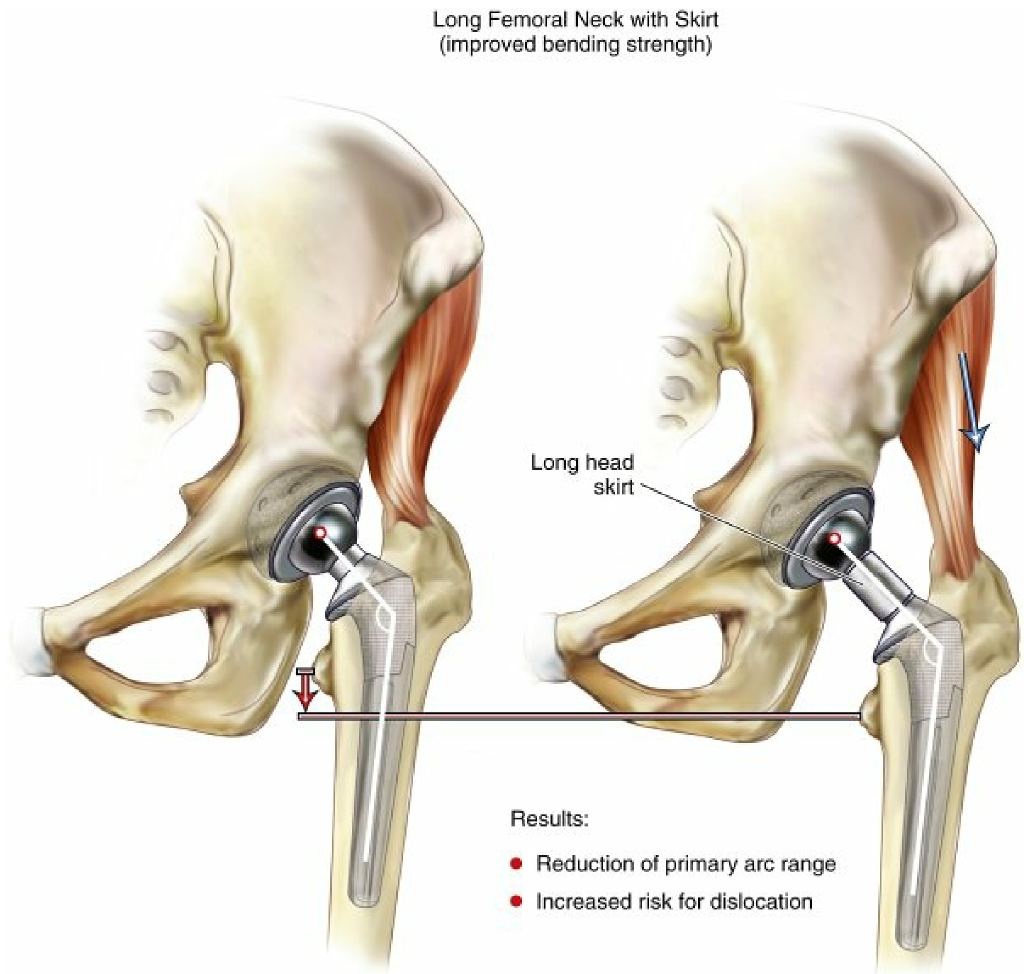


FIG. 5.59 Diagram demonstrating the problem of using a long femoral head. A low neck cut is compensated by employing a long femoral neck (typically 9 mm or longer). When a long head is used, a metal skirt is added to improve bending strength (to prevent metal fatigue and failure). The thick metal skirt can significantly reduce primary arc range, resulting in an increased risk for dislocation.

   - Peripheral nervous system
   - Local soft tissue integrity (surrounding hip region)
- □ CNS mechanisms causing disruption to hip function and increasing risk for dislocation
   - Muscle dysfunction
   - Sensory impairment
   - Impaired coordination
   - Impaired balance
   - Cognitive loss of restraint (i.e., compliance/memory)
- □ CNS conditions affecting hip function
   - Cerebral dysfunction
      - Stroke, seizure, CNS disease
   - Cerebellar dysfunction
      - Balance/coordination
   - Delirium
      - Medications, withdrawal phenomenon
   - Dementia

- Psychiatric problems
  - Psychosis, addiction

□ Peripheral nervous system mechanisms causing disruption to hip function and thereby increasing risk for dislocation
- Muscle dysfunction
- Sensory impairment
- Pain

□ Peripheral nervous system conditions affecting hip
- Spinal stenosis
- Radiculopathy
- Neuropathy
- Paralysis/paresis

□ Local soft tissue integrity mechanisms causing disruption to hip function and increasing risk for dislocation
- Muscle dysfunction
- Soft tissue dysfunction (other than muscle)
- Soft tissue loss
- Skeletal deformity
  - Example: patients with ankylosing spondylitis have increased risk for anterior dislocation.

□ Local soft tissue conditions affecting hip function
- Trauma
  - Soft tissue loss
  - Myoligamentous disruption
- Deconditioning
  - Poor health
  - Aging process
- Irradiation
  - Radiation fibrosis with soft tissue contraction
- Dysplasia
  - Musculoskeletal hypoplasia
- Osteolysis
  - Bone loss
  - Myotendinous disruption

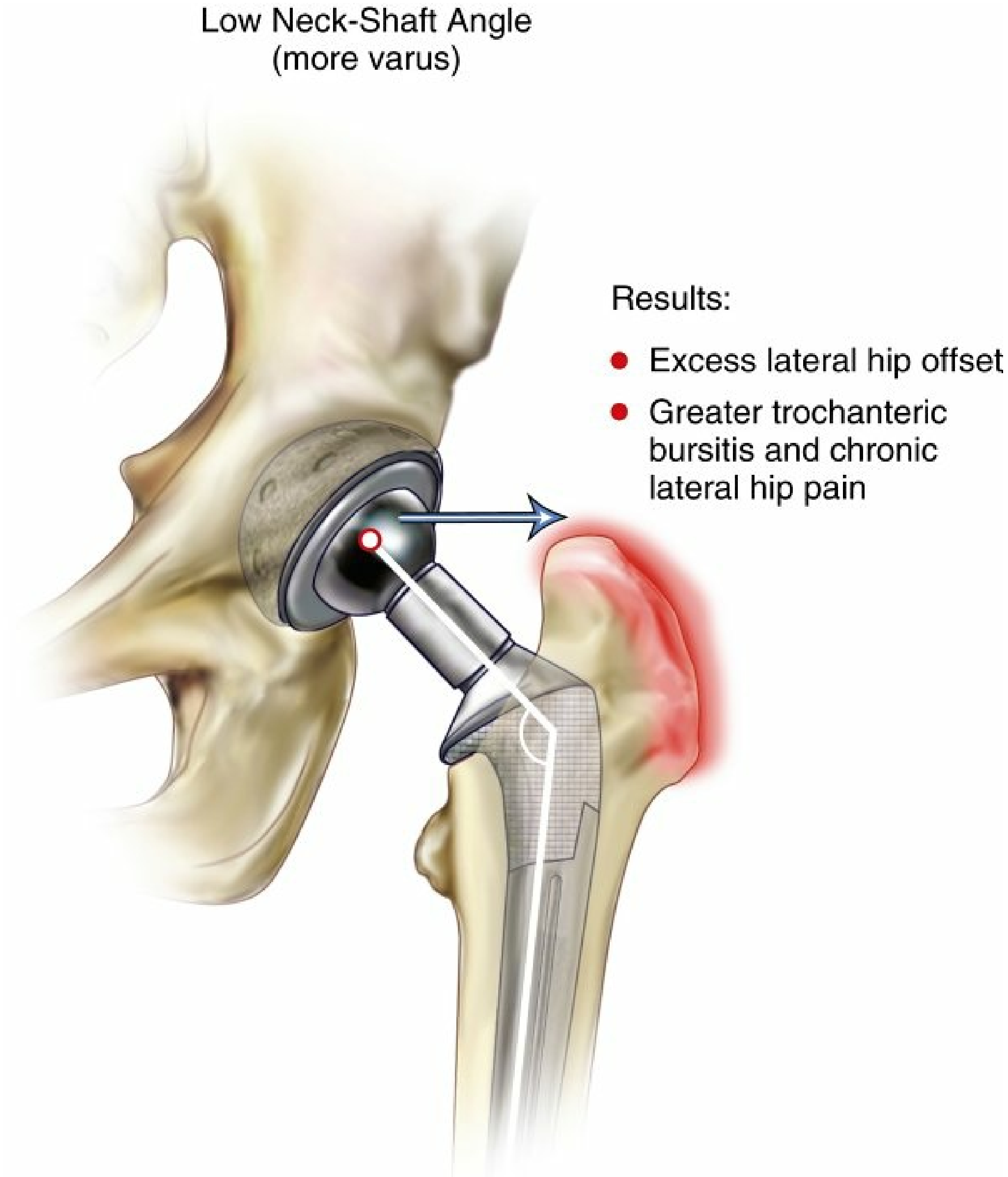


FIG. 5.60 Diagram demonstrating the problem of excess lateral hip offset. A low neck cut is compensated by employing a longer femoral head length (i.e., neck length). However, when the neck-shaft angle of the prosthesis is lower (i.e., more varus) than the native femoral neck, the addition of neck length excessively increases hip offset. This causes excess tension of the iliotibial band over the greater trochanter, which leads to chronic pain and bursitis.

- Collagen abnormalities
  - Clinical hyperelasticity
- Myopathy
- Malignancy
- Infection

- **Spinopelvic alignment**
  - Increasingly recognized as a potential contributing factor to instability following THA
  - **Patients with fixed spinopelvic alignment in sitting and standing positions are at higher risk of dislocation.**
    - Patients with lumbar spine disease and previous lumbar

spine surgery may have reduced spinopelvic motion and are at higher risk for instability.

Treatment

- **Each case of hip dislocation is unique. There is not one common treatment.**
- **In each case the following issues, as previously described, should be assessed:**
  - Component design
  - Component alignment
  - Soft tissue tension
  - Soft tissue function
  - Spinopelvic mobility
- **Clinical review of dislocating event important**
  - Was dislocation at extreme end range or within the range for usual activities of daily living?

FIG. 5.61 Radiographs showing trochanteric escape after revision THA. The radiograph on *left* shows greater trochanter pulled away from the proximal femur. The greater trochanter was damaged by osteolysis, leaving little surface area for healing. Cyclic fatigue eventually resulted in cable breakage and detachment of the greater trochanter from the femur. When the greater trochanter is not attached to the vastus lateralis, it is pulled cephalad toward the joint region. In this region, the greater trochanteric fragment is an impingement source. Radiograph on *right* shows subsequent dislocation. When the greater trochanter is not attached to the femur, prosthetic rotation range is increased and the hip is more likely to lever out of the socket. Also note head skirt *(arrow),* which diminishes primary arc range.

- □ Patient's cognition—impaired versus normal
- □ Clinical examination
    - Determination of where THA starts to lever and sublux
- □ Radiographic review
    - Implant design and position should be scrutinized.
    - Sitting lateral and standing lateral x-rays may be obtained to assess spinopelvic relationship and mobility.

- **Initial treatment for dislocated THA**
    - □ **Two-thirds of patients with first-time THA dislocation early in the postoperative period can be successfully treated with closed measures.**
    - □ Closed reduction
        - Sedation or anesthesia preferred to minimize soft tissue

trauma

- During closed reduction, hip is taken through full range to assess position of dislocation.
    - Subluxation is identified as being either within patient's activities of daily living or at extreme end range.
- Posterior hip dislocation
    - In supine position, the leg lies in internal rotation, adduction, and shortened position.
    - Reduction maneuver for posterior hip dislocation
        - Flexion to 80–90 degrees
        - Internal rotation
        - Adduction
        - Distraction
- Anterior hip dislocation
    - In supine position, the leg lies in external rotation, slight abduction, and slightly shortened position.
    - Reduction maneuver for anterior hip dislocation
        - Extension
        - External rotation
        - Slight abduction
        - Distraction
    - Postreduction treatment
        - Education—hip precautions
        - Immobilization of joint (usually 6 weeks)
            - Spica brace/cast
            - Knee immobilizer—to keep patient from putting hip in a compromised position
        - Physical therapy
            - Focus on strength, balance, agility, coordination
        - Optimization of medical conditions

▪ **Surgical treatment**

□ Surgical options

- Implant revision
- Greater trochanter advancement
- Constrained acetabular socket (cup)
- Conversion to bipolar hemiarthroplasty

- Resection arthroplasty

- **Rule 1 for surgical treatment: If any implant component is malaligned, it needs to be changed.**
  - May require complete hip revision
- Goals of component revision
  - Maximizes head/neck ratio to increase primary arc range.
    - No neck skirts or acetabular hoods
  - Accurate component alignment
  - Re-creates center of hip rotation and head offset.
  - Stabilizes greater trochanter (if possible) if it is detached.
  - Dual-mobility cups may allow for use of a larger femoral head and improve range of motion before impingement.
- Greater trochanter advancement (also known as *Charnley tensioning)* (Fig. 5.62)
  - Technique is to perform trochanteric osteotomy, advance the greater trochanter distally on the lateral femur, and resecure it with claw, cables, and/or wires.
  - With distal advancement of the greater trochanter, the abductor complex is tensioned more tightly, thereby increasing hip compression forces.
  - Requirements
    - No component malalignment
    - Adequate distal bone surface for bony fixation and bone healing
    - Intact superior gluteal nerve
- Constrained PE liner

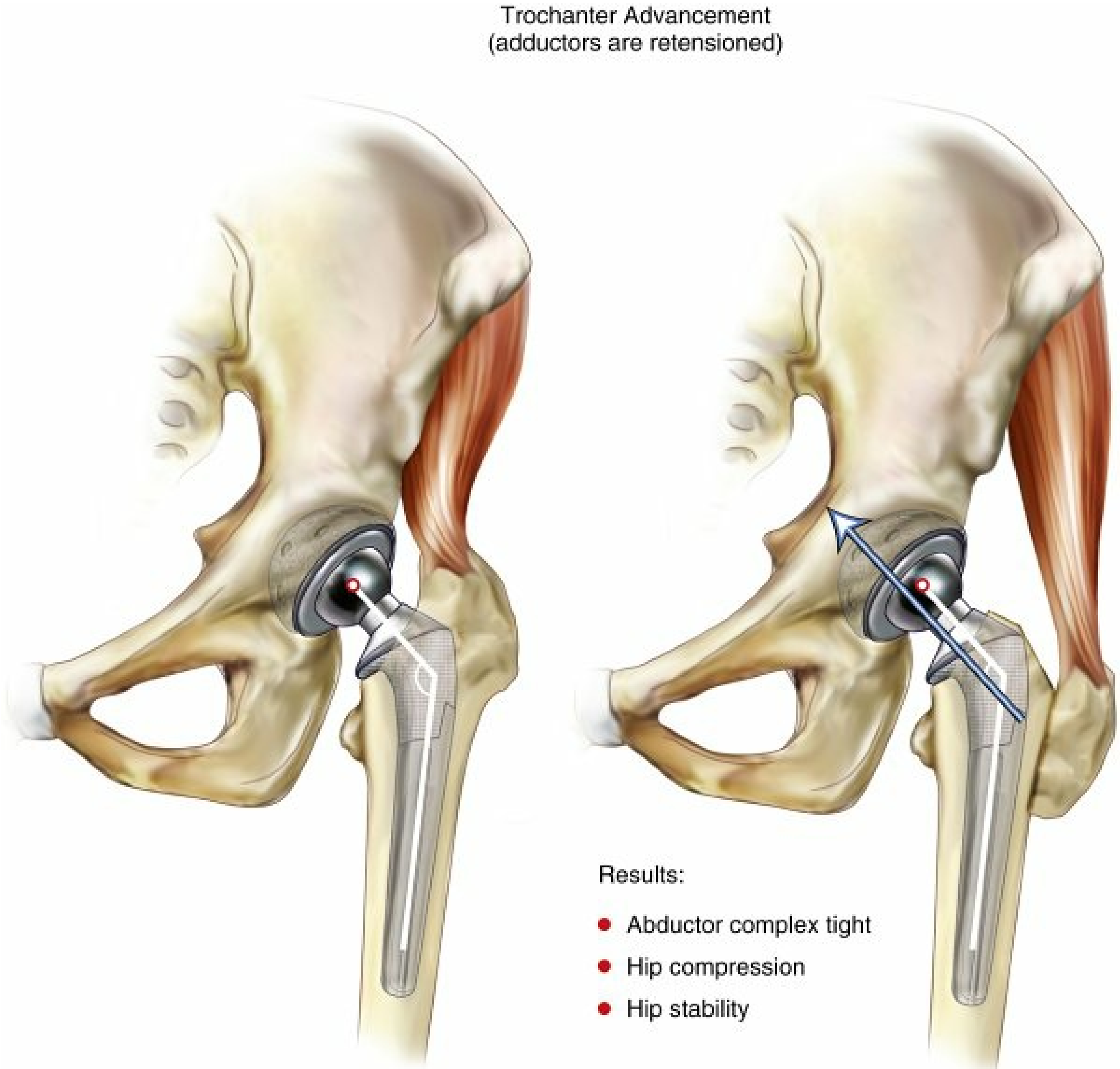


FIG. 5.62 Example of greater trochanteric advancement. Diagram on the *left* shows implants in good alignment, but the abductor sleeve is lax in tension. When the greater trochanter is distally advanced *(right)*, the abductor tension is improved, resulting in higher hip compression forces. This change improves hip stability.

- A constrained PE liner encloses the femoral head and *mechanically* prevents hip from distracting out of socket.
- **Reserved as a last resort for the patient who has experienced multiple dislocations with soft tissue dysfunction and appropriately positioned implants**.
- Best indications
  - Elderly patient (i.e., low demand) with normal component alignment
  - Abductor deficiency/dysfunction
  - Central neurologic decline
- Revision THA with reconstruction cage (Fig. 5.63)
  - Significant soft tissue dissection and potential muscle dysfunction with cage placement
  - Contraindication
    - Cup malposition

- Failure mechanisms
    - Because a constrained cup significantly reduces primary arc range (to as low as 60–70 degrees), the cup is exposed to more frequent and more intense lever range forces. With repetitive loading, the constrained cup will fail via two different mechanisms.
    - The PE deforms at the edges of the socket and the hip dislocates.
    - The PE does not deform. In this case the levering forces are then transmitted to the acetabular prosthetic-bone interface, resulting in mechanical loosening of the cup.
    - In the patient with failed constrained PE liner, the rate of subsequent failure is high if revision involves use of another constrained PE liner.

□ Conversion to bipolar hemiarthroplasty

- Rarely done and should be reserved for unusual circumstances
- Technique: removal of acetabular component; reaming of remaining bone to a hemisphere; press fitting of bipolar ball to rim of acetabulum (minimizes risk for medial migration of head).
- Requirements
    - Fully intact acetabular bone
        - No segmental rim deficiencies; otherwise the bipolar ball will dislocate
    - Good bone density
    - Rim fit technique
- Advantages
    - Maximizes fully head/neck ratio
    - Bipolar construct has a little more inherent stability than monopolar ball.
- Disadvantages
    - Groin pain—metal articulating on bone (Fig. 5.64)
    - Medial migration of head developing into protrusio deformity
    - Accelerated PE wear
        - Larger overall PE wear surface area

□ Resection arthroplasty

- Indications
    - Nonambulatory patient

- Neurologic deficits in which stability cannot be achieved
- Recurrent/ongoing periprosthetic infection
- Drug-seeking behavior with purposeful voluntary dislocations

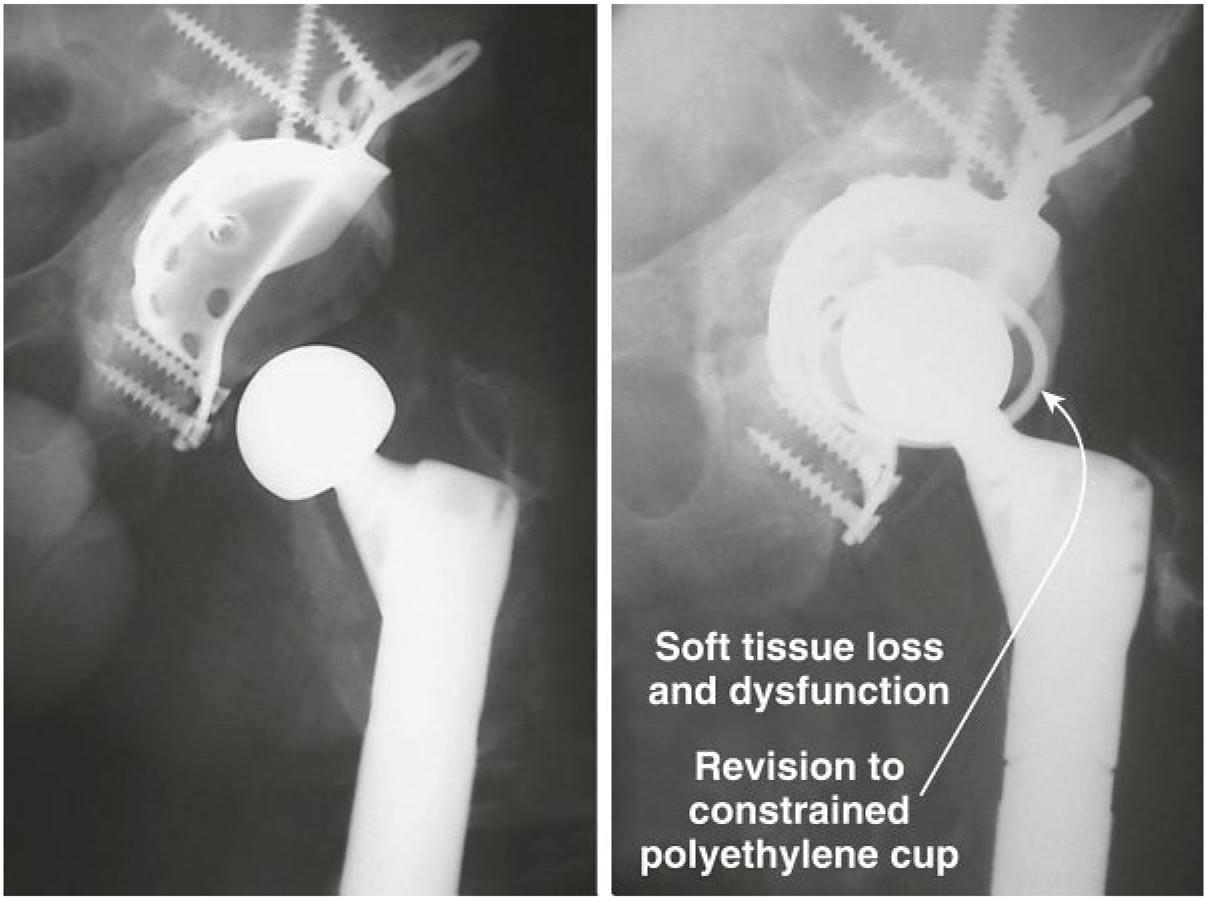


FIG. 5.63 Radiographs showing dislocation in a multiply revised THA. In this example the patient had multiple risk factors for dislocation: cage revision, greater trochanteric escape, spinal stenosis, and peripheral neuropathy. Note the loss of soft tissue tension as the hip has literally dropped out of the socket *(left).* Stability was achieved with placement of a constrained PE socket *(right).*

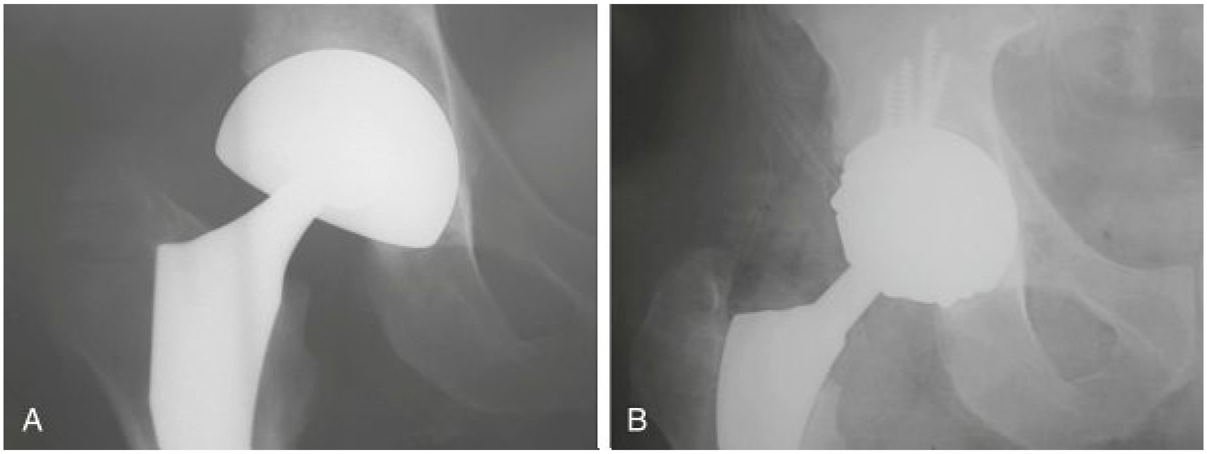


FIG. 5.64 Example of hemiarthroplasty for recurrent THA dislocation. The patient, a 66-year-old man, underwent revision for recurrent THA dislocation. (A) Bipolar ball articulating on bone. Although hip was stable, this active patient experienced significant groin pain. (B) The acetabular socket was revised to a fixed acetabular socket with revision of the femoral component to provide proper alignment of acetabular and femoral components. This patient remains stable with current construct.

Section 11 Knee Arthritis Assessment

Patient assessment of knee pain includes a physical examination and diagnostic radiographic modalities.

Clinical Presentation

- **Pain with weight bearing**
  - Aggravated by stairs, hills, moving from sit to stand
- **Bowing deformity and instability**
  - Seen later in presentation
- **Knee thrust—later in clinical presentation**
  - Indicates ligament stretch-out (i.e., abnormal) on convex side of thrust
    - Varus thrust
      - Knee pushes outward with stance phase, overloads medial compartment, and increases cartilage degeneration in medial compartment (a.k.a. adductor moment of force, because tibia is in adduction relative to femur).
    - Valgus thrust
      - Knee pushes inward with stance phase, overloads lateral compartment, and increases cartilage degeneration in lateral compartment.

Imaging Studies

- **Radiographs are still the standard for initial evaluation. Images should include:**
  - Weight-bearing AP and lateral views
  - **View of weight-bearing knee bent at 45-degree angle**, imaged posterior to anterior (Fig. 5.65)
    - X-ray plate is positioned parallel to tibia
  - Sunrise view (i.e., Merchant view)
  - Extension and flexion lateral views
  - Full-length AP radiograph
    - AP radiograph from hip joint to knee joint (standing stance preferred)
    - Used to evaluate limb and knee alignment when abnormal femoral or tibial bowing deformity is present (developmental or traumatic)
- **MRI**

- ◽ Grossly overused in the arthritic patient population
- ◽ If the joint space is significantly narrowed on radiograph, then MRI is *not* indicated.
- ◽ Used when osteonecrosis is suspected

- **CT**
    - ◽ Three-dimensional CT with remodeling used for preoperative planning for reconstruction associated with dysplasia, posttrauma planning, and complex total knee arthroplasty (TKA) planning

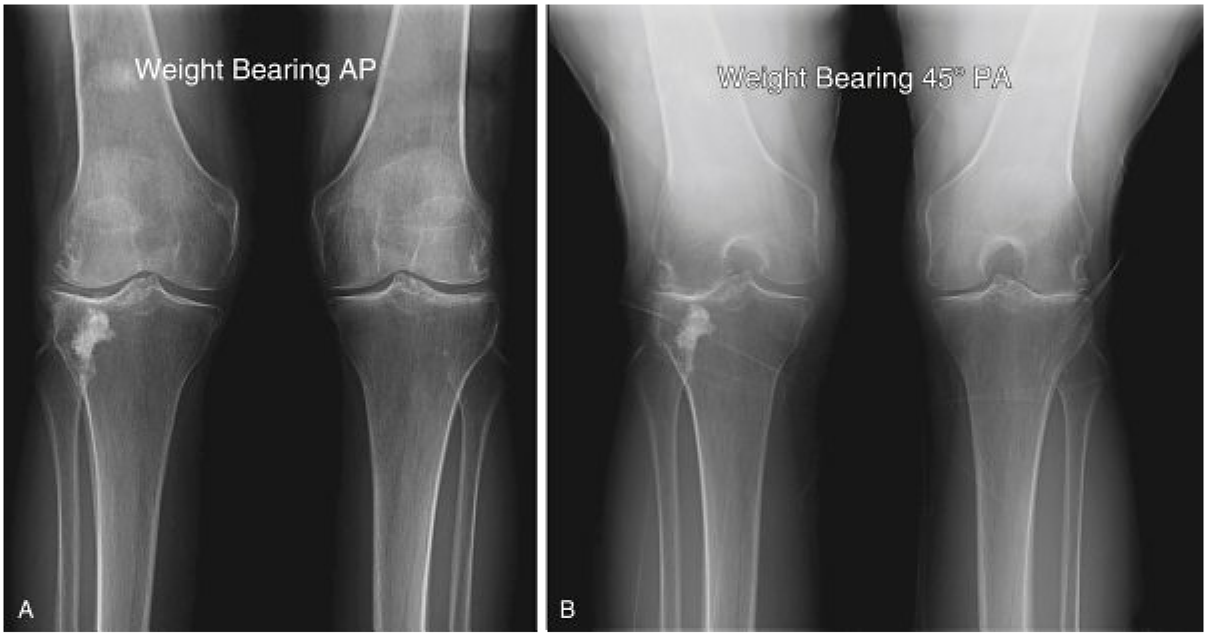


FIG. 5.65 Standing radiographs for arthritis treatment. (A) A standing AP radiograph of a patient with debilitating arthritic knee pain. In this radiograph, the joint spaces are relatively preserved. It does not correlate with the patient's subjective pain with walking. (B) A standing 45-degree PA view of the patient taken at the same visit. This radiograph shows the complete loss of lateral compartment joint spaces, which corroborates the patient's debilitating pain symptoms.

Section 12 Knee Arthritis Treatment

Consensus Treatment

- **A stepwise approach is recommended with graduated interventional treatment as pain and functional debility progress**
- **American Academy of Orthopaedic Surgeons (AAOS),** *Treatment of Osteoarthritis of the Knee: Evidence-Based Guideline,* 2nd edition:
  - Systematic review of evidence-based studies
  - Recommendations for noninvasive and less invasive alternatives to knee replacement
  - Treatments rated into three categories:
    - Recommended—advised use
    - Not recommended—advised avoidance
    - Inconclusive—used with clinical discretion on a case-by-case basis
  - Recommendations summarized in Table 5.7
- **Osteotomy**
  - Best indication
    - Young active patient, generally younger than 45 years, **and**

Table 5.7

AAOS: Evidence-Based Guidelines for Treatment of Osteoarthritis of the Knee.

Treatments	Recommendation
Conservative	
Self-management programs	Recommended
Weight loss when BMI ≥25	Recommended
Physical agents (taping, electrotherapeutic modalities, etc.)	Inconclusive
Manual therapy	Inconclusive
Valgus-directing unloading brace	Inconclusive
Acupuncture	Not recommended
Lateral wedge insoles for medial compartment disease	Not recommended
Glucosamine and chondroitin	Not recommended
Pharmacologic	
NSAIDs	Recommended
Tramadol	Recommended
Acetaminophen	Inconclusive
Opioids	Inconclusive
Pain patches	Inconclusive
Procedural	
Intraarticular corticosteroid injections	Inconclusive
Growth factor and/or platelet-rich plasma injections	Inconclusive
Hyaluronic acid	Not recommended
Needle lavage	Not recommended
Surgical	
Valgus osteotomy for medial compartment disease	Recommended
Arthroscopic partial meniscectomy for OA and torn meniscus	Inconclusive
Arthroscopy with lavage and/or débridement	Not recommended
Free-floating interpositional device (i.e., unispacer)	Not recommended

Adapted from American Academy of Orthopaedic Surgeons: *Treatment of osteoarthritis of the knee: evidence-based guideline*, ed 2, https://www.aaos.org/research/guidelines/treatmentofosteoarthritisofthekneeguideline.pdf. Accessed May 18, 2013.

- Occupation precludes the use of prosthetic joint replacement owing to significant implant loading and cycles (i.e., high-load, high-stress type occupation)

- □ Most likely to succeed when disease affects predominantly one compartment
- □ For varus knee malalignment
    - Treatment is valgus-producing proximal tibial osteotomy
    - Reason: problem is usually due to proximal tibial varus.
        - Goal of surgery: correct the deforming problem
    - **Osteotomy goal: maintains joint line of knee perpendicular to mechanical axis of leg**
        - Mechanical axis of leg defined as center of hip through center of knee to center of ankle
- □ For valgus knee malalignment
    - Treatment is varus-producing supracondylar femoral osteotomy
    - Reason: problem typically is result of **lateral femoral condylar hypoplasia.**
        - Goal of surgery: correct the deforming problem
    - **Osteotomy goal: maintain joint line of knee perpendicular to the mechanical axis of leg**
- □ **Valgus-producing tibial osteotomy (for varus knee deformity)**
    - Selection criteria
        - Clinical examination and radiographs show that other two compartments are free of arthritis.
        - Clinical pain is isolated to medial knee compartment.
        - Patient is **physiologically young** and has an occupation or activity level that makes prosthetic arthroplasty less appropriate
    - Contraindications
        - Inflammatory arthritis
        - Lack of flexion—minimum of 90 degrees needed
        - Flexion contracture more than 10 degrees
        - Ligament instability
            - Especially varus thrust gait (this indicates abnormal lateral compartment ligament/capsular stretch-out)
            - Femoral-tibial subluxation more than 1 cm (viewed on AP radiograph)
            - Note: ACL deficiency acceptable if all other criteria are met
        - Medial compartment bone loss
        - Lateral compartment joint narrowing

- Detected by **valgus stress** radiograph
- Osteotomy less successful in following conditions
  - Smoking
  - Age 60 years or older
  - Varus deformity of 10 degrees or more
    - There is just not enough bone to remove to correct deformity.
  - Concomitant arthritis in other compartments
- Main problems
  - Closed-wedge technique
    - Patella baja deformity (most common)
      - Patella baja results in loss of knee flexion
    - Loss of tibial posterior slope
  - Open-wedge technique
    - Patella baja deformity (also most common)
    - Nonunion
    - Loss of valgus correction (i.e., collapse of open wedge)

□ **Varus-producing femoral osteotomy (for valgus knee deformity)**

- Selection criteria
  - Valgus deformity of 12 degrees or greater
  - Clinical pain isolated to lateral knee compartment
  - Clinical examination and radiographs show medial knee compartment free of arthritis.
  - Patellofemoral joint should also be free of arthritis, but minimally symptomatic patellofemoral disease is acceptable (reduction of Q angle improves patellofemoral mechanics and reduces pain).
  - Patient is physiologically young and has an occupation or activity level that makes prosthetic arthroplasty less appropriate.
- Contraindications
  - Inflammatory arthritis
  - **Prior medial meniscectomy**
  - Lack of flexion—minimum of 90 degrees needed
  - Flexion contracture more than 10 degrees
  - Ligament instability
    - Especially valgus thrust gait (this indicates abnormal medial

compartment ligament/capsular stretch-out)
            - Femoral-tibial subluxation seen on AP radiograph
        - Medial compartment joint narrowing
            - Detected by **varus stress** radiograph
        - Age older than 65—relative contraindication
        - Osteoporosis—relative contraindication
    - Main problems
        - Nonunion
        - Loss of varus correction
            - Seen more often in patients with osteopenia/osteoporosis
        - Residual patellofemoral maltracking may require a lateral retinacular release.
    - Osteotomy technique (for femoral osteotomy)
        - Crescentric dome preferred
            - This osteotomy produces the **least** bone displacement.
            - Allows for femoral stem with TKA

- **Unicompartmental knee arthroplasty (UKA)**
    - Utilized for patients in whom arthritis predominantly affects one compartment of knee
    - The most common UKA, by far, is medial compartment replacement
    - Advantages of UKA (medial or lateral) over TKA and knee osteotomy
        - Quicker recovery
        - Fewer short-term complications
        - Shorter hospital stay with less postoperative pain
        - Better knee function than with TKA
            - ACL is preserved as it is in TKA
    - Results
        - High rate of short-term to mid-term satisfaction
        - However, long-term survivorship is not comparable to that with TKA when measured by revision rates.
    - Contraindications
        - Inflammatory arthritis
        - Significant **fixed** deformity
            - Deformity must be correctable on clinical exam (e.g., resting varus attitude must be correctable to normal valgus)
        - Previous meniscectomy in **opposite** compartment
        - ACL-deficient knee
            - ACL deficiency is an **absolute** contraindication to

        - a mobile-bearing UKA
        - Mobile-bearing UKA is utilized only for medial compartment replacement
    - Flexion contracture less than 10 degrees
    - Tricompartmental arthritis
- □ Selection criteria—important:
    - Pain must be localized to the compartment being replaced
        - Medial knee pain signifies medial compartment disease
        - Lateral knee pain signifies lateral compartment disease
        - Anterior knee pain signifies patellofemoral compartment disease
        - Diffuse or global pain signifies tricompartmental disease
- □ Surgical technique
    - Overcorrection must be avoided.
        - Overcorrection puts increased load on unresurfaced compartment.
            - Can result in early revision owing to accelerated progression of arthritis
        - For medial UKA, correction to 1–5 degrees of clinical valgus
- □ Complications unique to UKA
    - Stress fracture of tibia (never femur)
        - Associated with heavy weight and high and early postoperative activity level
            - Typical presentation: pain-free interval (usually 4–6 weeks), then spontaneous acute onset of pain with weight-bearing activity
        - Aspiration of knee reveals blood
        - Treatment
        - If tibial fixation stable
            - Relative rest and limited weight bearing
        - If tibial fixation compromised
            - Revision of tibial implant with or without ORIF of the medial tibia
            - Conversion to TKA with tibial stem support when medial bone is compromised
- □ Failure mechanisms

- Overcorrection at time of surgery
  - Risk is disease progression in opposite compartment
  - Pain localized to arthritic compartment
- Undercorrection at time of surgery
  - Risk is implant overload with subsequent failure due to accelerated polyethylene wear/failure, osteolysis, and/or mechanical loosening
- Implant subsidence
  - Tibial side only
  - Due to weak metaphyseal bone; factors:
    - The deeper the tibial cut, the weaker the metaphyseal bone
    - Undercoverage—preference is to place tibial implant on host rim bone, which is stronger.
  - Osteoporosis
- Patellar impingement upon femoral implant causing pain
  - Related to implant design and surgical technique
  - Pain is localized anteriorly
  - Requires revision to TKA
- Arthritis progression in other compartments (i.e., natural progression of disease)
  - Pain in other knee compartments
  - Requires revision to TKA

▪ **Isolated patellofemoral arthritis**
- □ TKA (not patellofemoral arthroplasty) is recommended choice in older patients (≥50 years)
  - Superior functional results than those of patellectomy and patellofemoral arthroplasty
- □ Lateral retinacular release commonly required with isolated patellofemoral arthritis
  - Reason: maltracking is usually the cause of isolated patellofemoral arthritis

▪ **TKA: see next section**

Section 13 Total Knee Arthroplasty

Indications

- **Debilitating pain affecting activities of daily living**
- **Pain not well controlled by conservative measures**
- **Medical fitness for surgery**
- **No active infection—anywhere**

Survival of TKA

- **Best survival**
  - Well-balanced knee
  - **Neutral mechanical alignment**
- **Decreased survivorship**
  - Young age—55 years or less
  - Osteoarthritis
  - Reason: high activity level
- **Increased survivorship**
  - Old age—70 years or more
  - Rheumatoid arthritis
  - Reason: low activity level
  - Cemented fixation (all components) in comparison with cementless fixation
    - Reason: cementless implants do not always achieve circumferential bone ingrowth and tend to be more susceptible to osteolytic debris.

Technical Goals

- **Restoration of neutral mechanical alignment of limb**
- **Restoration of joint line**
- **Balanced ligaments**
- **Normal Q angle**

Preoperative Planning

- **Preoperative radiographs should include**
  - *Standing* bilateral AP views of knees
  - Extension and flexion lateral views

- Sunrise (Merchant) view
- Standing *full-length* AP hip to ankle in following situations
  - Bony angular deformity present
  - Very short stature
    - Less than 60 inches (152 cm)
  - Very tall stature
    - More than 75 inches (190 cm)

- **Preoperative radiographic analysis should be used to:**
  - Determine end cuts—femur and tibia.
  - Determine position of femoral canal entry site at the knee.
  - Identify bone defects.
  - Identify joint subluxation.
  - Identify ligament stretch-out.
    - If varus thrust gait is evident, standing single-leg AP radiographs are recommended (Fig. 5.66)
  - Determine anticipated ligament releases.
  - Anticipate extent of constraint needed
- **End cuts—distal femur and proximal tibia**
  - Goal of end cuts is to restore neutral mechanical alignment of the limb.
    - *Neutral mechanical alignment* is defined as a line from hip head center, through knee center, to ankle center
  - Preoperative analysis of femur (review of full-length radiographs) is used to determine the following (Fig. 5.67):
    - Anatomic axis of femur (AAF)
      - A line that bisects the medullary canal of the femur
      - The AAF, drawn to the distal end of the femur, **determines *entry point* for the femoral medullary guide rod** for the cutting jigs
    - Mechanical axis of femur (MAF)
      - A line from center of distal femur (entry point hole) to center of femoral head

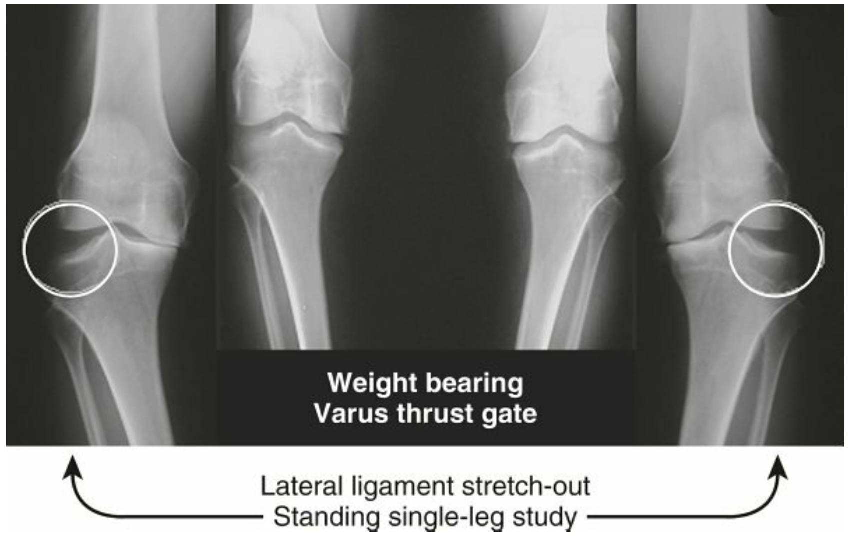


FIG. 5.66 Preoperative review of patient in preparation for TKA. Standing AP radiograph *(middle)* shows varus attitude of knees. Patient clinically had significant varus thrust bilaterally. Standing single-leg-stance radiographs *(left and right)* demonstrate severity of lateral ligament stretch-out. In this case, a revision knee system was ordered to accommodate potential instability problems that may be encountered during balancing and trialing.

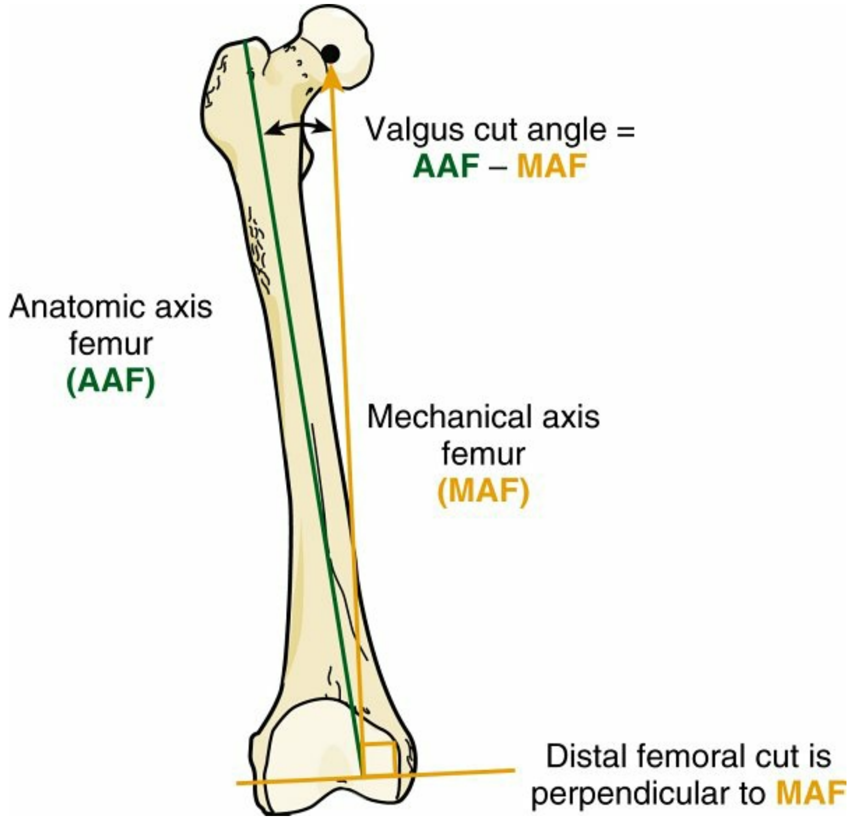


FIG. 5.67 Diagram showing preoperative measurements of femur to make distal femoral end cut. The distal femur is cut perpendicular to the mechanical axis of the femur. The anatomic axis of the femur (AAF) is defined clinically by the intramedullary guide that is placed into the canal. A cutting jig is placed onto the medullary guide rod. The distal valgus cut angle is the value set into the cutting jig to make the distal femoral cut perpendicular to the mechanical axis. Also note the location where the AAF exits the distal femur. This is the position to open the distal femur to insert the medullary guide rod.

- **Significance—distal femur is cut *perpendicular* to MAF**.
    - Allows even mechanical loading to knee implant
- Valgus cut angle
    - Defined as angle between AAF and MAF
    - Intramedullary guide rod is placed into femur (this defines AAF).
    - Distal femoral cut jig is assembled to intramedullary guide rod.
    - Surgeon selects valgus cut angle (typically between 4 and 7 degrees).
    - Distal femur should end up being *perpendicular* to MAF.
    - Valgus cut angle should always be measured in tall and short patients (Fig. 5.68).

- Hip offset remains *relatively* constant.
- Femur length, therefore, has more influence on valgus cut angle.

□ Preoperative analysis of tibia (review of full-length AP radiograph) is used to determine the following (Fig. 5.69):

- Anatomic axis of tibia (AAT)
  - A line that bisects the medullary canal of the tibia
  - The AAT, drawn through the proximal tibia, **determines the entry point for the tibial medullary guide.**
    - Both intramedullary and extramedullary cutting jigs for the proximal tibial end cut are acceptable techniques.
- Mechanical axis of tibia (MAT)
  - A line from center of proximal tibia (entry point hole) to the center of ankle
  - **Significance—proximal tibia is cut *perpendicular* to MAT**.
    - Allows even mechanical loading to knee implant

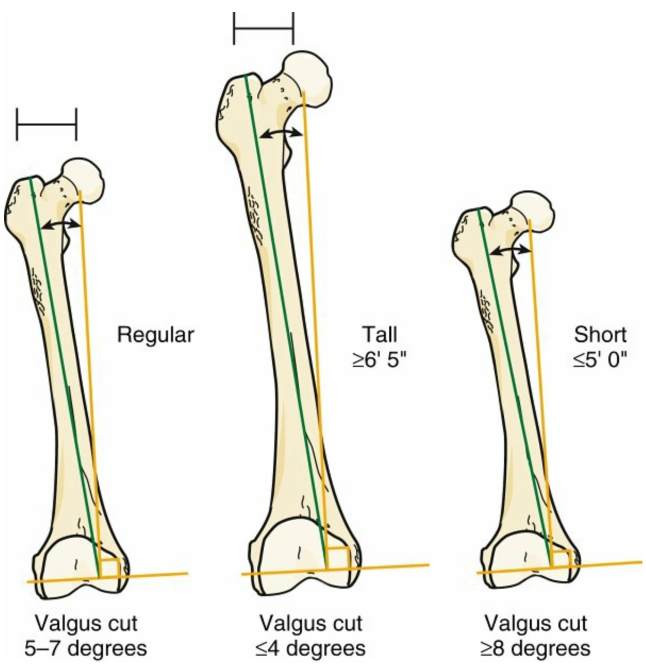


FIG. 5.68 Effect of femoral length on valgus cut angle. Hip offset does not vary widely. Therefore valgus cut angle is more influenced by femoral length. Tall patients will have a lower valgus cut angle, whereas short patients will have a higher valgus cut angle.

- Tibial cut angle
    - Defined as angle between AAT and MAT
    - Intramedullary guide technique
        - Intramedullary guide is placed into tibia.
        - Proximal tibia cut jig is assembled to intramedullary guide.
        - Surgeon selects tibial cut angle (usually 0 degrees).
        - Proximal tibia should end up being cut *perpendicular* to MAT.
    - Extramedullary guide technique
        - The extramedullary guide technique is placed over the anterior tibia. A jig distally holds guide centered over ankle. A proximal jig holds guide centered over proximal tibia (**landmark is medial one-third of tibial tubercle**).
        - Surgeon selects tibial cut angle.
        - In most cases the AAT and MAT are coincident. Therefore tibial cut angle is zero.
        - When there is a tibial deformity (e.g., fracture or bowing deformity), the AAT and MAT are divergent. The tibial cut angle is then carefully measured and selected to provide a proximal tibial end cut perpendicular to MAT.

Goals of Bone Cuts in TKA

- **Measured resection—replace bone and cartilage with implants that are of the same thickness**
    - Maintains joint line, which is important for proper ligament function
        - The maximum alteration of joint line allowed is 8 mm.
            - Reason: posterior rotational axis of the knee requires alignment of the collateral ligaments with a restored joint line.
    - Maintains ligament tension
    - Accurate bone cuts are accomplished with cutting jigs.

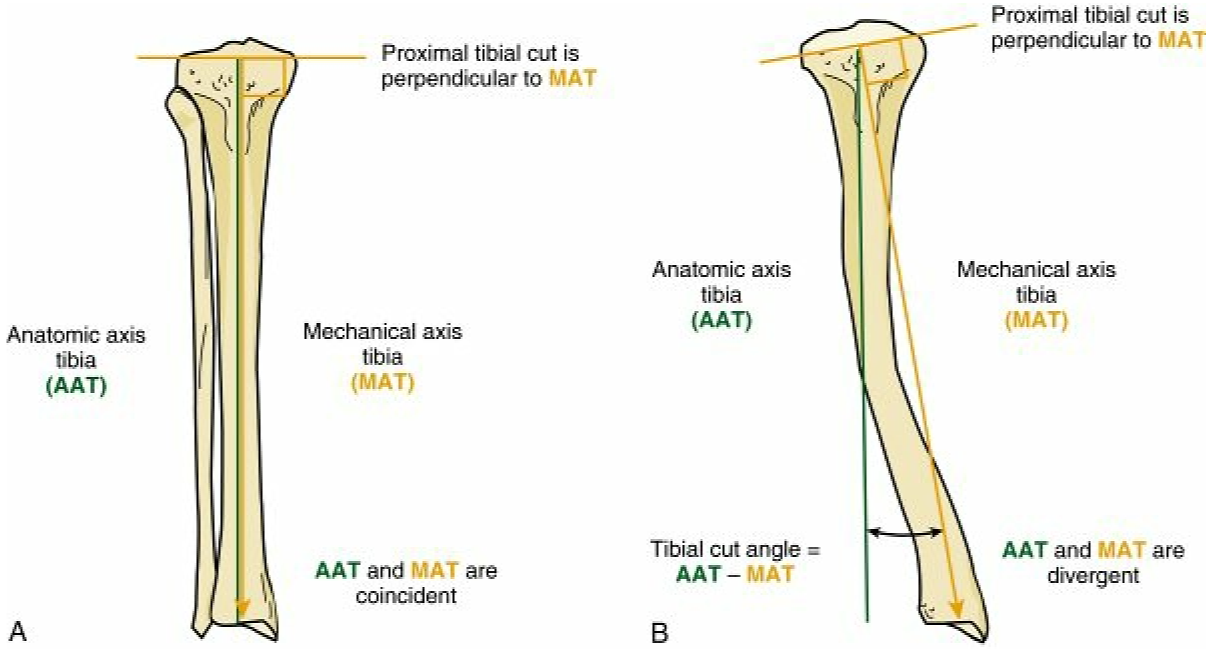


FIG. 5.69 Diagrams showing preoperative measurements of tibia to make proximal tibial end cut. The proximal tibia is cut perpendicular to the mechanical axis of the tibia (MAT). (A) Usually the anatomic axis of the tibia (AAT) and MAT are coincident. In this situation the tibial end cut is zero. (B) In the situation in which a tibial angular deformity is present, the AAT and MAT are divergent. The tibial cut angle is carefully measured to make a tibia end cut perpendicular to the MAT.

Coronal Plane Ligament Balancing

- **Correction of varus or valgus deformity**
- **Balancing goals**
    - Equal ligament tension in medial and lateral knee compartments tested in extension and in flexion
- **Principle (Fig. 5.70)**
    - Release concave side—tight side
    - Retension convex side—loose side
- **Varus deformity**
    - Convex side is lateral—loose
    - Concave side is medial—medial compartment release needed
    - Medial compartment release in sequence
        - Osteophytes
        - Deep medial collateral ligament (also known as *meniscal tibial ligament*)
            - Includes medial knee capsule
        - Posterior medial corner
            - Capsule
            - Semimembranosus
        - **Superficial MCL—key structure (Fig. 5.71)**
            - Posterior oblique portion tight in extension
                - Release for medial extension

tightness
- Anterior portion tight in flexion
  - Release for medial flexion tightness

- **Valgus deformity**
  - Convex side is medial side—loose
  - Concave side is lateral side—lateral compartment release needed
  - Lateral compartment release in sequence
    - Osteophytes
    - Lateral capsule
    - Iliotibial band—key structure
      - **Tight in extension**
        - Release for lateral extension tightness
    - Popliteus—key structure
      - Tight in flexion
        - Release for lateral flexion tightness
      - Release of popliteus off anterior portion of lateral epicondyle (Fig. 5.72)
      - Note: the inadvertent cut of a *noncontracted* popliteus tendon does not significantly affect the static stability of the knee.
    - Lateral collateral ligament (LCL)—last
- **Extraarticular coronal bone deformity and TKA**
  - General rules
    - The closer the extraarticular coronal bone deformity is to the knee joint, the greater the mechanical malalignment at the joint line.
      - For any given magnitude, the farther a deformity is from the knee, the smaller the intraarticular bone cut needed to correct the mechanical alignment.
      - An extraarticular deformity within the distal one-fourth of the femur or proximal one-fourth of the tibia is the most difficult to correct if bone cuts are made only at the knee joint. Reasons:
        - Large bone resections required may compromise ligament attachment sites.
        - Large bone resections adversely affect implant sizing, fitting, and rotational alignment.
        - Extreme releases required to balance the knee often render the ligament incompetent (Fig. 5.73).

- **McPherson one-fourth rule**: when coronal deformity is within the distal one-fourth of the femur or proximal one-fourth of the tibia and the deformity is 20 degrees or more, the recommended treatment is:
  - Concomitant osteotomy and TKA
    - Closing wedge osteotomy preferred
    - Diaphyseal press fit stem with splines recommended
      - Provides rotational stability and obviates the need for additional fixation at osteotomy site

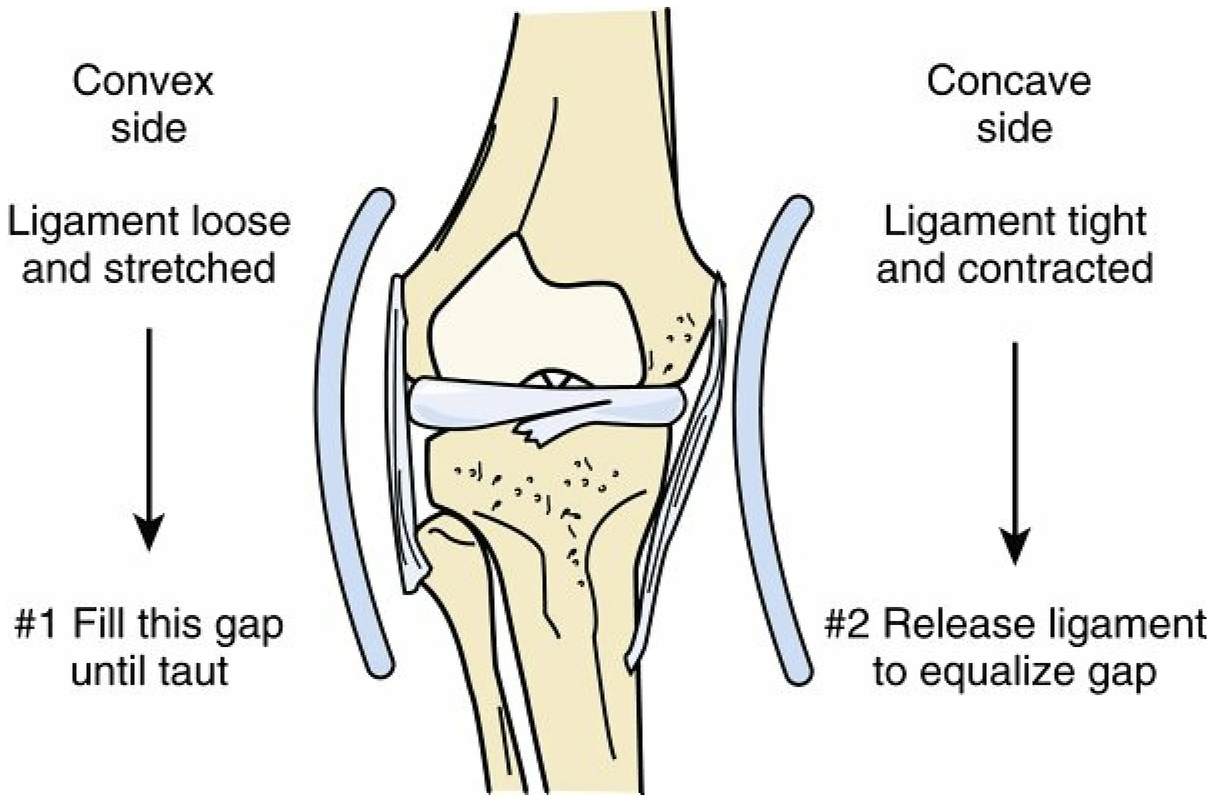


FIG. 5.70 Diagram demonstrating principle of coronal plane balance in TKA. The knee in this example has a varus deformity. The lateral side of the knee is the convex side, where the ligaments have been stretched from the deformity. On this side, the lateral joint space is filled with the prosthesis until the ligament is once again under normal tension. The concave side is the medial side, where the ligament is tight and contracted. The medial ligament complex is released until there is equal tension between the medial and lateral compartments.

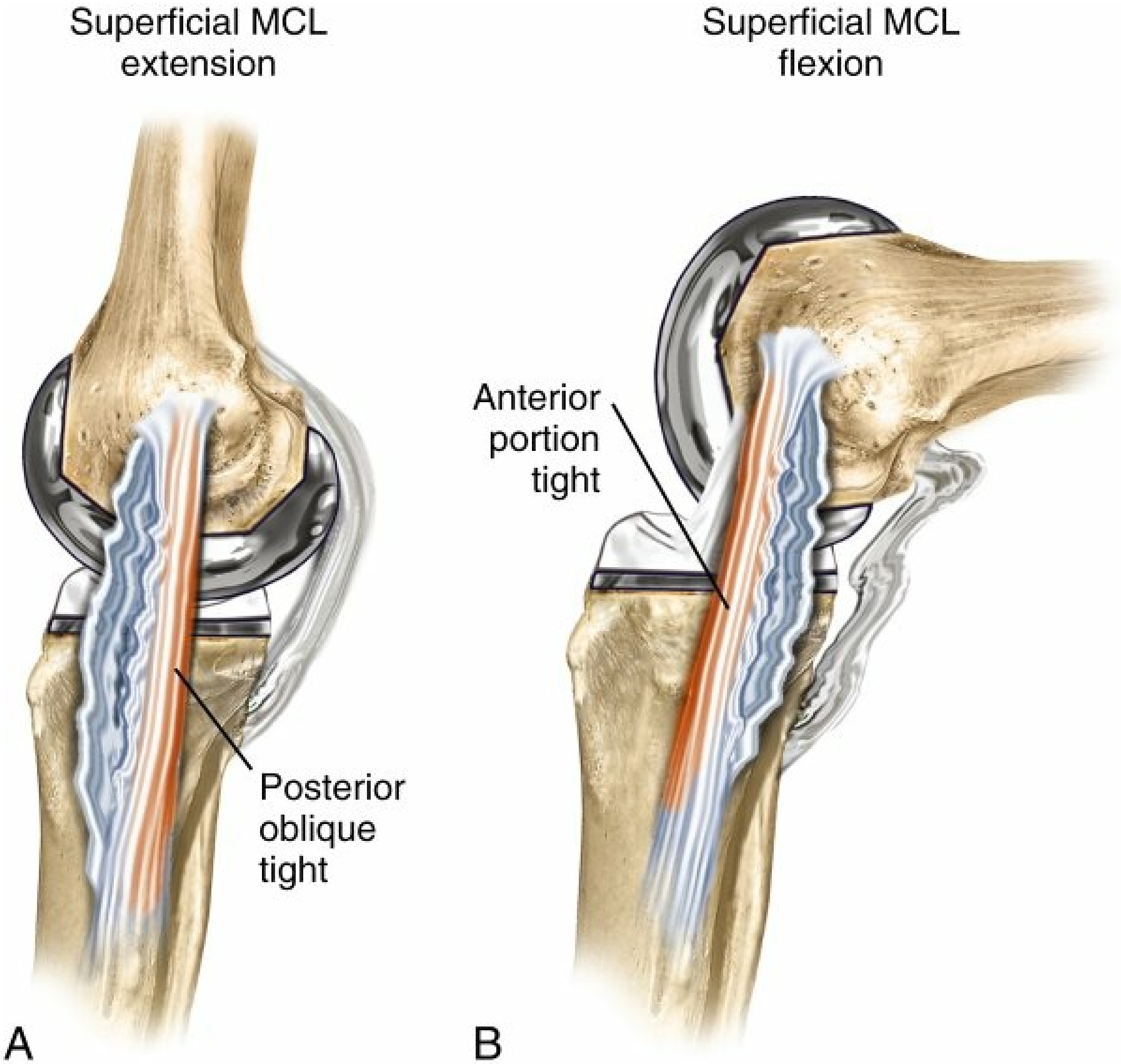


FIG. 5.71 Diagram showing the two major portions of superficial medial collateral ligament. (A) In extension, the posterior oblique portion of the ligament is taut. The posterior oblique portion is released for medial extension ligament contracture. (B) In flexion, the anterior portion is tight. The anterior portion is released for medial flexion ligament contracture. (Courtesy Leo Whiteside, MD.)

Flexion Deformity (i.e., Flexion Contracture)

- **Concave side is posterior—posterior knee release required**
- **Posterior knee release procedure—in sequence is:**
  - Osteophytes
  - Posterior capsule
  - Gastrocnemius muscle origin
- **Posterior releases are performed with the knee flexed (generally at 90 degrees of flexion).**
  - Less danger to popliteal artery

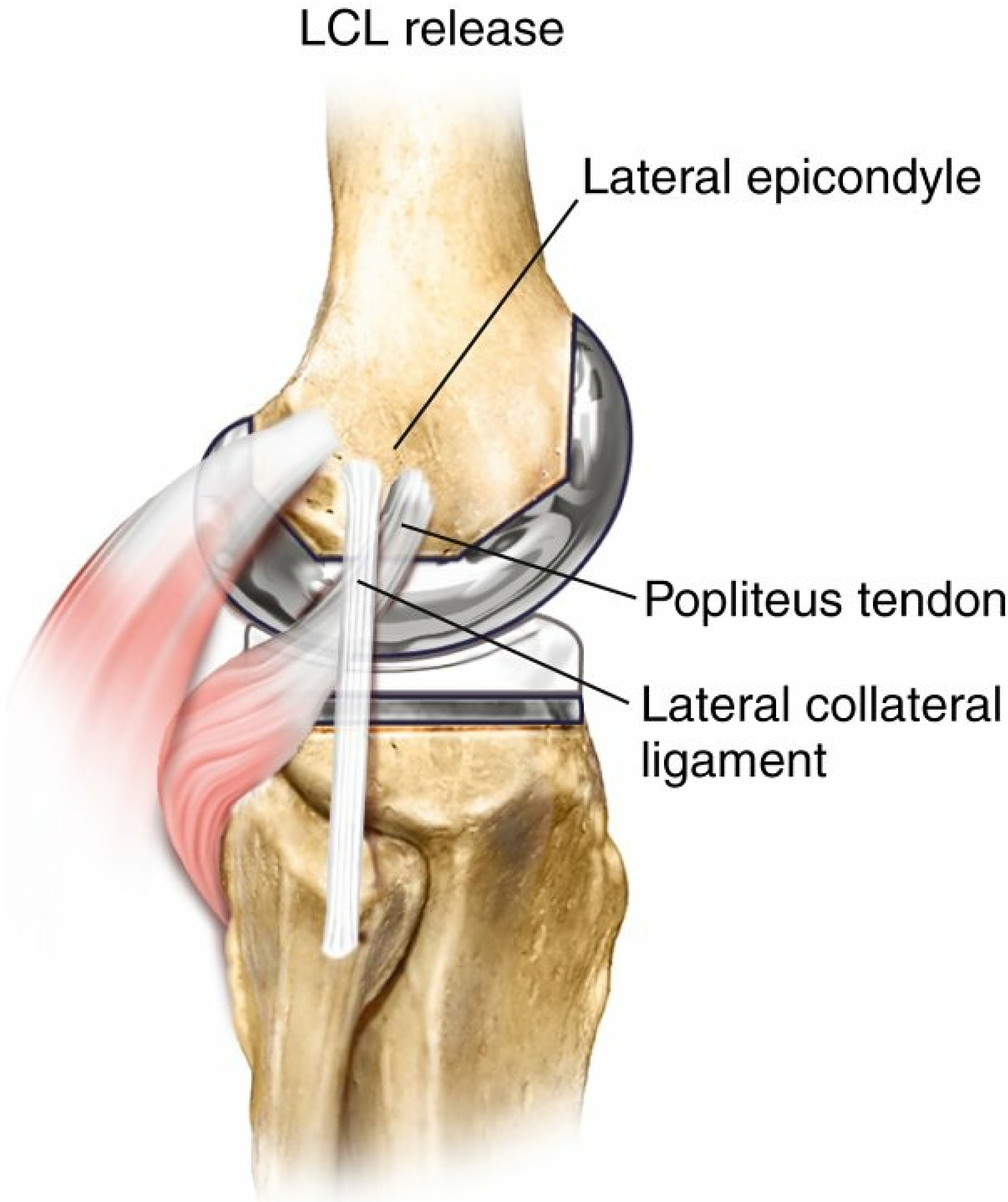


FIG. 5.72 Anatomic relationship of popliteus tendon to lateral collateral ligament. The popliteal tendon inserts onto the lateral epicondyle just in front of (distal and anterior to) the lateral collateral ligament.

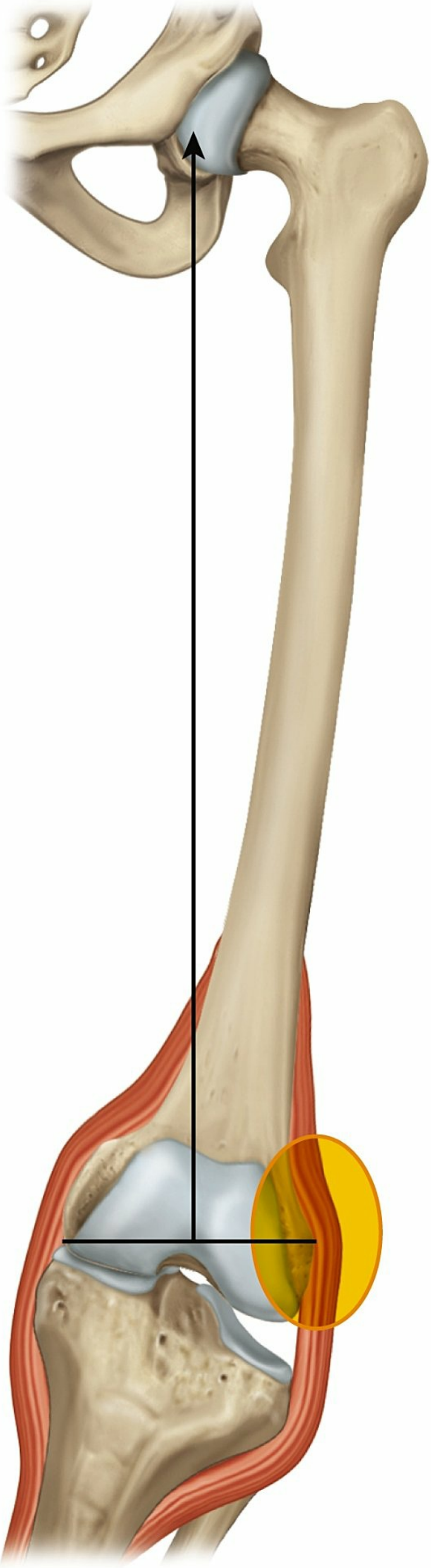


FIG. 5.73 This diagram illustrates the difficulty of restoring mechanical alignment with an adjacent coronal bone deformity. When the distal femoral bone cut is made to restore the mechanical axis of the femur, the lateral bone cut will violate the lateral epicondyle, damaging or removing the lateral collateral ligament and posterolateral corner complex. This can be obviated with a concomitant distal femoral osteotomy placed at the coronal deformity site.

Sagittal Plane Balancing

- **Also known as balancing the gaps**
- **Balancing goal**
  - Full extension and full flexion of the knee
- **Importance**
  - Full functional knee range
  - Stability
  - Pain relief
    - Unbalanced gaps cause pain from tightness or pain from instability.
- **Flexion gap (** Fig. 5.74)—controlled by:
  - **Posterior** cut of femur
  - Tibial cut
  - **Posterior** cruciate ligament (PCL)
- **Extension gap (** Fig. 5.75)—controlled by:
  - **Distal** cut of femur
  - Tibial cut
  - Posterior capsule
- **Balancing the gaps**
  - McPherson rule
    - **Symmetric** gap problem—adjust **tibia** first
    - **Asymmetric** gap problem—adjust **femur first**
  - Table 5.8 and Fig. 5.76 review **all sagittal plane gap scenarios.** Following McPherson rule guides surgeon to a solution.
    - For some gap imbalance scenarios, there is more than one possible solution.

Perioperative Nerve Blocks

- **Goals**
  - Reduce acute perioperative pain
    - Allow earlier and easier patient mobilization
    - Reduce total narcotic load to patient

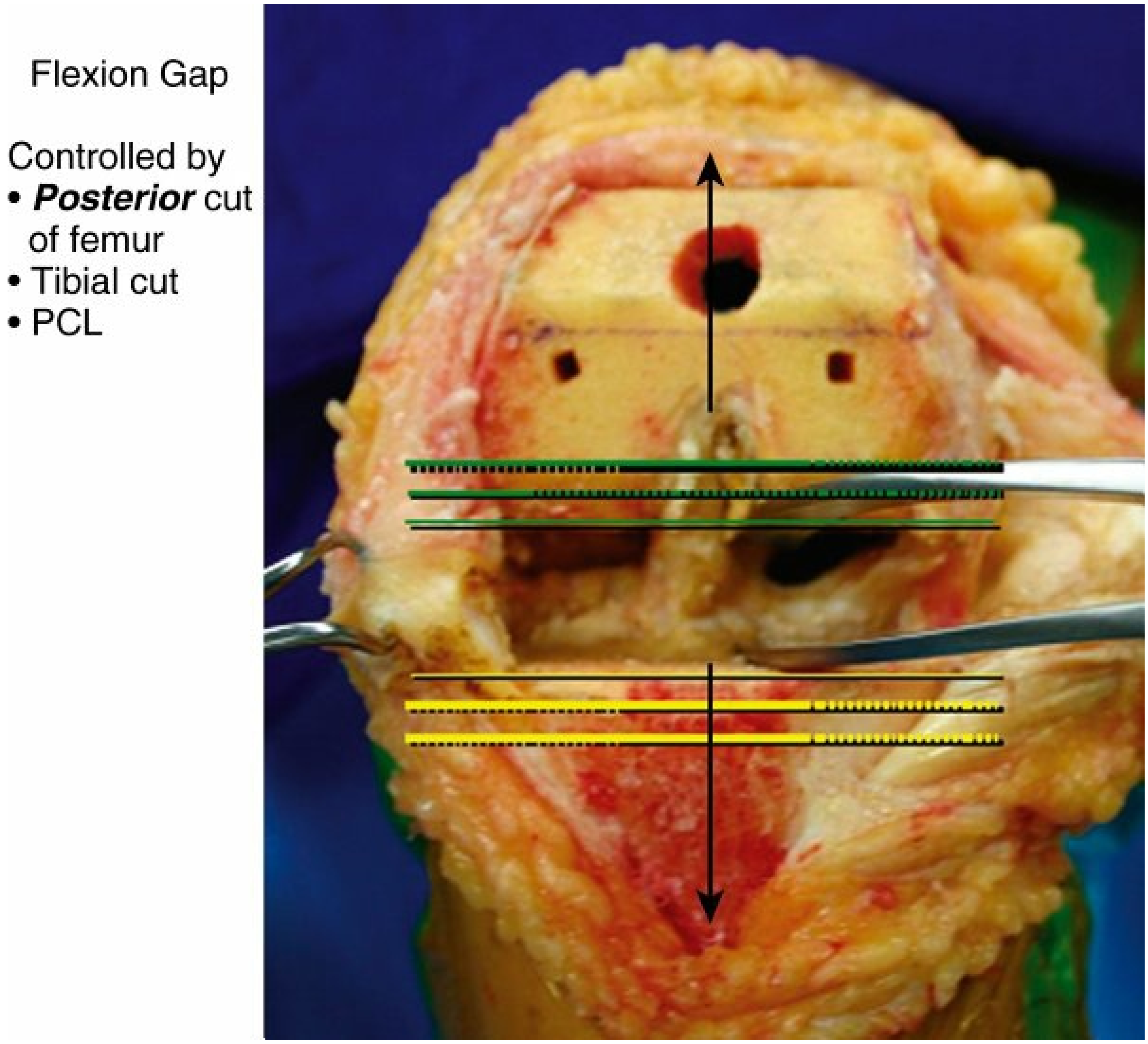


FIG. 5.74 Intraoperative photo of knee showing structures that control flexion gap space. Knee is at 90 degrees of flexion. The gap between the green and yellow lines is the flexion gap, created after bone cuts have been made in the "posterior" femoral condyles and the proximal tibia. The flexion gap can be increased by cutting more posterior femur, cutting more proximal tibia, or removing (recessing) the PCL.

- **Two common blocks: femoral nerve block (groin) and adductor nerve block (mid-medial thigh)**
  - □ Femoral nerve block (FNB)
    - **Motor** and sensory block
    - Sensory blockade is medial and anterior knee
      - *Posterior* knee is not covered by FNB
    - Postoperatively patient does not have active knee extension
      - Knee buckles with gait
      - Knee immobilizer needed until block wears off
  - □ Adductor nerve block (ANB)
    - Sensory block only
    - Nerves blocked are saphenous nerve and articular branches of nerve to vastus medialis
    - Sensory blockade is for medial and anterior knee
      - *Posterior* knee is not covered by ANB

Postoperative Therapy

- **No difference in early knee ROM between patients who use a continuous passive motion (CPM) machine versus patients in whom the knee was closed in flexion and who do not use a CPM**

Complications

- **Femoral notch**
    - Occurs during anterior femoral bone cut when saw cuts into femoral cortex
        - Happens when cutting jig is placed a little too low on distal femur
    - An anterior femoral notch
        - Lessens load needed to cause fracture
        - In torsional load, there is no change in fracture location.

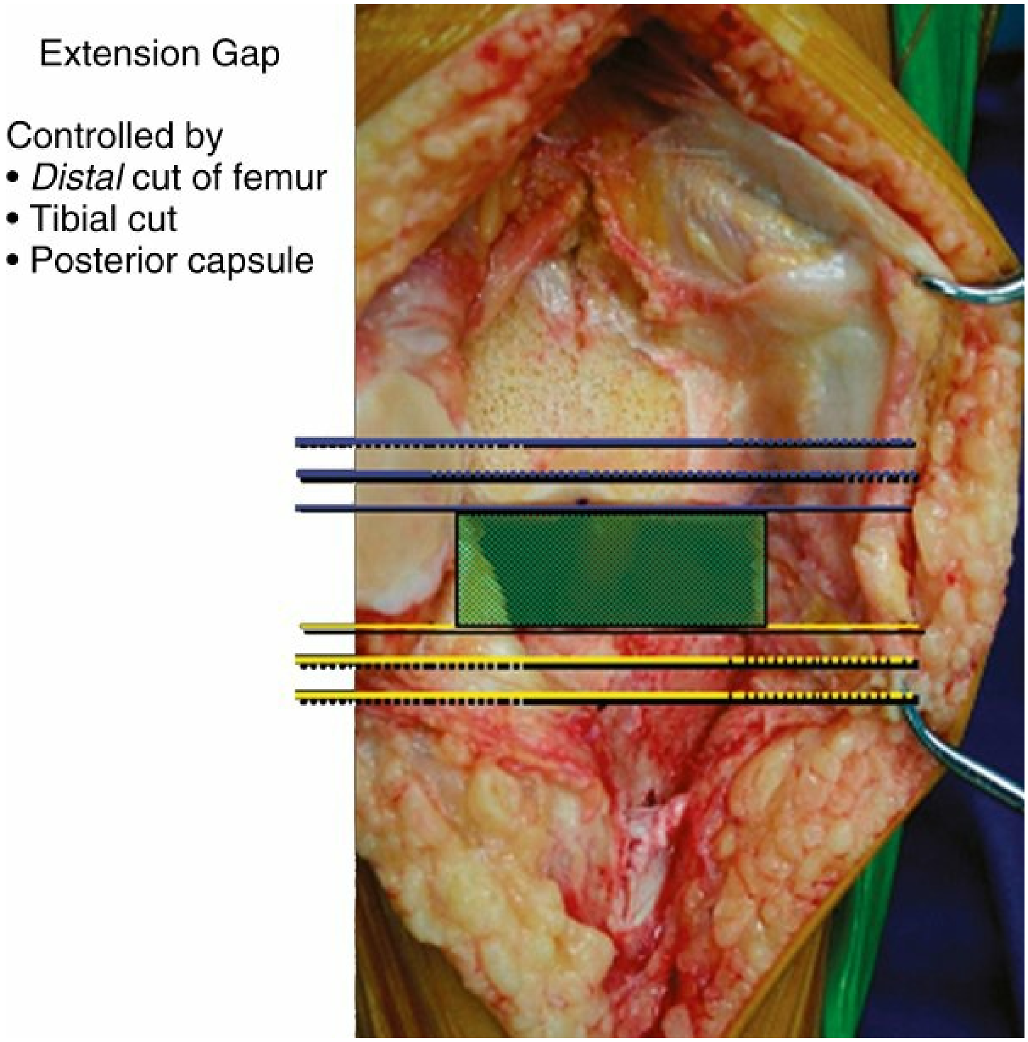


FIG. 5.75 Intraoperative photo of knee showing structures that control extension gap space. The extension gap is controlled by the distal cut of the femur, the tibial cut, and the posterior capsule. Knee is in extension. The rectangle is the extension gap created after bone cuts have been made in the "distal" femur and the proximal tibia. The extension gap can be increased by cutting more "distal" femur, cutting more proximal tibia, or recessing the posterior capsule.

Table 5.8

Review of Sagittal Plane TKAGap Scenarios.

Scenario	Problem	Solution
Tight in extension (contracture) Tight in flexion (will not bend fully)Loose in extension (recurvatum) Loose in flexion (large drawer test)Extension	Symmetric gap • Not enough tibial bone cut	1. Cut more proximal tibia.
	Symmetric gap • **Too much tibial bone cut**	1. Use thicker polyethylene insert *and/or* 2. Perform metallic tibial augmentation.
	Asymmetric gap • **Too much posterior**	1. Increase size of femoral component from anterior to

good **Loose in flexion (large drawer test)**	**femur cut**	posterior (i.e., go up to next size). Fill posterior gap with either cement or metal augmentation. 2. Translate femoral component posteriorly (femur size unchanged). Fill posterior gap with either cement or metal augmentation. 3. Use thicker polyethylene insert and readdress as tight extension gap (two-step solution).
Tight in extension (contracture) **Flexion good**	Asymmetric gap • Not enough posterior capsule released *or* • Not enough distal femur cut	1. Release posterior capsule (contractures <15 degrees) *or* 2. Take off more distal femur bone (1–2 mm at a time). Rule: 2 mm of distal bone resection ≅10 degrees of correction of flexion contracture.
Extension good **Tight in flexion (will not bend fully)**	Asymmetric gap • Not enough posterior bone cut *or* • PCL scarred and too tight (assuming use of a PCL-retaining knee system) • No posterior slope in tibial bone cut (i.e., anterior slope)	1. Decrease size of femoral component from anterior to posterior (i.e., recut to next smaller size). 2. Recess PCL. 3. Check posterior slope of tibia, and recut if anterior slope is present.
Loose in extension (recurvatum) **Flexion good**	Asymmetric gap • Too much distal femur cut *or* • Anteroposterior size too big	1. Perform distal femoral augmentation. 2. Use thicker tibial polyethylene insert, and readdress as tight flexion gap (two-step solution).

			3. Decrease size of femoral component from anterior to posterior (i.e., recut to next smaller size), and readdress as symmetric gap problem (i.e., loose extension and loose flexion) (two-step solution).

- In **bending**, fracture starts at notch, creating a short oblique fracture.
- **Caution—a TKA with a notch should never be manipulated**.

▪ **Peroneal nerve palsy**

- □ Deformity most likely to cause nerve palsy with TKA is valgus flexion deformity.
  - Valgus deformity *plus*
  - Flexion contracture
- □ Most common cause without knee deformity is aberrant retractor placement in posterolateral corner of knee.
- □ When peroneal palsy is identified postoperatively, the first treatment is removal of compressive wraps and flexion of the knee
- □ If the nerve is not cut, palsy in most cases resolves within 3 months.
- □ If nerve palsy does not resolve after 3 months and nerve has not been cut (tested by electromyogram/nerve conduction velocity), recommendation is to explore and decompress the peroneal nerve

▪ **Arterial transection during lateral retinacular release**

- □ The artery at risk for transection is the **lateral superior genicular artery.**
  - Transection of this artery increases risk for **osteonecrosis** of the patella.
  - Note: the largest arterial contribution to the patella is from *inferomedial* and this blood supply is disrupted with medial arthrotomy and fat pad removal.

▪ **Patella fracture**

- □ Causes
  - Overresection of patella bone
    - Minimum thickness is 13 mm
  - Compromised circulation
    - Big lateral retinacular release (transection of lateral superior geniculate artery)
    - Result: osteonecrosis with fracture and fragmentation
  - Patellofemoral maltracking

- Direct trauma
- Loose patellar implant
  - Cement fatigue ± osteolysis
  - Mechanical damage to patella bone resulting in fracture

□ Treatment

- Patella component solid and minimal lag—no surgery
  - Controlled motion brace initially locked in extension; flexion is slowly increase in increments as healing occurs.
- Patella fracture with significant lag (>10 degrees)
  - If TKA is stable
    - Open extensor repair with address of patella fracture
      - Implant stable—no change
      - Implant loose—see Loose patellar implant
  - If TKA is *unstable*
    - Revision TKA, open extensor repair, and address of patella fracture
      - Implant stable—no change
      - Implant loose—see next section
- Loose patellar implant
  - Component revision if enough bone
    - Removal of smaller fragments
  - Component resection if not enough bone for resurfacing
    - Suturing of bone and soft tissues
  - Patellectomy if fragmented/comminuted

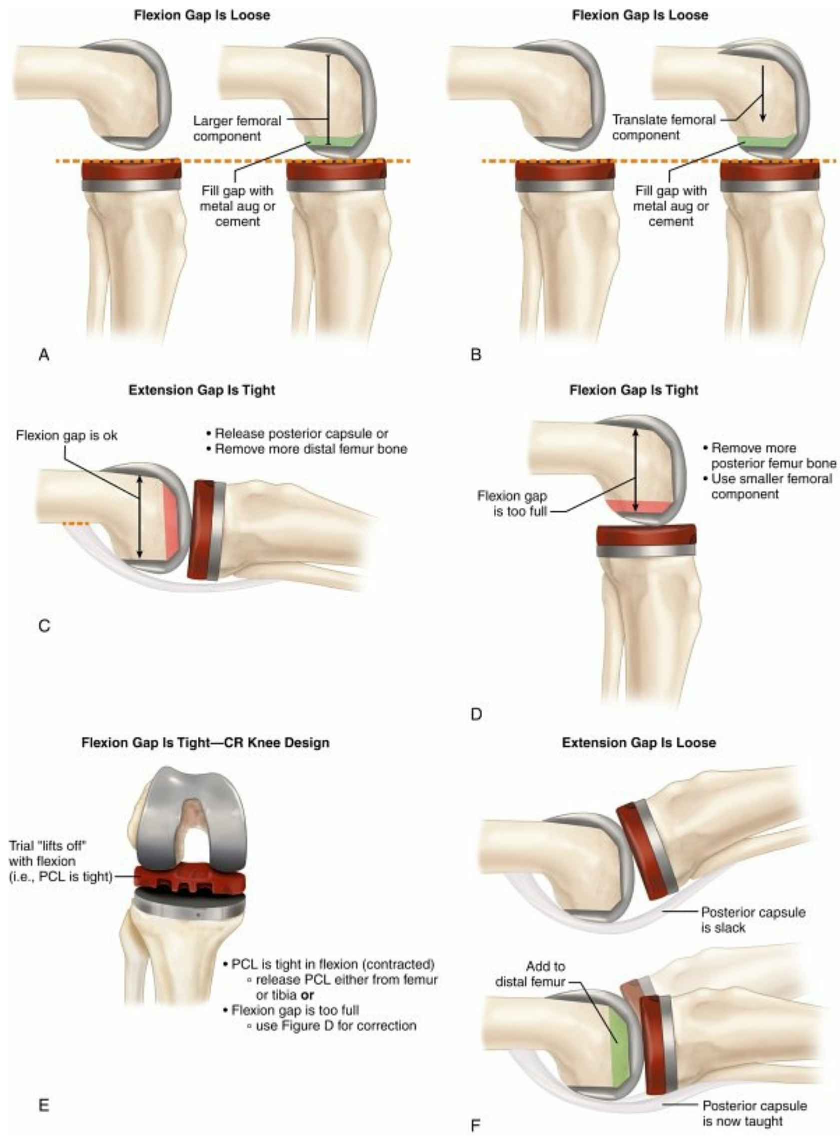


FIG. 5.76 Illustrations of scenarios presented in Table 5.8.

- Extensor imbrication
- Extensor reconstruction later if significant lag and clinical buckling
    - Extensor allograft *or*
    - Expanded polytetrafluoroethylene (Gore-Tex) mesh extensor reconstruction

▪ **Intraoperative MCL injury**
  - □ Recommended treatment is to convert to revision prosthesis with high post for varus/valgus support (i.e., constrained post, not a posterior stabilized post).
  - □ Primary repair of MCL is acceptable.
    - Postoperative brace with full knee range for 6 weeks

▪ **Extensor disruption**
  - □ Almost always occurs at patellar tendon attachment to tibial tubercle
  - □ Direct repair and nonsurgical treatment do not work.

- Extensor allograft reconstruction provides best chance for successful salvage.
  - Fresh frozen allograft preferred
    - Better healing than with irradiated allografts
  - When allograft is used, it is tensioned as tight as possible with the knee in full extension.
    - This maneuver gives best chance to minimize residual knee lag
- Gore-Tex mesh extensor reconstruction is an acceptable alternative in a lower-demand patient
  - Extensor power is not as good as an allograft because there is no patella to optimize extensor mechanics.

- **Arthrofibrosis**
  - Postoperative manipulation of knee should be performed between **4 and 12 weeks** (6–8 weeks is typical)
    - Later manipulation has high rate of fracture (usually of femur)
  - Late stiffness—a big problem
    - Arthrotomy with scar resection and reduction of modular PE thickness is not recommended
      - Very high failure rate with recurrent pain and stiffness
    - Revision TKA is recommended if a problem with alignment, sizing, or component positioning can be identified preoperatively.
- **Postoperative flexion contracture**
  - In a well-balanced TKA (with full intraoperative ROM), a postoperative flexion contracture is due to **hamstring tightness and spasm.**
  - Treatment is physical therapy
    - Knee kept straight at rest
      - No pillows under knee
- **Hypersensitivity (metal allergy)**
  - Incidence is low: ≤1%
  - Most common offending agent is nickel within metallic alloy
  - Mechanism of reaction is T cell–mediated hypersensitivity
  - Skin path testing has **no** correlation with internal metal allergy
- **Osteolysis**
  - Presentation in TKA
    - Starts later in life of implant—7–15 years
    - Gradual increase in effusion and weight-bearing pain
    - Mild warmth in knee
      - Not hot
      - No erythema

- Normal infection biomarkers (CRP, etc.)
  - Aspiration results negative
    - Normal WBC count
      - A WBC count higher than 3000 cells/μL is suspicious for a chronic periprosthetic infection.
    - No crystals
    - Culture results are negative
- Radiographs show round lytic lesions behind implant (Fig. 5.77).
  - **Most common site is behind posterior femoral condyle**.

□ Treatment

- If implants are mechanically loose, revision TKA is indicated.
  - Radical débridement of osteolytic bone lesions
  - Filling of segmental defects with bone graft or metal augmentation
- If implants are mechanically stable, they are retained, and modular tibial PE bearing is changed.
  - Radical débridement of osteolytic bone lesions
  - Filling of segmental defects with bone graft and/or cement

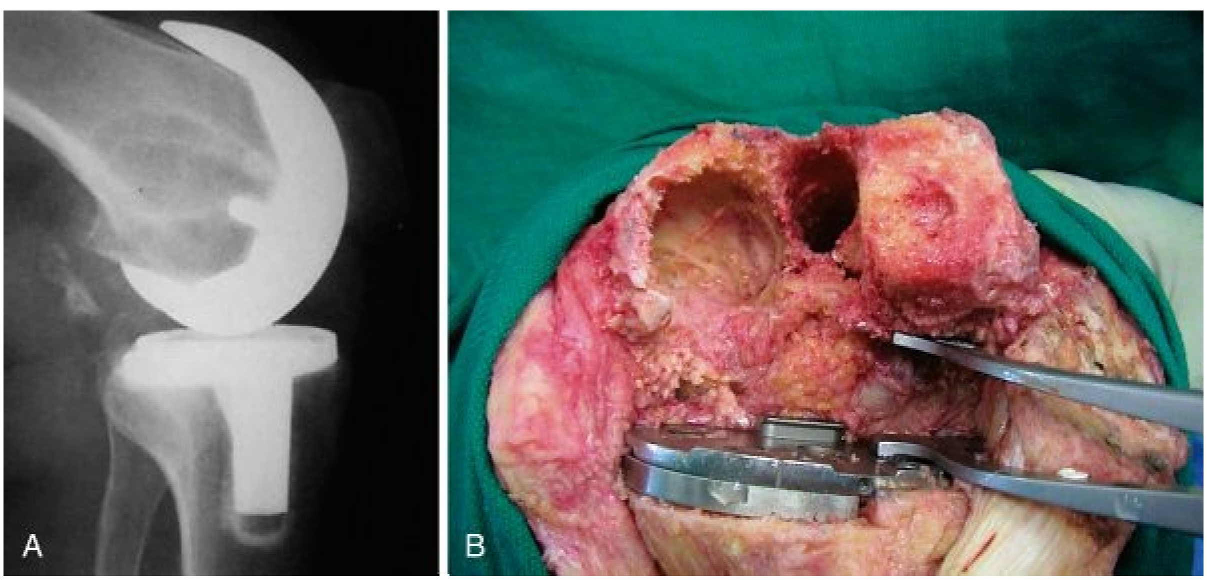


FIG. 5.77 Osteolysis in TKA. (A) Classic radiographic appearance of osteolysis in a TKA that is 10 years old. Note large round lytic lesions behind the posterior femoral condyle. (B) Intraoperative photograph of same knee. Note severe bone loss in medial femoral condyle. This lesion required structural bone allograft. Knee was revised using a constrained revision knee system because the medial collateral ligament attachment onto the medial femoral condyle was compromised from osteolytic bone loss.

▪ **Heterotopic ossification**

- □ Overview
  - HO forms in periarticular tissues after surgery without a well-defined precipitating event.
    - Transformation of primitive mesenchymal cells into osteoblastic tissues occurs within 16 hours of surgical procedures, with maximum stimulus for HO formation occurring within 32 hours.
    - Optimal prophylaxis should be instituted preoperatively or within the first 24–48 hours postoperatively.
  - HO in TKA is relatively frequent (small islands of bone seen in periarticular tissues), but symptomatic HO is rare (≤1%); problems include:
    - Loss of motion (extension and/or flexion)
    - Pain
    - Clicks, crunches, snaps
- □ Risk factors
  - Hypertrophic osteoarthritis
    - Increased bone density (secondary to hypertrophic bone) correlates with increased risk of HO.
  - Diffuse idiopathic skeletal hyperostosis (DISH)
  - Patient with prior history of HO after surgery
  - Ankylosing spondylitis
  - Surgical technique
    - Periosteal stripping/damage, especially of the femur
    - Femoral notch
    - Tearing of/trauma to quadriceps mechanism (e.g., stiff knee exposure)
  - Postoperative conditions
    - Knee hematoma and/or large effusion
    - Forced manipulation for stiffness
    - Aggressive postoperative therapy for a tight/stiff TKA
- □ Diagnosis
  - Standing AP and lateral radiographs
    - Most common site is anterior femoral cortex superior to femoral prosthesis.
    - Also frequent: islands of bone within tissue of suprapatellar region
- □ Treatment
  - It should be kept in mind that spontaneous resolution of

pain and restricted knee range does occur as the inflammatory process abates and the HO process matures; **first step is to wait while continuing with modified therapy.**
  - Surgical removal of HO masses is indicated when pain and limited motion persist
    - Excision procedure should be performed when HO process has **matured.**
      - Preferred timing of surgery is 12–18 months after index TKA.
      - HO process is considered mature when bone scan of HO region is "quiet" (i.e., scintigraphic appearance of HO site is similar in intensity to that of adjacent bone).
      - Serum alkaline phosphate level (indicator of bone remodeling) must also have returned to normal levels.

- **Periprosthetic femur fracture**
  - □ Rule 1: If implants are **mechanically loose**
    - Treatment is revision TKA and ORIF of fracture.
      - Usually spline diaphyseal stem, which provides rotational stability to TKA implant, is used.
    - Treatment with fracture resection and endoprosthetic hinged TKA is an acceptable alternative when
      - Fracture is highly comminuted *and*
      - Patient is elderly *and/or*
      - Bone is significantly osteoporotic
  - □ Rule 2: If implants are **mechanically stable**
    - Treatment options
      - ORIF with premolded supracondylar plate—preferred choice
        - Submuscular plating has lower nonunion rate than extensile approach.
        - A locked plate is better than an unlocked plate.
      - Revision TKA with ORIF of femur fracture is acceptable.
        - Usually used when TKA is symptomatically painful prior to injury.
      - Fracture resection with endoprosthetic hinge TKA is an acceptable alternative when

- Fracture is highly comminuted *and*
- Patient is elderly *and/or*
- Bone is significantly osteoporotic

- Retrograde nailing is best suited for a distal **diaphyseal** fracture.
  - A small knee arthrotomy is recommended to visualize knee and make sure that the nail does not impinge upon PE bearing, which would damage/break bearing.

- ▫ Intraoperative femur fracture
  - Femoral condyle—most common
    - Medial condyle more likely than lateral
    - Posterior stabilized (PS) knee design more likely than cruciate-retaining (CR) knee design
      - Reason: PS bone box cut comes close to outer femoral cortex and will split condyle when implant is impacted into position.
  - Treatment
    - Screws into condyle ± femoral stem extension on femoral implant

- ▪ **Periprosthetic joint infection (PJI)**
  - ▫ Principles also apply to THA, TSA, and other joints with prosthetic replacement
  - ▫ Risk factors
    - Diabetes
      - Optimized by reduction of Hg A1C to ≤7.0
    - Smoking
      - Cessation 30 days prior helps decrease risk.
    - Prior surgery
      - Posttraumatic knee arthritis with limited knee range is at higher risk.
    - Obesity
      - BMI ≥40
    - Autoimmune inflammatory disease states, such as
      - Rheumatoid arthritis
      - Psoriatic arthritis
      - Systemic lupus erythematosus
    - Immune system disorders, such as
      - Myelodysplastic syndrome (MDS)
      - Chronic myeloma, leukemia, lymphoma
    - Immunosuppressive drugs

- For autoimmune disease states
    - TNF-α inhibitors/blockers, such as
        - Infliximab (Remicade)
        - Adalimumab (Humira)
        - Certolizumab (Cimzia)
    - TNF-α inhibitors increase the risk for opportunistic infections including
        - Mycobacteria, fungus, *Legionella*, and *Listeria*
        - Reason: TNF-α stabilizes old granulomas. Using TNF-α inhibitors leads to granuloma dissociation and release of the organisms, thus reactivating the infection.
- Antimetabolites, such as
    - Methotrexate (Rheumatrex)
    - Leflunomide (Arava)
    - Azathioprine (Imuran)
- Glucocorticoids, such as
    - Prednisone
    - Dexamethasone
    - Betamethasone
        - Allogeneic blood transfusion
    - Allogeneic blood causes an immune modulation resulting in relative immune suppression.

□ Bacterial inoculation of a prosthetic joint

- The majority of PJI cases result from bacterial inoculation of the prosthetic joint at the time of surgery
    - The model of bacterial inoculation in the operating room is from airborne particles containing bacteria (bioburden) that deposit into the wound or are transferred from contaminated equipment (from airborne particles) into the surgical wound.
    - All healthcare personnel shed bacteria into the air from degrading skin cells, which are shed from the body at a rate of 10^3–10^4 particles per minute. These particles (called fomites) contain bacteria that are embedded within human skin (called the

bacterial biome). These ultrasmall particles float into the air and are carried by vortex air currents and deposited onto the surgical wound or surgical equipment.

- A minority of PJI cases occur via bacterial inoculation after surgery.
    - Early postoperative infection
        - Bacterial inoculation through open draining wounds that allows bacteria to enter directly from the skin level into the joint without a concomitant superficial surgical site infection (SSI)
        - Bacterial inoculation from an overlying SSI that later penetrates into the deep periprosthetic joint space
    - Late event infection (i.e., years later)
        - Proximal seeding of the deep joint space from a dependent area of infection (i.e., lower leg). Mechanism is lymphatic delivery of bacteria into the joint area.
        - Hematogenous seeding (i.e., from bacteremia) of bacteria into the joint area

▫ Biofilm (Fig. 5.78)

- The most important factor influencing periprosthetic infection treatment
- All bacteria make biofilm.
- Biofilm consists of approximately 15% cells and 85% polysaccharide matrix.
- Biofilm forms on
    - All foreign materials
    - Devitalized tissues
        - Soft tissue and bone
- Biofilm, once established, matures into sophisticated microenvironment.
    - Bacteria communicate via signaling molecules and nanowires.
        - *Nanowires* are very small cell-to-cell connections that allow bacteria in a biofilm to communicate with one

another.

- Clinical importance of biofilm state
    - Bacteria become 1000 to 10,000 times more resistant to antibiotics
    - Essentially, bacteria within a biofilm state cannot be killed with standard dosing regimens of antibiotics
    - In vivo, biofilm can colonize, grow, and cover a surface within 4–8 days
- Effective treatment for established biofilm infection requires:
    - Removal of implants and foreign bodies
    - Removal of all devitalized bone and soft tissue
- Inadequate débridement of biofilm material is the reason for treatment failure and infection recurrence.
    - This includes retained cement and metal left in the medullary canals adjacent to the affected prosthetic joint
- A PJI is considered a **chronic** infection (i.e., biofilm state) when known clinical symptoms of infection are present for 3 weeks or longer.
    - There is at present **no direct test** to detect a biofilm.
    - Diagnosis of a biofilm state is based on a temporal presentation and the diagnostic algorithm outlined in the next section.

□ Diagnosis

- Diagnosis of chronic PJI requires diligent evaluation including

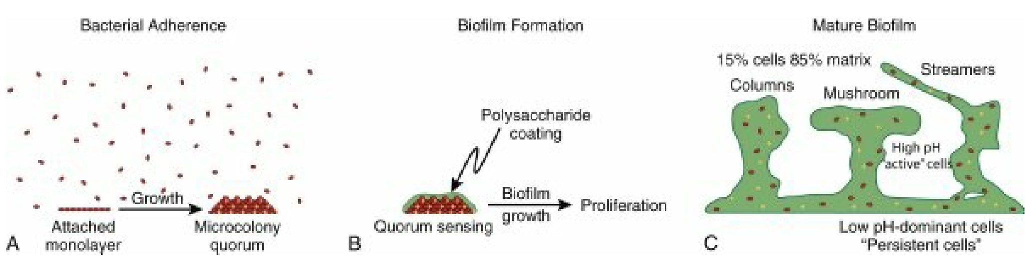


FIG. 5.78 Diagram depicting biofilm formation on a prosthetic implant. (A) Bacteria within the joint space adhere to implant (via adhesins) and multiply. Once the population of bacteria reaches a predetermined concentration (defined as a quorum), the colony expresses the biofilm. (B) The biofilm under ideal conditions can rapidly proliferate and develop into mature biofilm. (C) Mature biofilm state, in which bacteria interact with each other via signaling molecules and nanowires.

    - Serum blood tests

    - Joint aspiration and testing
  - Confirmation is straightforward in most cases.
  - In some cases confirmation can be difficult for diffuse reasons
    - Responsible agent is fastidious organism that does not grow on culture.
    - Immunocompromised patient does not mount an inflammatory response that meets diagnostic criteria.
    - Biomarkers cross-react with another condition, such as metal particulate debris synovitis, autoimmune disease, or crystalline arthropathy.
  - Most current criteria are based on International Consensus Meeting (ICM) on Musculoskeletal Infection (July 2018)
    - Diagnostic criteria were updated and are listed in Table 5.9
    - New minor criteria utilize an algorithm based on weighted average of
      - Fluid aspirate parameters
      - Culture results
      - Serum blood test findings
    - Algorithm was designed to produce a high positive predictive value (i.e., when positive, the joint is truly infected).
- ▫ Treatment algorithm
  - Classification
    - Acute infection (<3 weeks' **known duration**)
      - Considered a non-biofilm state
      - Implants are salvageable
      - Treatment is surgical
    - Chronic infection
      - Biofilm state
      - Implants are not salvageable
      - Treatment is surgical and implants are removed
  - Acute periprosthetic infection
    - Currently, acute infection is defined as known infection of less than 3 weeks' duration.
      - Reason: no method to identify a biofilm with routine laboratory tests; 3 weeks has been selected as a reasonable time frame to treat as acute.

- Treatment
  - Radical débridement surgery is performed, including synovectomy and lavage.
  - Modular bearings are exchanged.
    - All prosthetic spaces must be accessed and flushed/débrided of bacterial load.
  - Intravenous antibiotic therapy used for 4–6 weeks.
  - **Arthroscopic lavage of an acutely infected joint replacement is *not* acceptable treatment.**
- Failure
  - If infection recurs, treated as a chronic infection. A second débridement surgery attempt should not be made.

- Chronic periprosthetic infection
  - Currently, chronic infection is defined as known infection for more than 3 weeks' duration.
  - Treatment
    - Implant removal
      - Includes all implant cement (PMMA), nonabsorbable suture material, screws, cables, and metallic fragments
    - Radical débridement, including synovectomy, removal of necrotic bone and all devitalized soft tissue, and copious lavage
    - Stabilization of joint with methylmethacrylate spacer loaded with high-dose antibiotics
      - Static spacer used if joint stability is compromised by soft tissue and/or bone loss
      - Articulated spacer preferred if joint stability preserved.

    Reason: better preservation of joint function
  - Types of spacers
    - Antibiotic-loaded acrylic cement (ALAC)
      - Construct consists primarily of methylmethacr cement loaded with high-dose antibiotics
      - Prosthesis with ALAC (Prostalac)
        - Construct that contains temporary metal and plastic prosthesis along with ALAC
    - Both constructs are acceptable for treatment. There is no proven superiority of ALAC over Prostalac.
      - Prostalac spacers tend to function better and are generally more stable.
- Intravenous antibiotic therapy for 4–6 weeks
- Second-stage reconstruction
- Options

Table 5.9

Criteria for Diagnosing Periprosthetic Joint Infection.

Two positive results of cultures growing the same organism using standard culture methods			
Sinus tract with evidence of communication to the joint or visualization of the prosthesis			
Minor Criteria	**Threshold**		**Score**
	Acute	**Chronic**	
Elevated serum CRP (mg/L) *or* Elevated serum D dimer (μg/L)	≥ 100 N/A (unknown)	≥10 ≥860	2
Elevated serum ESR (mm/hr)	No role	≥30	1
Elevated synovial WBC count (cells/μL) *or* Positive leukocyte esterase result (joint fluid) *or* Positive alpha defensin result (joint fluid)	≥10,000 ++ (Not +) ≥1.0	≥3000 ++ (Not +) ≥1.0	3
Elevated synovial PMN (i.e., neutrophil) count (%)	≥90	≥70	2
Single positive culture result			2
Positive histology at surgery*			3
Positive intraoperative purulence (cannot be used when there is adverse local tissue reaction due to metal debris)			3

* Positive histology defined as ≥5 neutrophils per high-power

field in 5 high-power fields observed at 400× magnification.

- Reimplantation of joint arthroplasty
    - Most common treatment
    - Requires revision/salvage system to accommodate bone and soft tissue loss from infection débridement surgery
- Bony arthrodesis
    - Used when there is significant loss of functional tissues
    - Bone stock must be adequate for fusion.
- Prosthetic endofusion device
    - Bone defects are spanned by modular rods connected at the knee
    - Device maintains functional leg length unlike classic bony arthrodesis.
- Amputation—indications:
    - Neuropathy and chronic pain too debilitating for reimplantation to be considered
    - Recurrent infection after resection arthroplasty
    - Patient too

medically compromised to be able to combat infection
- Permanent resection
  - Patient unfit for surgery

□ Infection (PJI) prevention in total joint replacement
- Proven infection prevention
  - Prophylactic antibiotics
    - Administered 30 minutes before skin incision
    - Continued for 24 hours after surgery
  - Vertical laminar air flow in operating room
    - Vertical flow systems are superior to horizontal flow systems
      - Reason: horizontal flow systems create large vortex currents that circulate unfiltered air into the surgical wound.
  - Antibiotic-impregnated cement
    - No more than 1 g of antibiotic powder per 40 g packet of cement (so as not to reduce mechanical properties of cement)
    - Indicated for higher-risk patients
    - Use may be associated with increased rates of aseptic loosening
      - Reason: even 1 g of antibiotic powder may reduce mechanical properties of the cement enough to cause premature cement fatigue in high-load situations

□ Wound coverage
- Medial gastrocnemius rotational flap
  - The *workhorse* for deficiencies about the knee
  - Blood supply—medial sural artery
  - Used to cover medial and anterior deficiencies
  - Good excursion

- Lateral gastrocnemius rotational flap
    - Blood supply—lateral sural artery
    - Used to cover lateral soft tissue deficiencies
    - Little excursion
    - Risk—peroneal nerve palsy from traction of the flap as it is pulled anteriorly to lateral side of knee

Section 14 TKA Design

Design Categories

- **Designs are categorized according to an increasing level of mechanical constraint in knee system.**
  - Least constrained
    - Cruciate-retaining TKA—**remove ACL and keep PCL**
    - Cruciate-sacrificing TKA—**remove ACL and PCL**
    - Both used for straightforward primary TKA
  - Constrained
    - Constrained nonhinged TKA
    - Used for complex primary or revision TKA
  - Highly constrained
    - Hinge TKA
    - Used for complex revision TKA

Cruciate-Retaining Primary TKA Design

- **Description (** Fig. 5.79)
  - PCL helps provide flexion gap stability.
  - PCL tension influences femoral prosthetic rollback.
    - *Rollback* is defined as the progressive posterior change in femoral-tibial contact point as the knee moves into flexion.
  - Generally, cruciate-retaining implants have more flat PE inserts to accommodate for flexion rollback.
- **Advantages**
  - Bone conserving
  - More consistent joint line restoration
    - Keeping PCL keeps flexion gap smaller
- **Disadvantages**
  - Harder to balance with severe deformities
    - **Cruciate-retaining implants should be avoided if**
      - **Varus more than 10 degrees**
      - **Valgus more than 15 degrees**
  - PCL balance is critical for long-term bearing wear
    - **A tight PCL in flexion causes increased PE wear**
      - PCL in flexion must be balanced.
      - Lift-off must be avoided (Fig. 5.80).
      - PCL can be released off femur or tibia.
      - PCL balance is sometimes hard to assess

intraoperatively.

- PCL balance is sometimes hard to achieve—over-release of PCL is common.

FIG. 5.79 Lateral view of cruciate-retaining (CR) TKA implant. This is the typical profile of the femoral component. In this design the posterior cruciate ligament is retained. The PE insert is generally more flat to allow the femur to roll back onto the posterior part of the tibial bearing.

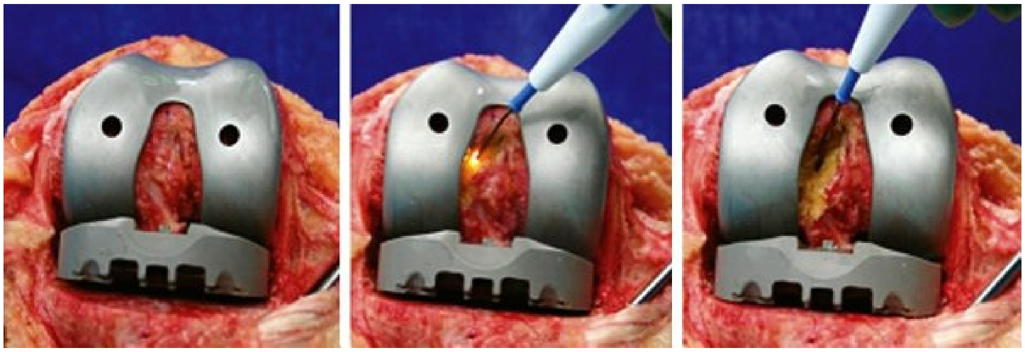


FIG. 5.80 Intraoperative demonstration of posterior cruciate ligament recession. PCL release off intercondylar notch allows flexion gap to increase in increments. Photograph on *left* shows classic presentation of tight PCL. With the knee in flexion, the tight PCL levers the anterior portion of the tibial insert upward creating lift-off. Sequential photographs show release of PCL just enough to allow tibial insert to lie back onto tibial. This sequence is termed *balancing the PCL.*

- Excess recession (i.e., release) can result in late failure caused by **flexion instability** and repetitive subluxation
  - Flexion instability is characterized by
    - Knee effusion
    - Chronic pain

- Inability to climb stairs with reciprocal gait
- Inability to arise from low chair
- Knee buckling

- Late rupture of PCL with resultant instability
  - PE particle debris can cause osteolysis and result in disruption of PCL from bony attachments
  - Traumatic fall onto flexed knee can cause rupture.
- Paradoxical forward sliding as knee flexes
  - With ACL removed, knee kinematics are drastically altered.
  - Prosthetic knee does not roll back like native knee.
  - As knee flexes, there is paradoxical forward-sliding movement, which causes sliding wear on PE insert.
    - Sliding wear causes significant PE wear.

Cruciate-Sacrificing Primary TKA Designs

- **Two options:**
  - Spine and cam mechanism in the posterior aspect of the knee
    - **Also called posterior stabilized knee**
  - An extended anterior PE lip with a concomitant smaller posterior lip
    - **Also called anterior stabilized knee**
- **Posterior stabilized primary TKA design**
  - Description (Fig. 5.81)
    - A cam connects between the two posterior femoral condyles.
    - The cam engages a tibial PE post during flexion.
    - The cam and post control rollback.
    - Generally, posterior stabilized implants have more dished (i.e., congruent) PE inserts.
  - Advantages
    - Easier balancing in severe coronal deformities (i.e., varus/valgus) because both ACL and PCL are removed
    - Controlled flexion kinematics with spine and cam, less sliding wear
  - Disadvantages
    - Femoral cam jump (Fig. 5.82)
      - Occurs when flexion gap is left too loose
      - Mechanism of cam jump
        - Varus or valgus stress when knee is flexed

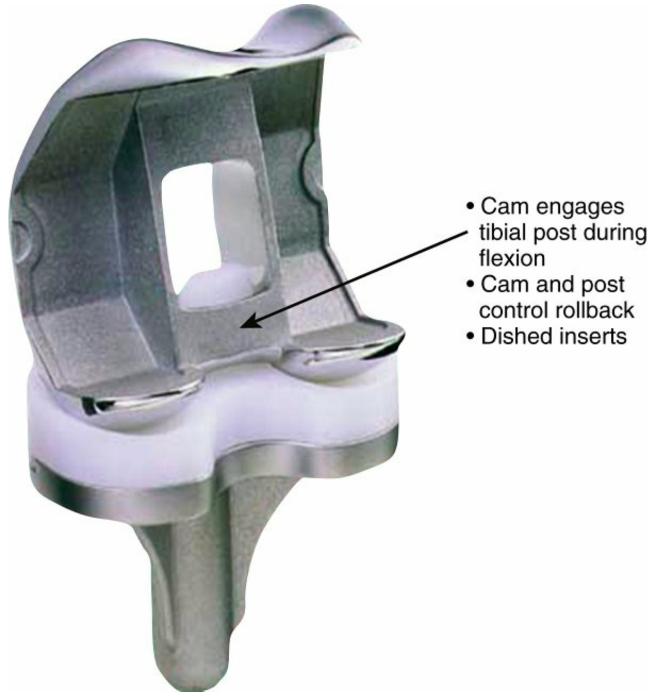


FIG. 5.81 Posterolateral view of posterior stabilized (PS) implant. This is the typical profile of the femoral and tibial components. The cam on the femur engages a tibial post when the knee moves into flexion. This prevents anterior translation of the femur on the tibia, stabilizing the knee in flexion in the absence of a posterior cruciate ligament.

    - Patient usually lying in bed or sitting on floor
    - Flexion gap opens up, and femoral cam rotates in front of post and then comes to rest in front of tibial post.
- Closed reduction maneuver
    - With use of anesthesia, knee is positioned at 90 degrees of flexion off the table (dependent dangle)
    - An anterior drawer maneuver is performed
        - Clunk will be felt as knee is reduced.
- Ultimate solution requires knee revision to address loose flexion gap
- Causes of loose flexion gap
    - Overrelease of contracted popliteus
        - Inadvertently occurs also with saw blade
    - Overrelease of *anterior portion* of

superficial MCL

- Anterior translation of femoral component

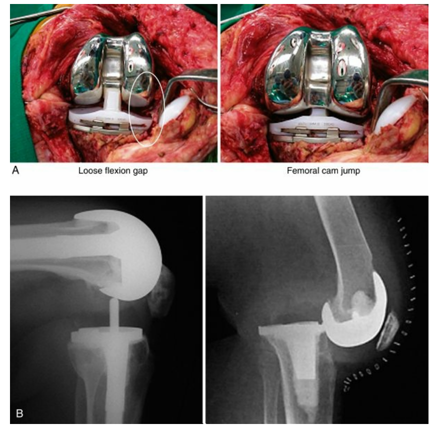


FIG. 5.82 Intraoperative and radiographic presentation of femoral cam jump in posterior stabilized TKA. (A) The photograph on *left* shows loose flexion gap. The *circled area* highlights loose lateral flexion gap caused by popliteal tendon deficiency. As the knee is stressed into varus, the tibia then rotates out in front of the tibial post. The cam then comes to rest (*right*) in front of the tibial post. (B) Two different presentations of femoral cam jump. Radiograph on *left* shows femur perched in front of tibial post (reinforced in this case with a metal post). Radiograph on *right* shows femur completely dislocated anteriorly when knee is brought into extension after cam jump.

- Anterior translation increases flexion gap space

- Patella clunk syndrome

- Scar tissue (descriptively, a nodule of scar) superior to patella gets caught in box as knee moves from flexion into extension.
- Scar catches in box, then releases with a clunk.
- Clunk occurs in range between 30 and 45 degrees.
- Treatment is removal of suprapatellar scar nodule (Fig. 5.83).
  - Arthroscopic removal is acceptable.
  - Miniarthrotomy is also acceptable.
- Preventive treatment (Fig. 5.84)
  - Synovectomy and débridement of all scar from quadriceps tendon at time of TKA
- Risk factors that cause patellar clunk are related to factors that *increase* quadriceps force. These include:
  - Small patella implant (decreased extensor offset)
  - Thin total patella height (decreased extensor offset)
  - Short patella tendon (patella baja)
  - Increased posterior condylar offset (patella pulled lower down)
    - A result of PCL removal requiring an increase in the AP femoral size to fill the increased flexion gap

- Tibial post wear and breakage
  - Tibial post is an additional PE surface that can wear and enhance risk for osteolysis.
  - Aseptic loosening and osteolysis are **correlated with tibial post wear** and damage.
  - **If the knee hyperextends, the edge of the femoral box can impinge on the anterior tibial post** (Fig. 5.85).
    - Causes anterior post damage and fatigue
    - Causes increased PE wear and osteolysis
  - Anterior tibial post wear occurs when TKA components are in **net hyperextension**, such as with

- Flexion of femoral component on distal femur
- Excess tibial posterior slope
- Knee hyperextension (i.e., loose extension gap)
- Anterior translation of tibial component on tibia (i.e., placing tibial implant toward front of tibia rather than placing on posterior tibial rim)
- **Anterior translation of femoral component has *no effect* on anterior tibial post impingement**.

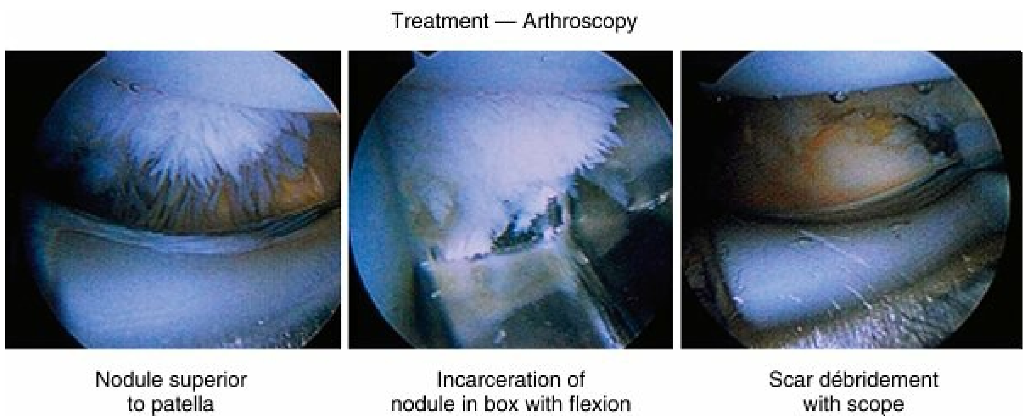


FIG. 5.83 Arthroscopic photographs demonstrating patella clunk syndrome. Classic appearance of fibrotic scar nodule in suprapatellar region *(left).* Incarceration of scar in posterior stabilized box as knee is brought from flexion into extension *(center).* Arthroscopic removal of nodule *(right).*

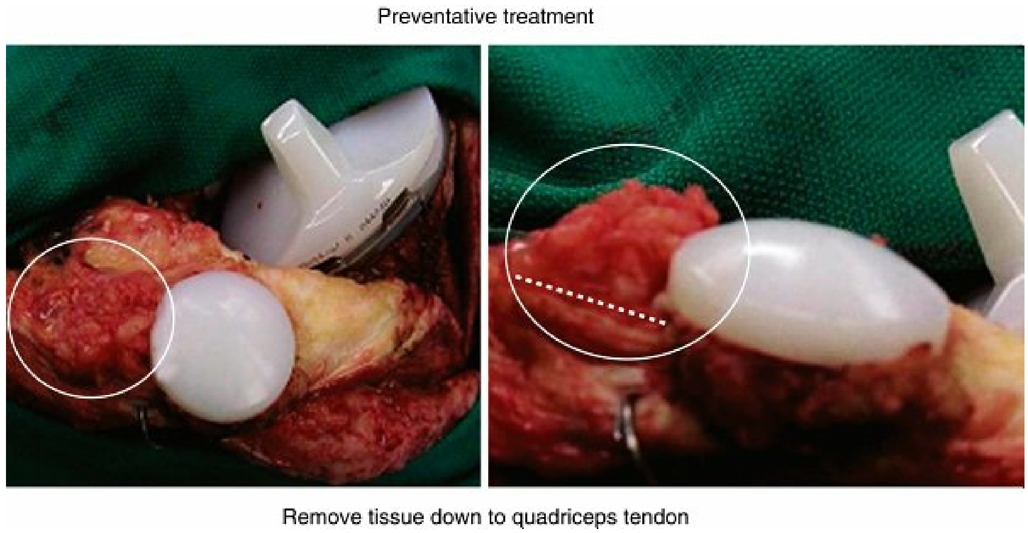


FIG. 5.84 *Left,* Inflammatory tissue *(circle)* around arthritic patella at time of primary TKA. This tissue, if not removed, will cause patellar clunk syndrome. *Right,* This tissue should be aggressively débrided to level of quadriceps tendon *(dotted line).*

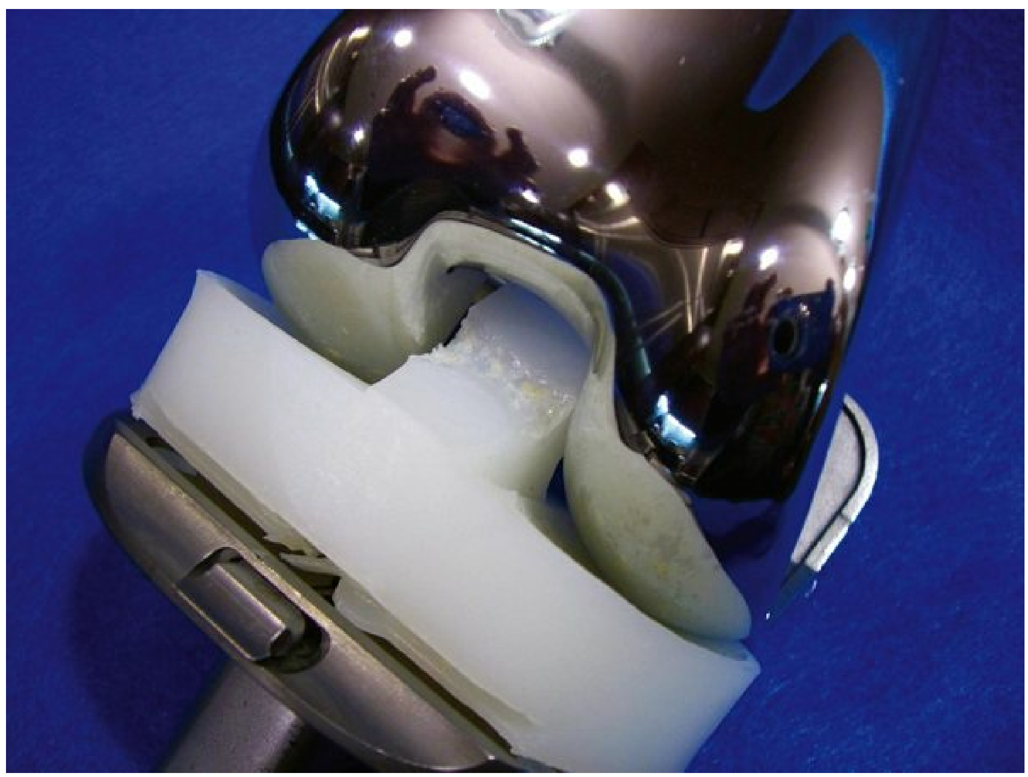


FIG. 5.85 Photograph of posterior stabilized implant with anterior tibial post wear. Note indentation on anterior post where the edge of femoral box impinges upon it. This occurs when the knee moves into hyperextension.

- Additional bone is removed from middle of distal femur.
    - Bone removed can be substantial in a small knee.
- Flexion gap is bigger
    - Flexion gap opens up when PCL is removed.
    - To balance the extension gap, additional distal femur bone is removed in a posterior stabilized

TKA.

- Consequence of additional distal femoral bone removal
  - Joint line elevation with possible baja deformity
- The maximum joint line elevation allowed in primary TKA is 8 mm so as to maintain knee ligament kinematics.
  - Ensures proper kinematic function and stability of collateral ligaments.

□ PS TKA must be used in following situations
- Patellectomy
  - Cruciate-retaining knee with a flat PE is prone to anterior subluxation when patella is absent.
- Inflammatory arthritis
  - PCL is at risk for rupture with erosive disease process
- Trauma with PCL rupture or attenuation

▪ **Anterior stabilized primary TKA design**

□ Description (Fig. 5.86)
- A cruciate-retaining femoral component is used.
- The PCL is removed (or highly recessed).
- Tibial insert is a highly congruent bearing with a raised anterior PE lip and a smaller posterior lip.
- No mechanism for rollback
- Anterior lip resists anterior translation.

□ Advantages
- Easier balancing in severe deformities (i.e., varus/valgus)
- Bone conserving—no box cut needed
- Operative versatility
  - Switch to posterior stabilized system not required if PCL is lost or overreleased.
- Regulated flexion kinematics
  - High congruency limits sliding wear
  - Knee flexion is achieved by
    - Posterior placement of tibial knee flexion center; this is called **posterior offset** center of rotation.
    - Placement of tibial component with native posterior slope; femur is less likely to impinge upon posterior tibia in flexion.

□ Disadvantages

- Increased PE surface area
  - Increases risk for greater PE wear debris and osteolysis
- Minimal rollback
  - Surgical technique must be adjusted to attain high flexion.
    - Posterior translation of tibial component on tibia, when possible; this will place tibial center of rotation more posteriorly.
    - Recreation of native tibial posterior slope.
- Flexion gap laxity causes rotational instability and pain
  - A loose flexion gap will cause instability usually in midflexion and full flexion.
    - Mechanism of midflexion instability
      - Varus or valgus stress when knee is flexed (between 50 and 90 degrees)

FIG. 5.86 Lateral view of anterior stabilized (AS) TKA design. This is the typical profile of the femoral and tibial components. The tibial PE bearing is highly congruent and also has a raised anterior PE lip and a smaller posterior lip to resist anterior translation. In this design there is minimal rollback.

- Patient usually lying in bed or sitting on floor
- Flexion gap opens up and tibia rotates

anteriorly. This creates a subluxing event, but knee usually does not lock up.

- Patient experiences pain when climbing stairs with reciprocal gait, arising from a chair, or negotiating uneven surfaces; it is usually associated with a knee effusion.

- Treatment requires revision to address loose flexion gap.

TIBIAL Rotating Platform in Primary TKA

- **Description (** Fig. 5.87)
  - The tibial PE bearing rotates on a polished metal tibial baseplate.
  - The rotating platform can be used with both anterior stabilized (high congruent) and posterior stabilized TKA designs.
  - The PCL is removed when a tibial rotating platform is used.
- **Advantages**
  - Better articular conformity through entire knee range
    - Theoretically less PE wear
  - Equivalent in survivorship to fixed-bearing knee, but not superior
    - Wear and osteolysis still seen
- **Disadvantages**
  - Bearing spinout (Fig. 5.88)
    - Occurs when flexion gap is left too loose
    - Mechanism of spinout
      - Varus or valgus stress when knee is flexed
      - Patient usually lying in bed or sitting on floor
      - Flexion gap opens up, and tibia rotates behind femur.

FIG. 5.87 Retrieved primary TKA with a tibial rotating platform. Tibial PE component has a yoke that inserts into tibial baseplate. The tibial PE bearing rotates on a polished tibial baseplate.

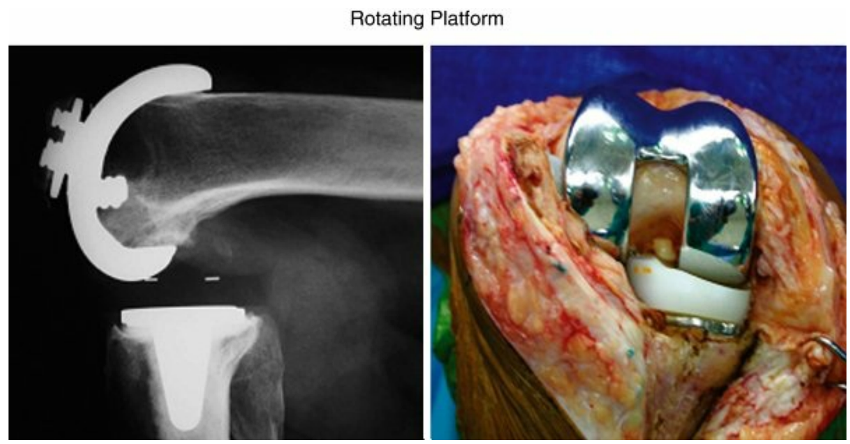


FIG. 5.88 Demonstration of bearing spinout. *Left,* Radiograph shows classic appearance of bearing spinout. Note that femur profile has no central box. Therefore this radiograph is not of a posterior stabilized knee with cam jump. *Right,* Photograph of intraoperative appearance of same patient. Note that the lateral tibial PE component is completely posterior to the lateral femoral condyle.

- Femur then comes to rest in front of tibial PE bearing and locks into spinout position.
- Closed reduction maneuver
  - With use of anesthesia, knee is positioned at 90 degrees of flexion off the side of the table (dependent dangle).
  - Tibial bearing is manipulated by digital palpation and pressure into reduced position.
- Ultimate solution requires knee revision to address loose flexion gap.

Modularity in Primary TKA

- **Modular tibial component is now standard.**
  - □ Metal baseplate
  - □ Modular PE insert
  - □ Stems can be attached to tibia and/or femur.
- **Advantages**
  - □ Greater intraoperative flexibility
  - □ Modular bearing change for worn PE in well-fixed implants—thus major revision is avoided.
- **Disadvantages**
  - □ Backside PE wear
    - Backside wear occurs when the tibial locking mechanism allows micromotion to occur between tibial baseplate and backside surface of tibial PE bearing.

- More osteolysis with modular designs
- Locking mechanisms for tibial PE inserts do not completely eliminate micromotion.
- Backside wear is *not* a problem with a monoblock design (does not occur).
  - With monoblock design, the tibial PE bearing is pressed onto metal baseplate at the factory.

□ Reduction of backside wear achieved with
  - Polished tibial baseplate
  - Tighter locking mechanisms

□ PE dissociation—uncommon event but signifies a significant problem
- Always requires revision because bearing surfaces are damaged
- Reasons for PE dissociation
  - Poor ligament balance/tension
  - Poor alignment

All-Polyethylene TIBIA (APT)

- **Implant is nonmodular**
- **Implant is cemented**
- **Economical (compared with metal tray–modular PE combo)**
- **Wear rate and aseptic loosening rates are similar to those of modular tibial implant.**
- **Disadvantages**
  - □ Cementing an APT is technically harder to perform.
  - □ "Forcing" the APT in place during cementing process can change balance of knee by damaging soft tissues.
- **Failure mechanisms**
  - □ Bending of PE implant at periphery, as there is no underlying metal to support cantilever bend forces
    - PE implant bends, causing cement to crack. Implant then becomes loose.

Constraint in TKA

- **Reason**
  - □ Soft tissues about knee will not support prosthesis.
    - Loss of key vital support structures
  - □ Prosthesis must then accommodate for loss of soft tissue support.
- **Constraint options**
  - □ High tibial post nonhinged

- Hinge with rotating tibial platform
- Hinge with no rotating tibial platform
  - Rarely used

- **Constrained non-hinged TKA**
  - Definition (Fig. 5.89)
    - High central post that **substitutes for MCL** and LCL function
    - A standard posterior stabilized post is not constrained.
  - Indications
    - Residual flexion gap laxity—most common reason
      - Owing to soft tissue weakness, the extension and flexion gaps cannot be completely balanced.
    - MCL attenuation
    - Lateral collateral ligament attenuation and deficiency
    - Complete MCL deficiency
      - Debatable—some surgeons recommend hinge rotating platform for complete MCL deficiency.

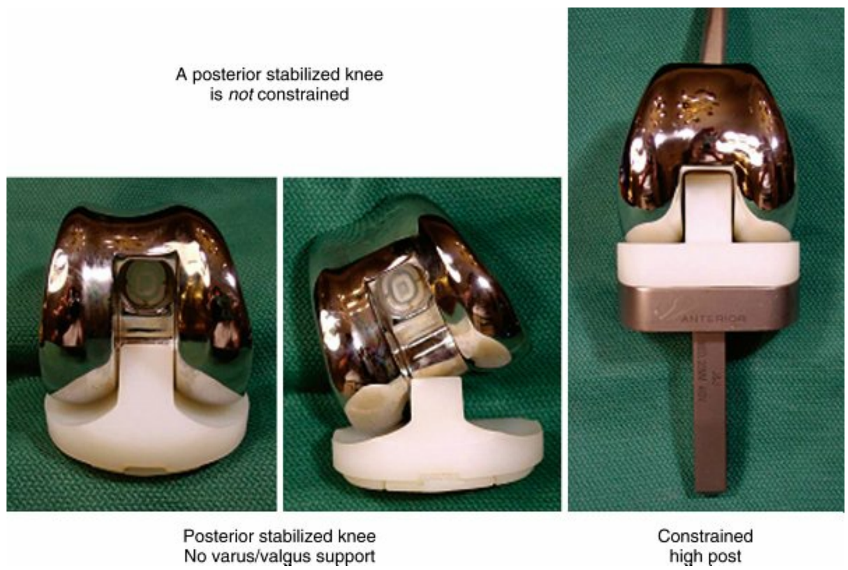


FIG. 5.89 Diagram showing high-post constrained TKA. Photographs at *left* and *center* show a typical posterior stabilized TKA. If medial collateral ligament or lateral collateral ligament function is lost, the posterior stabilized post will not resist varus or valgus forces and the knee will be unstable. The photograph at *right* shows a constrained high-post design. This PE post is very tall and will not allow varus or valgus opening of the knee.

Hinge Basics

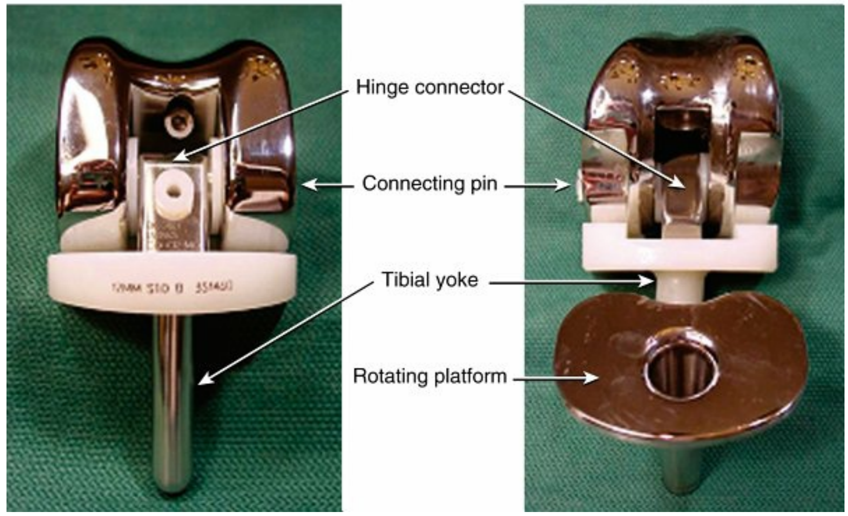


FIG. 5.90 Diagram showing basic components of hinge TKA. In all hinge systems, the femur is connected to the tibia via a connecting post placed into the middle of the knee. A connecting pin of metal is placed through the femur and tibial post. A locking pin keeps connecting pin in position. A tibial yoke rests in the tibial component. This allows rotation of the tibia.

- Reason: too much stress is placed on central PE post.
- Charcot arthropathy
  - Debatable—some surgeons recommend hinged rotating platform for Charcot arthropathy
    - Reason: too much stress is placed on central PE post.
- □ Disadvantages
  - More constraint upon implant places more forces through implant and implant-bone interface, leading to
    - Higher rate of aseptic loosening
    - More PE wear/damage to PE post
  - Constrained high-post knee system **requires medullary stem support** in femur and tibia to help distribute increased load forces (i.e., load share) through the implant and into host diaphyseal bone.

▪ **Hinged TKA**

- □ Definition (Fig. 5.90)
  - Femoral and tibial components are linked with a connecting bar and bearings
  - There is a fixed extension stop.
  - Most designs incorporate a tibial rotating platform.
    - Reduces torque stress to implant bone interface
- □ Indications
  - Global instability number one reason

- Due to trauma or infection
- Hyperextension instability (Fig. 5.91)
    - This is *absolute* indication for hinge.
    - Hyperextension conditions include
        - Postpolio knee or spina bifida
            - Increased knee extension forces to lock and hold knee in extension during gait, eventually causing posterior capsule to stretch out
        - Erosion of posterior capsular attachments to bone as a result of
            - Advanced bony osteolysis
            - Autoimmune disease states (particularly rheumatoid arthritis)
- Native knee removal
    - Tumor
    - High-energy fracture with communication
    - Massive infection

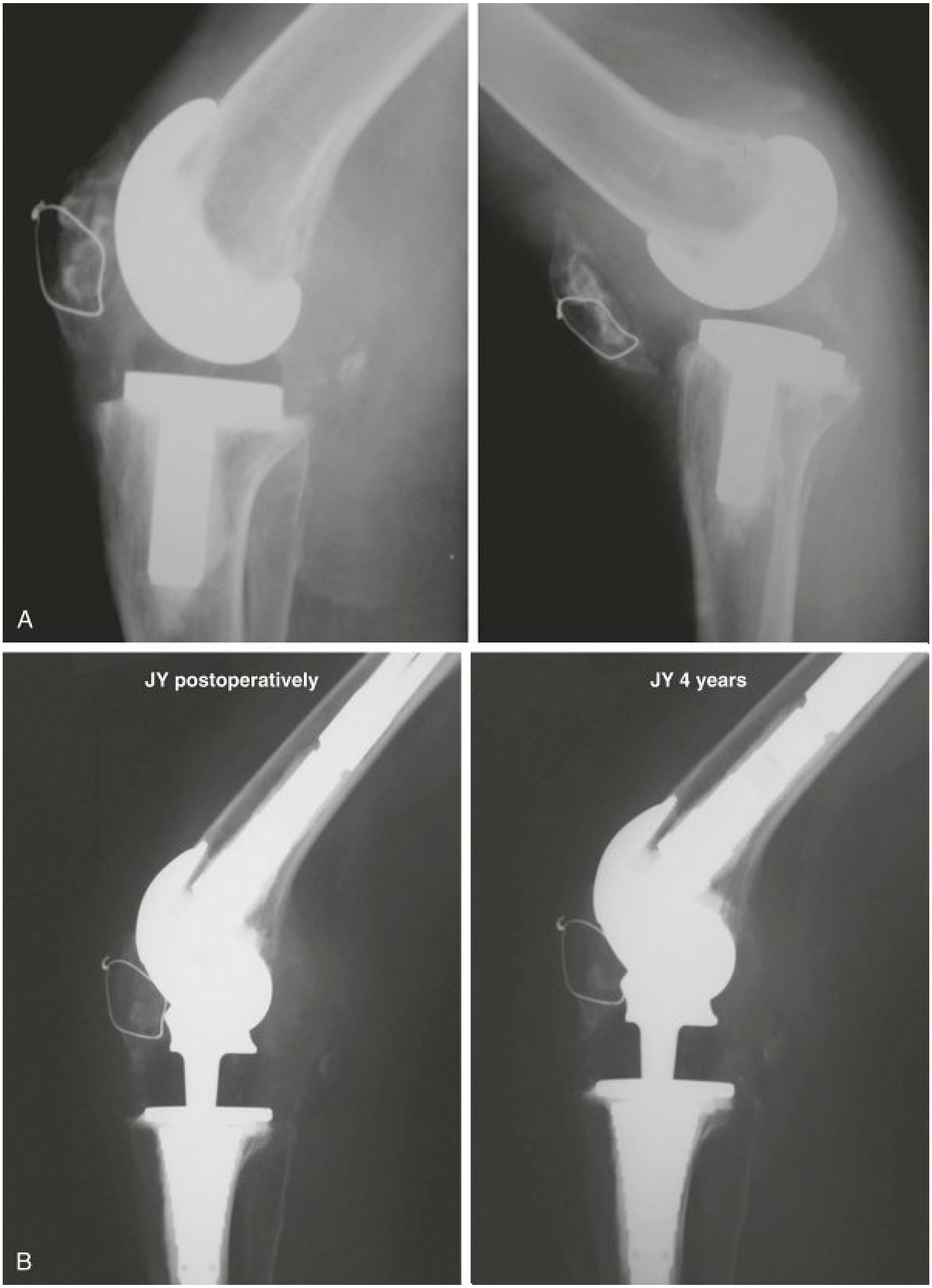


FIG. 5.91 Case showing hyperextension instability. (A) TKA in a patient with postpolio syndrome. Extension lateral view shows severe hyperextension, which on presentation was only mildly painful. However, the patient had significant difficulty with walking. (B)Radiographs of revision to a hinge TKA, immediately and then 4 years postoperatively.

Section 15 Revision TKA

Preoperative Evaluation

- **Revision of a painful TKA without identification of a specific cause of pain is likely to have a poor outcome.**
- **First, pain must be determined as having either an intrinsic intraarticular source or an extrinsic source.**
- **Extrinsic sources of knee pain**
  - Referred pain from the hip
    - *Most common* missed diagnosis
    - Hip pain typically refers to anterior-medial knee region (distal branch of obturator nerve).
  - Referred pain from the spine
    - Typically L3 nerve root
  - Extraarticular at the knee
    - Allodynia—chronic regional pain syndrome
    - Local superficial neuroma
- **Intrinsic sources of knee pain**
  - Mechanical loosening
  - Osteolysis with PE debris synovitis
  - Malposition and/or malalignment of implants
  - Instability
  - Infection
    - Typically, presentation is **constant global pain** with abnormal infection biomarkers and positive aspiration findings.
    - PJI is currently the number one reason for revision within the first 2 years of primary TKA.
  - Hypersensitivity—rare
    - Typically, constant global pain with normal infection laboratory results and negative aspiration findings.
    - Most common metal ion involved in knee hypersensitivity is **nickel.**
- **Intraarticular aspiration**
  - WBC count greater than 3000 cells/μL raises suspicion for a chronic PJI.
- **Intraarticular lidocaine challenge**
  - Administration of at least 15 mL of lidocaine or 50/50 mixture of lidocaine/bupivacaine
  - Relief of more than 90% of pain constitutes a positive result.
    - Indicates that pain emanates primarily from within the knee joint
- **Radiographs**

- Smooth radiolucent lines around cement mantle and metallic implants suggest aseptic loosening.
- Stem tilt to side of medullary canal with an outer cortical periosteal reaction suggests aseptic loosening.

- **CT**
  - Evaluation for rotational malalignment of implants
    - Posterior condylar axis of metallic femoral condyles should be compared with epicondylar axis.
      - Posterior condylar axis should be parallel or slightly externally rotated in relation to epicondylar axis.
        - Internal rotation of femoral implant is a known cause of flexion gap imbalance.
    - Tibial implant axis should lie over medial third of tibial tubercle.
      - A tibial implant axis lying medial to tibial tubercle indicates malalignment (i.e., relative increase of tibial tubercle external rotation).

Surgical Approach

- **The prior incision should be used instead of a new incision made.**
  - Reason: a "skin bridge" can necrose from devascularization.
  - If a second incision is required, the minimum distance between incisions is 7 cm.
  - If two or more longitudinal incisions are present in the anterior knee, the most lateral incision should be chosen for revision.
    - Reason: blood supply for the anterior knee skin comes from medial side of distal thigh and knee.
- **Difficult exposure sequence**
  - Extended proximal arthrotomy
    - To most proximal end of quadriceps tendon
  - External rotation of tibial bone from soft tissue envelope
    - Subperiosteal dissection of soft tissues from medial tibial tubercle all the way around to posterior-medial corner of knee
    - Release of posterior-medial corner structures and, if needed, posterior tibial capsule
  - Lateral knee débridement
    - Removal of scar from patella, tendon, and lateral gutter
    - Gradual eversion of patella as tibia is externally rotated

- Lateral retinacular release—only if needed
- Quadriceps tendon snip (usually 2 cm)
  - Transverse snip at most proximal region
  - Snip will not cause quadriceps dysfunction or lag

- **Tibial tubercle osteotomy**
  - Used as last resort
  - Best indication is for a stiff TKA (<90 degrees flexion) with patella baja deformity.

Implant System

- **Comprehensive revision system must be available.**
  - Revision surgery is often unpredictable.
  - Constrained tibial insert option is a must.
  - Stems and metallic augmentations are required.

Modular Bearing Change for *Premature* Excessive Wear

- **Most current tibial PE bearings should last at least 13–15 years with an average patient wear scenario in a well-balanced knee.**
  - Failure of a PE bearing within 5–7 years is premature and indicates a problem with knee balance and/or alignment.
- **Failure rate of isolated modular bearing change for excessive premature PE failure is 30%–40%.**
  - Reasons for premature failure
    - Unappreciated malalignment
    - Poor knee balancing in either coronal or sagittal plane
- **Isolated modular bearing change in this scenario is not** recommended.

Technique of Revision TKA

- **Workflow sequence**
  - First—implant removal
  - Second—joint line restoration with tibial implant
    - Joint line is generally 1.5 cm superior to top of fibular head.
    - Failure to restore joint line will result in diminished knee flexion.
  - Third—femur restoration
    - Extension gap restored first
      - Surgeon must ensure that patella is in appropriate position (i.e., no baja or alta).

- Restoration of flexion gap
- Gap balance fine tuned.

- □ Fourth—adjustment of femoral and tibial implant rotation for best patellar tracking
- □ Fifth—selection of constraint
  - The least constraint needed for **stable** knee function should be used.
- □ Sixth—assessment of patellar tracking
  - Large lateral retinacular release should be avoided if possible. Lateral superior genicular artery should not be cut.

- **Segmental defect femur or tibia**
  - □ Metadiaphyseal trabecular cones are preferred solution to provide prosthetic support (Fig. 5.92).
  - □ Trabecular cones have predictable osteointegration to host bone.

Revision TKA—Patella

- **Isolated patella component failure usually indicates subtle malalignment in patellar tracking.**
  - □ Higher failure rate for isolated patellar revision
  - □ Full revision should be considered.
- **A mechanically loose patellar component can cause significant patellar bone loss.**
  - □ **For revision to another patellar component, bone thickness must be at least 12 mm, and there must be enough bone to support PE pegs within bone.**
  - □ If bone is inadequate for revision resurfacing
    - Débridement of patellar implant with bone retention is acceptable
    - Patellectomy is recommended for bony fragmentation.

Section 16 Patellar Tracking in TKA

Introduction

- **The most common complications in TKA involve abnormalities in patellar tracking.**
- **Most important factors for successful patellar tracking**
  - Maintaining normal Q angle
  - Proper rotation of components
  - Maintaining normal patellofemoral tension (i.e., patellofemoral gap should not be overstuffed)

Q Angle in TKA

- **Q angle definition—the angle between a line defining the axial pull of the quadriceps tendon and a line bisecting the patellar tendon**
- **Reasons an increased Q angle in TKA is bad (** Fig. 5.93)
  - An increased Q angle increases the resultant lateral subluxation force (i.e., lateral pull effect).
  - Prosthetic patellar replacements (by design) are less restrained than native patella (native patella is V-shaped).
  - Prosthetic patellar replacements are therefore more likely to sublux with increased Q angle forces.
- **Q angle goal in TKA**
  - Restoration of proper Q angle with techniques that do not compromise mechanical alignment or stability of the knee

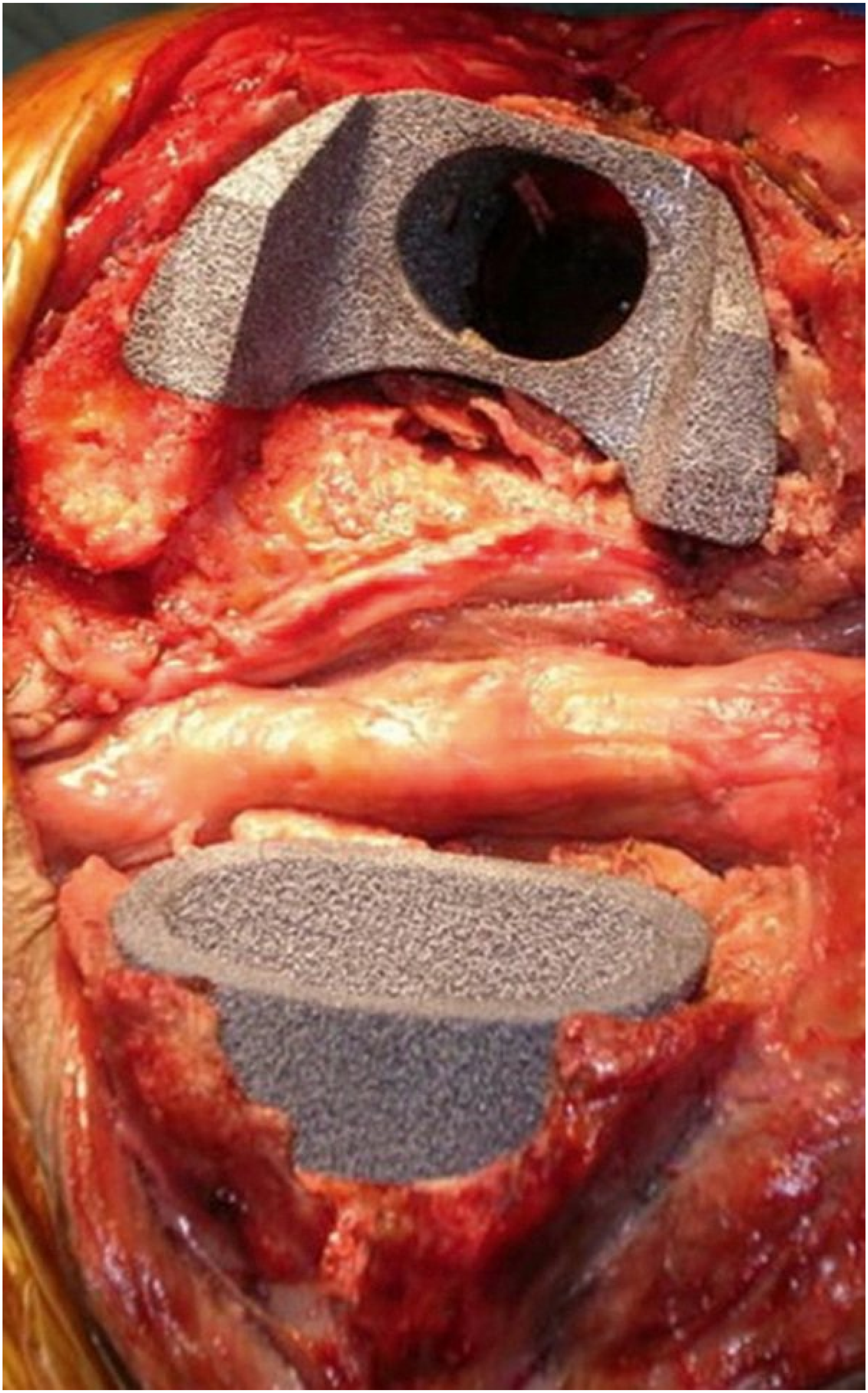


FIG. 5.92 Intraoperative photograph showing placement of tibial trabecular cone for segmental deficiency of proximal tibia. In this example, the cone achieves bony osteointegration at the outer periphery. The tibial baseplate and stem are then cemented into the construct. The cone provides additional support to minimize

proximal tibial implant loosening.

TKA Techniques to Optimize Patellar Tracking

- **Reduction of excess valgus**
  - Valgus deformity must be corrected to a neutral mechanical alignment —*always.*
  - Severe valgus deformities that require radical ligamentous releases can be adequately managed with sophisticated revision-style prosthetic systems.
- **Component positioning**
  - **Patellar maltracking—causes**
    - **Internal rotation of**
      - **Femoral component**
      - **Tibial component**
    - **Medialization of**
      - **Femoral component**
      - **Tibial component**
- **Femoral component rotation**
  - Femoral component should never be *internally rotated.*
  - Internal rotation of femur—resultant problems (Fig. 5.94)

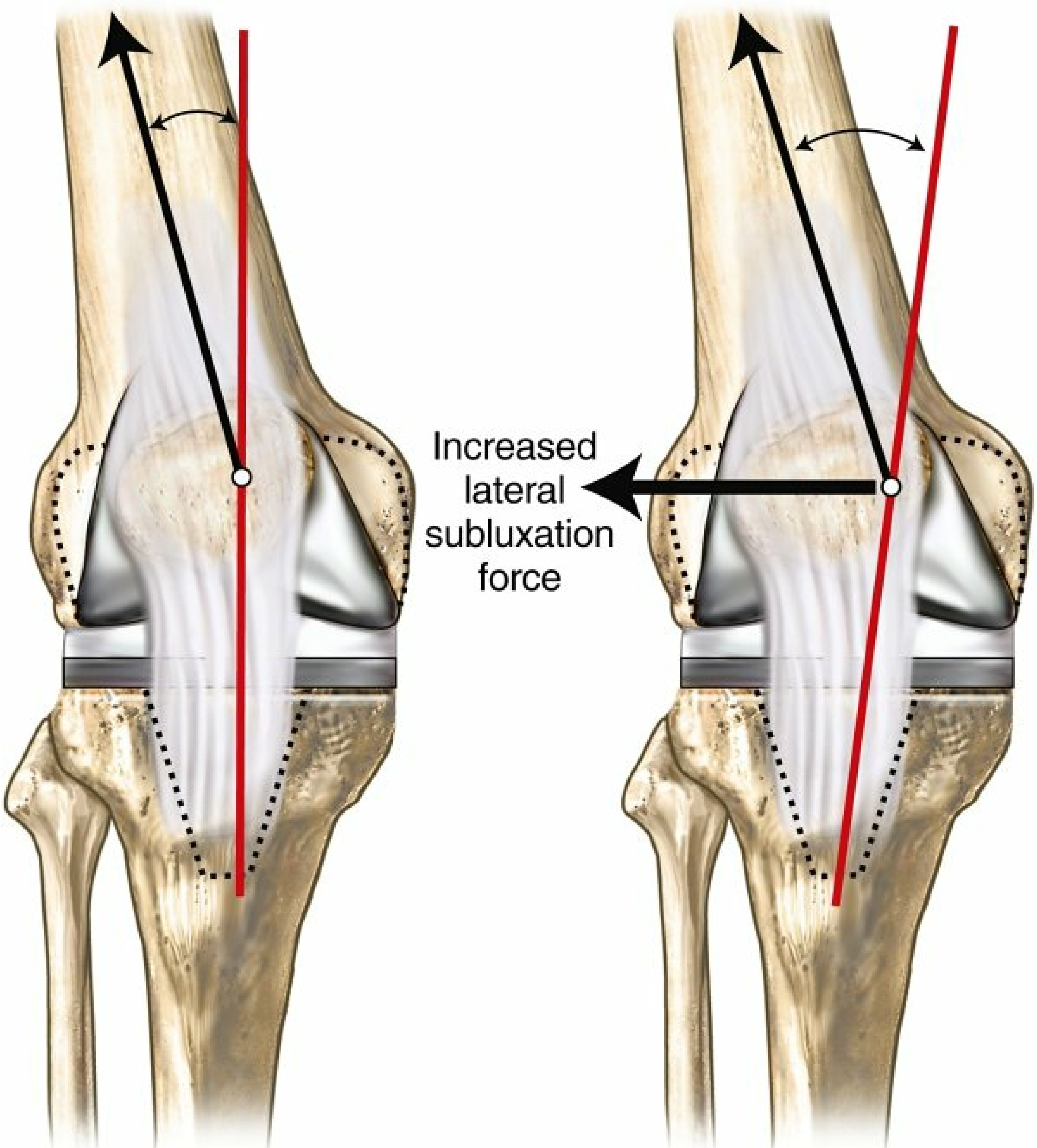


FIG. 5.93 Diagram depicting effect of an increased Q angle in TKA. As the Q angle increases, so does the resultant lateral subluxation force. Because the shape of the resurfaced patella is a dome, this design is less able to resist the lateral pull effect. The result is an increased risk for patellar subluxation.

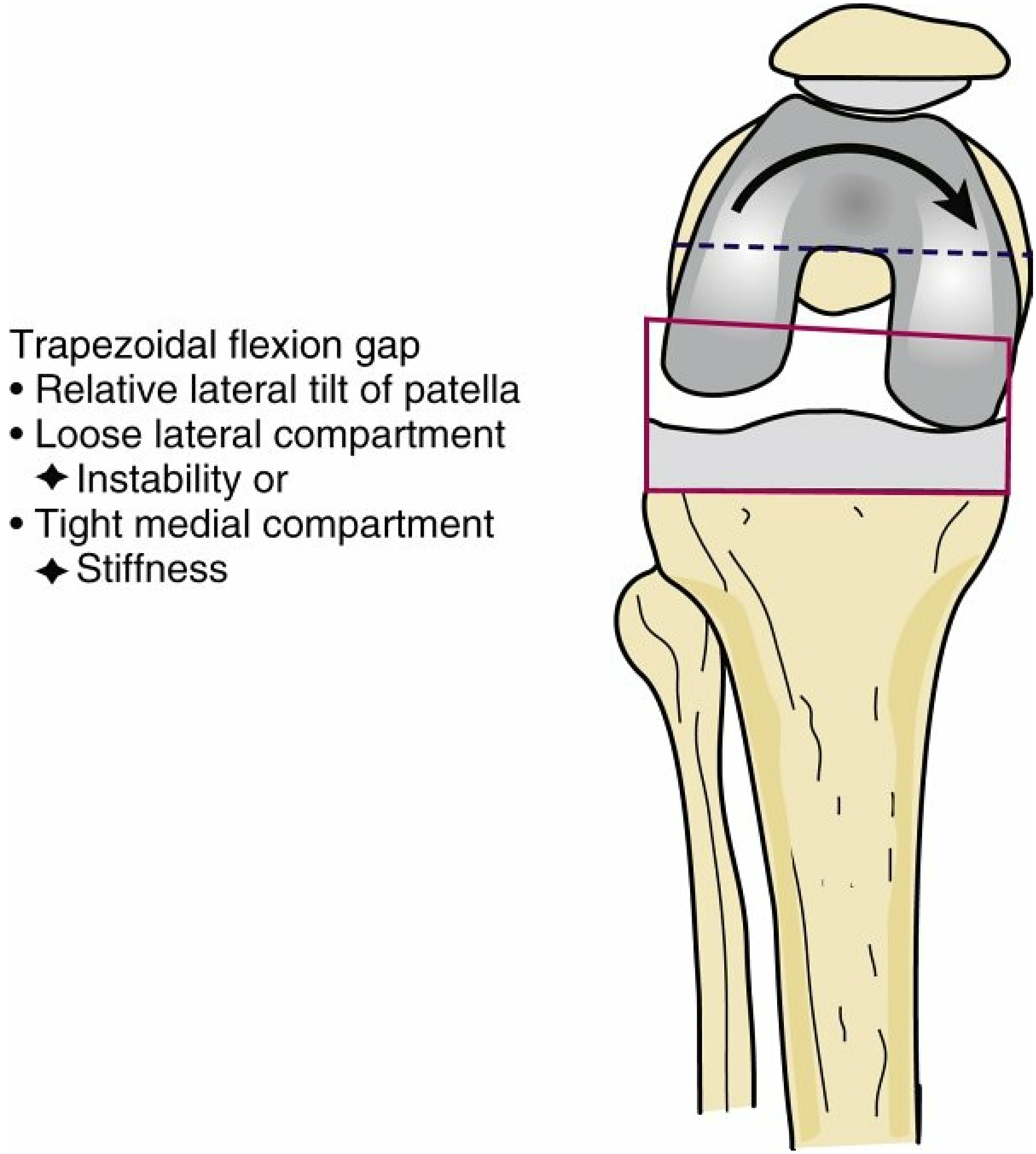


FIG. 5.94 Diagram showing adverse effects of internal rotation of femoral component. Diagram depicts TKA at 90 degrees of flexion. With internal rotation of femur, the patellar groove faces inward and the flexion gap becomes asymmetric. Patellar tracking and flexion kinematics are both adversely affected.

- Relative lateral tilt of patella
  - Patellar groove faces inward
- Trapezoidal flexion gap
  - Unbalanced flexion gap

□ Technique goal is slight external rotation of femur (Fig. 5.95).

- Patellar groove is centered under patella.

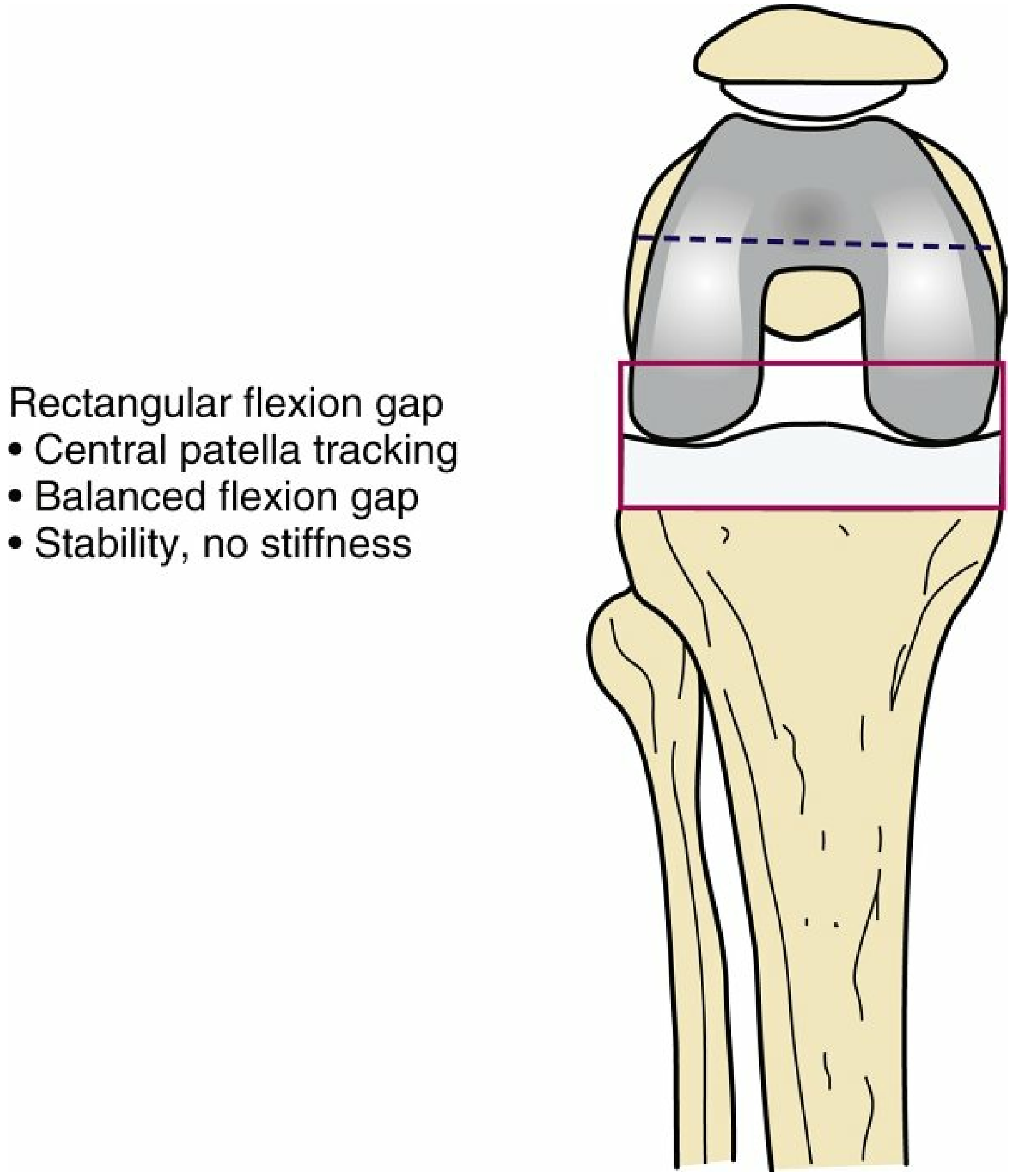


FIG. 5.95 Diagram showing proper positioning of femoral component in slight external rotation. With slight external rotation, the patellar groove is centered under the patella and the flexion gap is balanced, optimizing flexion kinematics.

- Rectangular flexion gap
  - Balanced flexion gap

□ Reasons for external rotation of femoral component (Fig. 5.96)

- Commonly the native proximal tibia is actually in slight varus.
  - Average is 3 degrees varus
- During TKA, the proximal tibia is cut perpendicular to mechanical axis.
- Results in trapezoidal (i.e., unbalanced) flexion gap
- To compensate, the femoral component is externally rotated a similar amount to obtain a rectangular (i.e., balanced) flexion gap and also optimize patellar tracking.

□ External rotation of femoral component—techniques

- There are five established techniques to determine proper femoral component rotation. All methods are acceptable (Fig. 5.97).

- Anteroposterior axis method
    - *Anteroposterior axis* is defined as line from intercondylar notch (specifically the most lateral border of PCL) to center of trochlear groove
    - A line drawn perpendicular to anteroposterior axis is used to set femoral rotation.
- Epicondylar axis method
    - The epicondylar axis is a line drawn from the center of the medial epicondyle to the center of the lateral epicondyle.
    - Femoral rotation is set along this line.
- Posterior condylar axis method
    - The posterior condylar axis is a line connecting the apex of the medial femoral condyle and lateral femoral condyle measured at 90 degrees of flexion.
    - The femoral rotation line is mechanically chosen along a line that is 3 degrees externally rotated to this line (acceptable range is 3–5 degrees of external rotation).
- Tibial alignment axis method

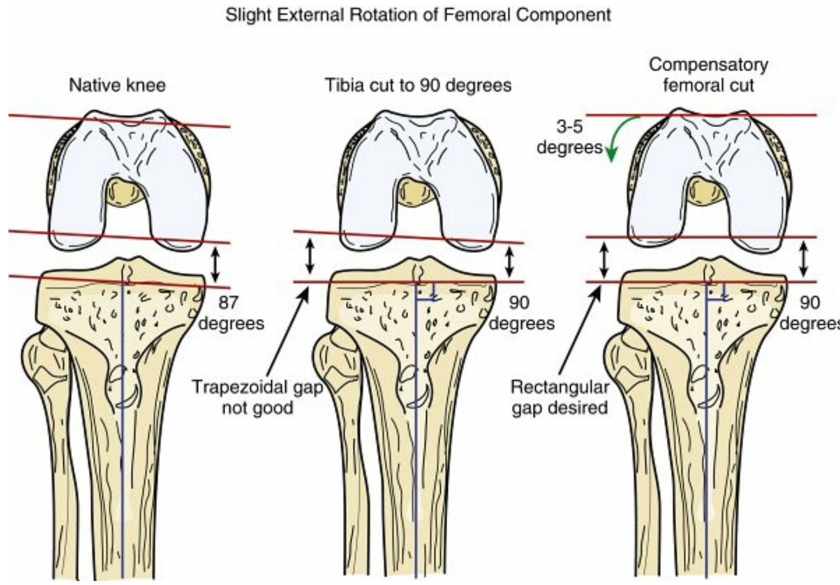


FIG. 5.96 Diagrams demonstrating proper component rotation during TKA. *Left,* Native knee in flexion. In many instances, the native proximal tibia is actually in slight varus (average is 3 degrees). *Center,* In TKA procedure, the proximal tibia is cut perpendicular to mechanical axis. This leaves the flexion gap asymmetric and unbalanced. *Right,* Compensatory cut on femur, which is externally rotated to create a rectangular (i.e., balanced) flexion gap and to optimize patellar tracking.

- The proximal tibial cut is with a cutting jig set 90 degrees to the mechanical axis of the tibia.
- With the knee at 90 degrees of flexion, the same guide is used to set femoral component rotation by drawing rotation line on the femur.

- Gap balance axis method
    - The proximal tibia is cut first.
    - With the knee at 90 degrees of flexion, tension devices are placed under the medial and lateral femoral condyles. A set tension is then applied to the flexion gap.
    - **The femoral rotation line is drawn to create a *rectangular* flexion gap**.

□ **Beware of lateral femoral condylar hypoplasia**

- In this condition the lateral femoral condyle is small owing to hypoplastic development.
    - Clinically, a knee with lateral femoral condylar hypoplasia has a prominent valgus deformity at presentation. With the knee viewed in flexion, the

lateral femoral condyle looks small relative to the medial femoral condyle (Fig. 5.98).

- **In lateral femoral condylar hypoplasia the posterior axis *cannot* be used**.
  - If the posterior condylar axis is used as the rotation reference, the femur will be placed in internal rotation and the flexion gap will be unbalanced.

- **Tibial component rotation**
  - Tibial component should never be *internally* rotated.
  - Internal rotation of tibia—resultant problems (Fig. 5.99)
    - Increases Q angle
    - Increases lateral subluxation force
  - Tibial component positioning should lie over medial half of tibial tubercle.
- **Implant medialization**
  - Femoral component should not be medialized.
    - Reason: medialization of femur moves patellar groove medial relative to tibial tubercle. Result is **net increase in Q angle.**
    - Lateralization is acceptable.
  - Tibial component should not be medialized.
    - Reason: medialization moves knee articulation medial relative to tibial tubercle. Result is **net increase in Q angle.**
    - Lateralization is acceptable
  - Patellar component medialization is acceptable (Fig. 5.100)
    - Reason: center of the patellar component is placed medial to the center of the patellar tendon. Result is **net decrease in Q angle.**
    - Lateralization of patellar component should be avoided.
- **Patellofemoral tensioning (also called** *third-gap balancing*)
  - Restoring normal patellar height maintains normal retinacular tension (Fig. 5.101).
    - **Increasing net patellar height increases retinacular tension**.
    - **Increased retinacular tension will increase lateral pull forces upon patella, causing maltracking**.
      - Reason: because knee alignment is clinically valgus, any incremental increase in retinacular tension will pull and tilt patella laterally.
  - Patellofemoral height (i.e., patellofemoral gap) is controlled by sum of total of
    - Patella bone thickness
    - Patella implant thickness
    - Trochlea bone thickness

        - Trochlea implant thickness
- Increased patellofemoral gap—worst case scenario
    - Thin bone cut on patella
        - Remaining patellar bone is too thick
    - Thick PE implant (by design)

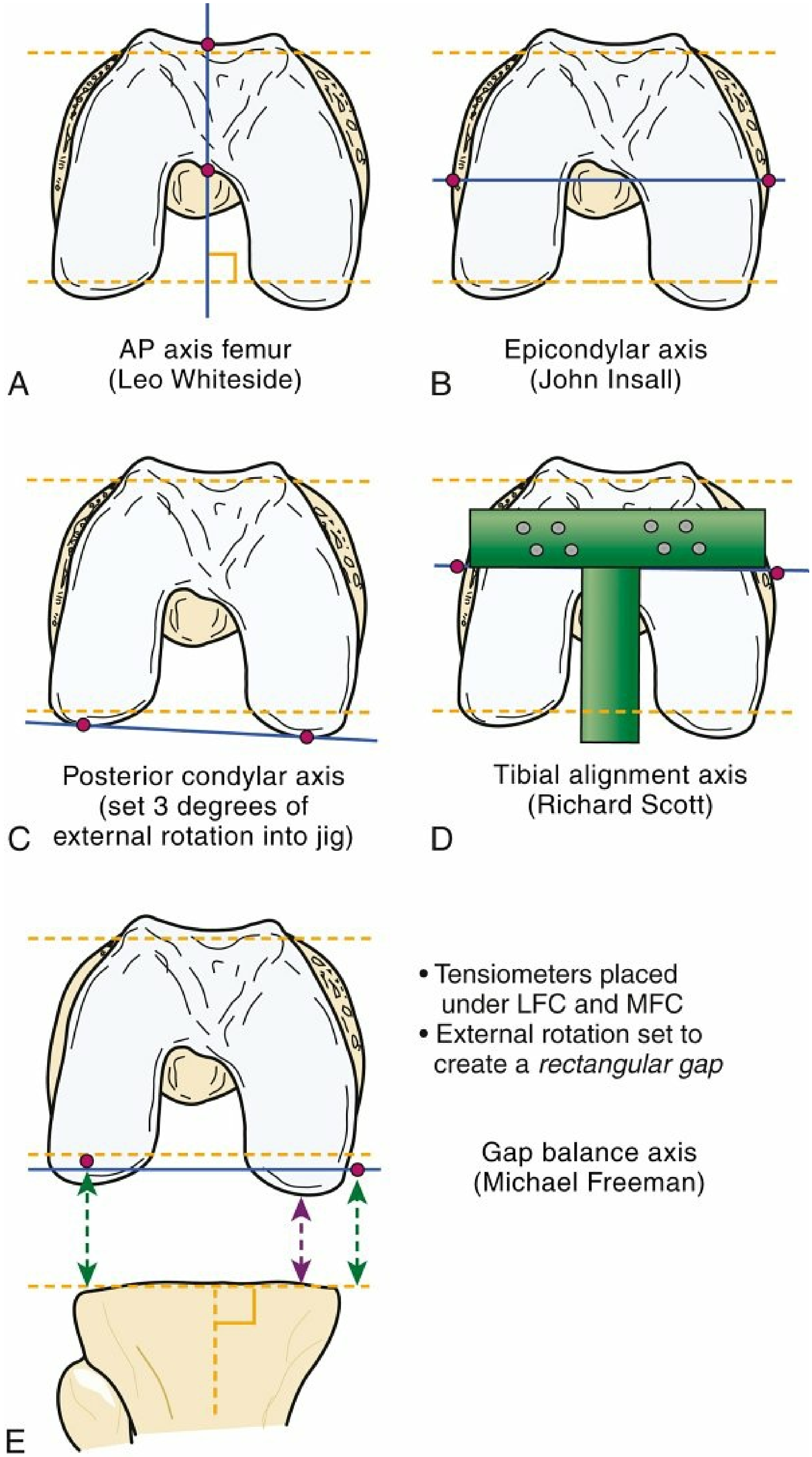


FIG. 5.97 Diagrams showing methods to determine femoral component rotation. (A) In the AP axis method, the AP line is drawn from the center of the intercondylar notch to the center of the trochlear groove. The femoral rotation is set along a line perpendicular to the AP axis. (B) The epicondylar axis is a line drawn from the center of the medial and lateral epicondyles. Femoral

rotation is set parallel to this line. (C) Posterior condylar axis. The posterior condylar line is drawn between the two femoral condyles (at 90 degrees of flexion). Femoral rotation is set at 3 degrees of external rotation relative to this line. (D) Tibial alignment axis. The tibial jig, used to cut the tibia at 90 degrees to the tibial mechanical axis, is also used to set femoral rotation. Either the jig is raised or a block is placed upon the jig to draw the femoral rotation line. (E) Gap balance axis method. Tensiometers are placed into the flexion gap, and tension is applied to the flexion gap. The femoral rotation line is drawn to create a rectangular flexion gap with the knee ligaments under tension. *LFC,* Lateral femoral condyle; *MFC,* medial femoral condyle.

- Thin bone cut on trochlea
    - Remaining trochlear bone is too thick
- Thick femoral trochlear implant (by design)

Intraoperative Assessment of Maltracking

- **If maltracking is seen with TKA implants in place, tourniquet is released** *first;* then situation is reevaluated before any changes are made.
- **The tourniquet can alter extensor tension and falsely create increased lateral pull forces.**

Postoperative Assessment of Maltracking

- **If physical examination and plain radiographs do not reveal the cause of postoperative patellar maltracking, a CT scan can be used to determine rotational alignment of femoral and tibial components.**

Patella BAJA

- **Patella sagittal position**
    - Defined by Insall-Salvati ratio
        - Patellar tendon length/patellar bone length; measured on lateral view of knee flexed 30 degrees
        - Normal ratio is 1:1
        - Baja deformity ratio less than 0.8
        - Alta deformity ratio greater than 1.2
- **Frequently seen after**
    - Proximal tibial osteotomy (both closed and open wedge techniques)
    - Tibial tubercle transfer/slide
    - Trauma
- **Baja in TKA (** Fig. 5.102) causes
    - Loss of knee flexion

- Impingement pain in flexion
- Patellar clunk (PS knee)

- **Operative solutions to reduce baja in TKA**
  - Superior placement of patellar component
    - Use of smaller patellar dome placed superiorly on patella
    - Trimming/tapering of inferior bone to reduce flexion impingement
    - Useful for mild baja deformity
  - Lower joint line—sophisticated technique (Figs. 5.103 and 5.104)
    - Tibial bone cut is made lower.
    - Distal femoral metallic augmentation is added.
    - Requires revision knee system
  - Cephalad transfer of tibial tubercle/anterior tibia
    - Procedure is risky.
      - Bone healing not always predictable (especially around a cemented tibial component).
      - Clinically, patient may have residual functional extensor lag.
  - Patellectomy for extreme cases
    - Patellectomy alters anterior knee tension.
      - Cruciate-substituting (or constrained) knee system must be used.

Patellar Resurfacing Versus Nonresurfacing

- **Between the two techniques, neither method has been established as superior.**
  - Overall, patellar resurfacing has a *lower* risk of reoperation than nonresurfacing.
  - Absolute indication for patellar resurfacing is autoimmune inflammatory arthritis.
- **Problems with resurfaced patella**
  - Patella component loosening
    - Due to maltracking
    - Due to osteolysis
  - Patella *clunk* and *crunch*

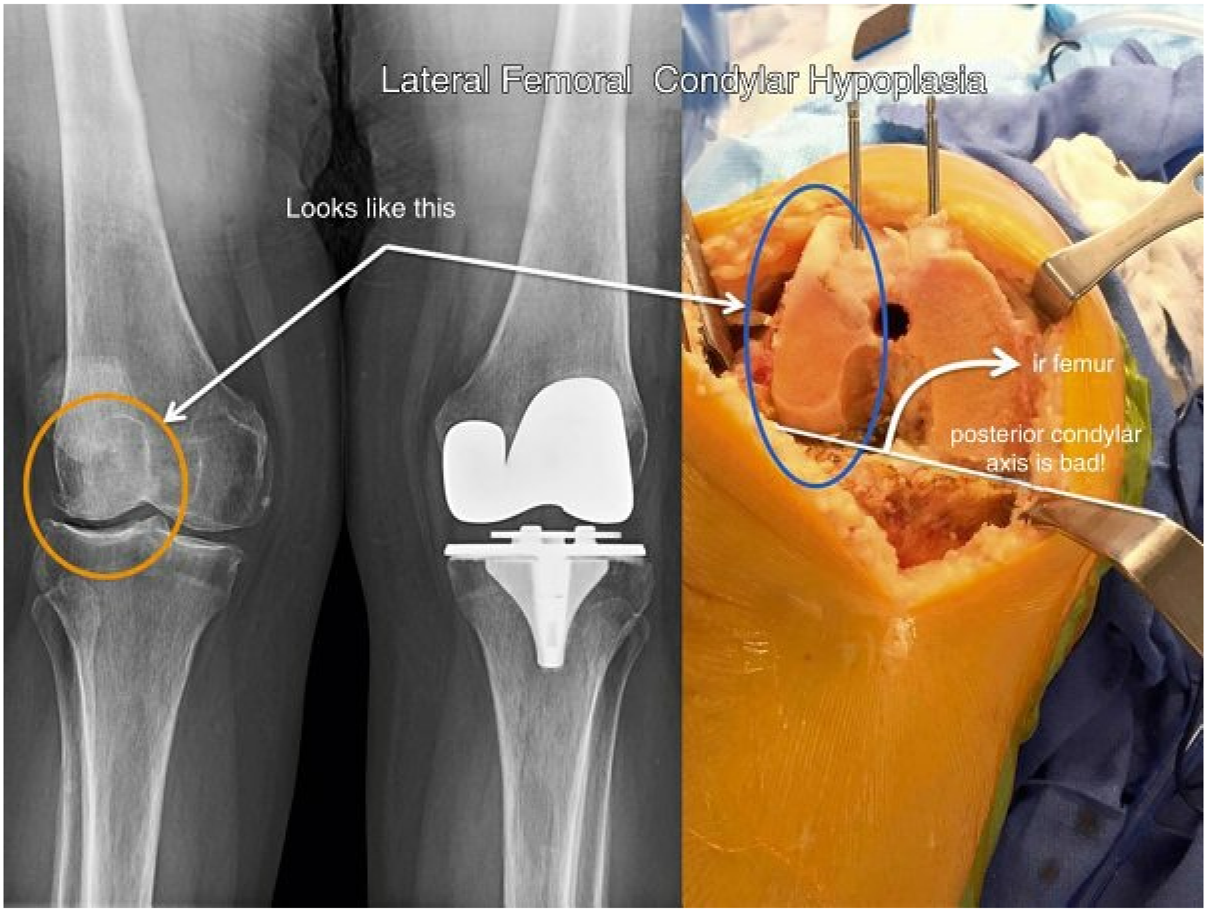


FIG. 5.98 This combined figure illustrates the ill effects of lateral femoral condylar hypoplasia. The AP radiograph of the right knee shows a valgus deformity and a lateral femoral condyle that is smaller than the medial femoral condyle. This is a classic radiographic presentation. The intraoperative photograph shows the same patient, highlighting the small size of the LFC. Furthermore, the posterior condylar line drawn in this picture clearly shows how this reference line is abnormally internally rotated.

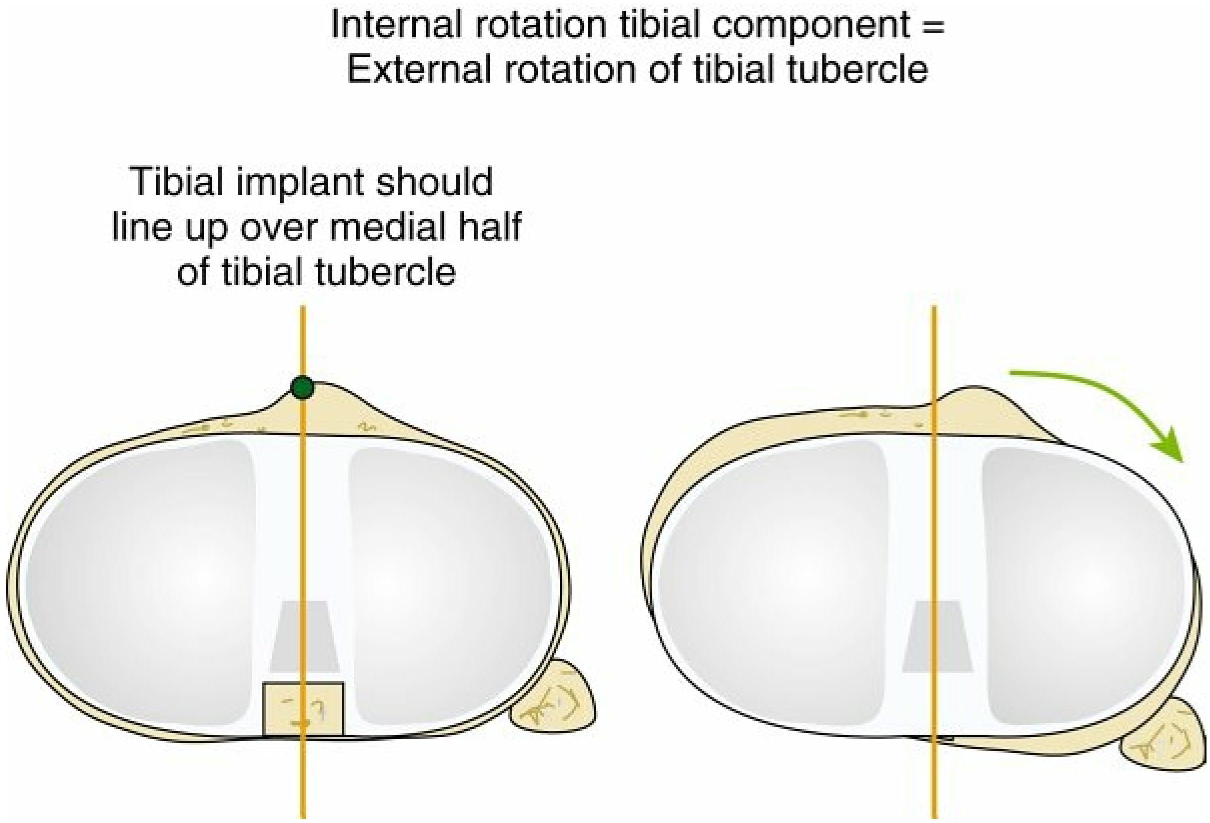


FIG. 5.99 Diagram showing tibial component rotation in TKA. For optimal patellar tracking, the tibial component should be rotated over the medial half of the tibial tubercle *(left).* Internal rotation of the tibia should be avoided *(right).* When the tibial component is internally rotated, the tibial tubercle is positioned in external rotation relative to the knee flexion plane. This increases the Q angle, which increases lateral subluxation forces.

- Clunk occurs when suprapatellar scar tissue gets entrapped within the posterior stabilized box as the knee comes from flexion into extension.
- Clunk is unique to posterior stabilized design.
- Patellar crunch occurs when scar accumulates around patellar component, creating a crunching noise as the knee comes from flexion to extension.

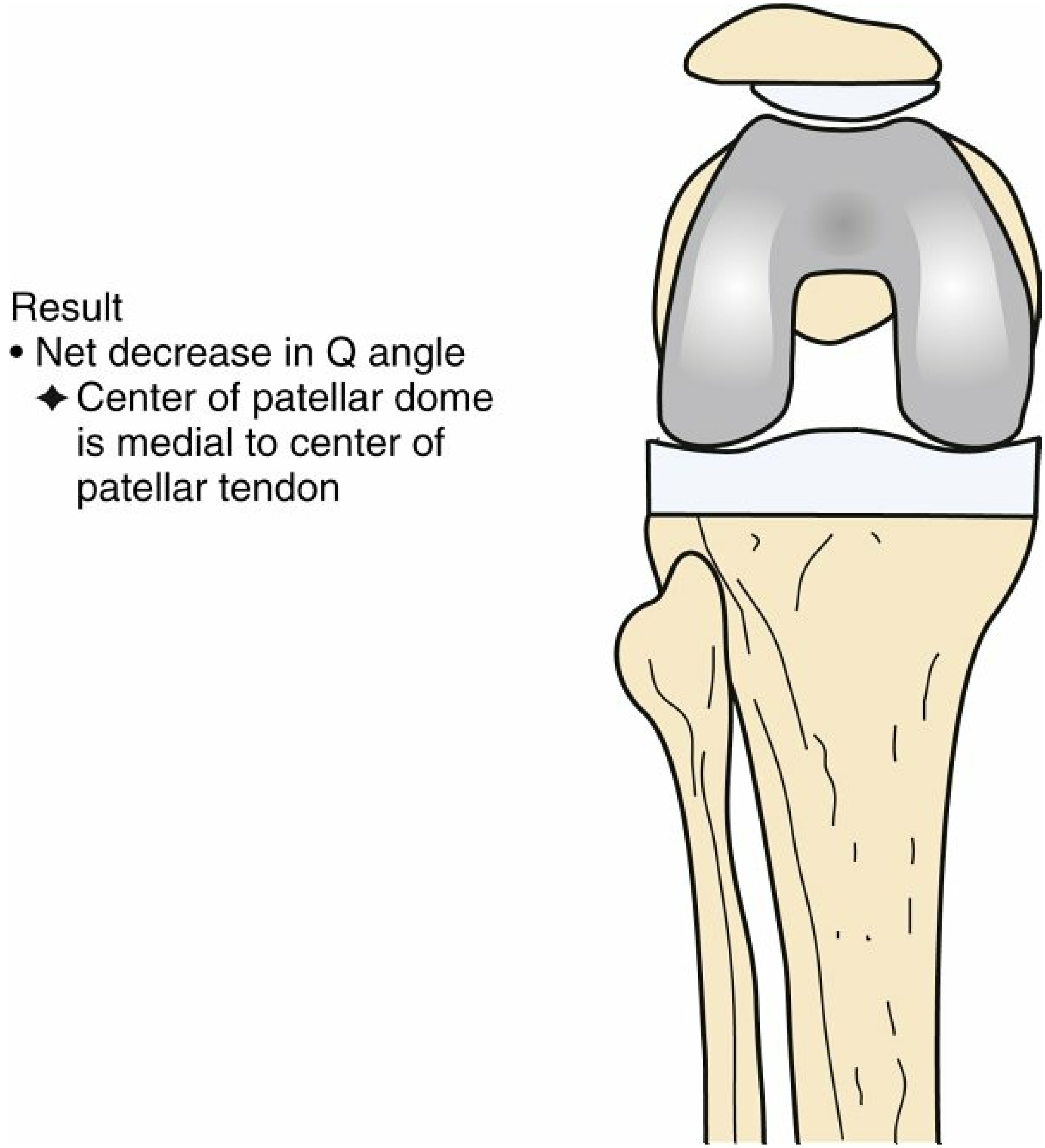


FIG. 5.100 Diagram showing medialized patellar component. In this technique, a small patellar dome is used. It is placed in a medialized position. The center of the patellar dome, being medial to the center of the patellar tendon, reduces the net Q angle.

- Patella fracture
  - Reason: bone cut too thin
  - Minimum thickness for patella is 13 mm.
- Avascular necrosis of patella with fragmentation

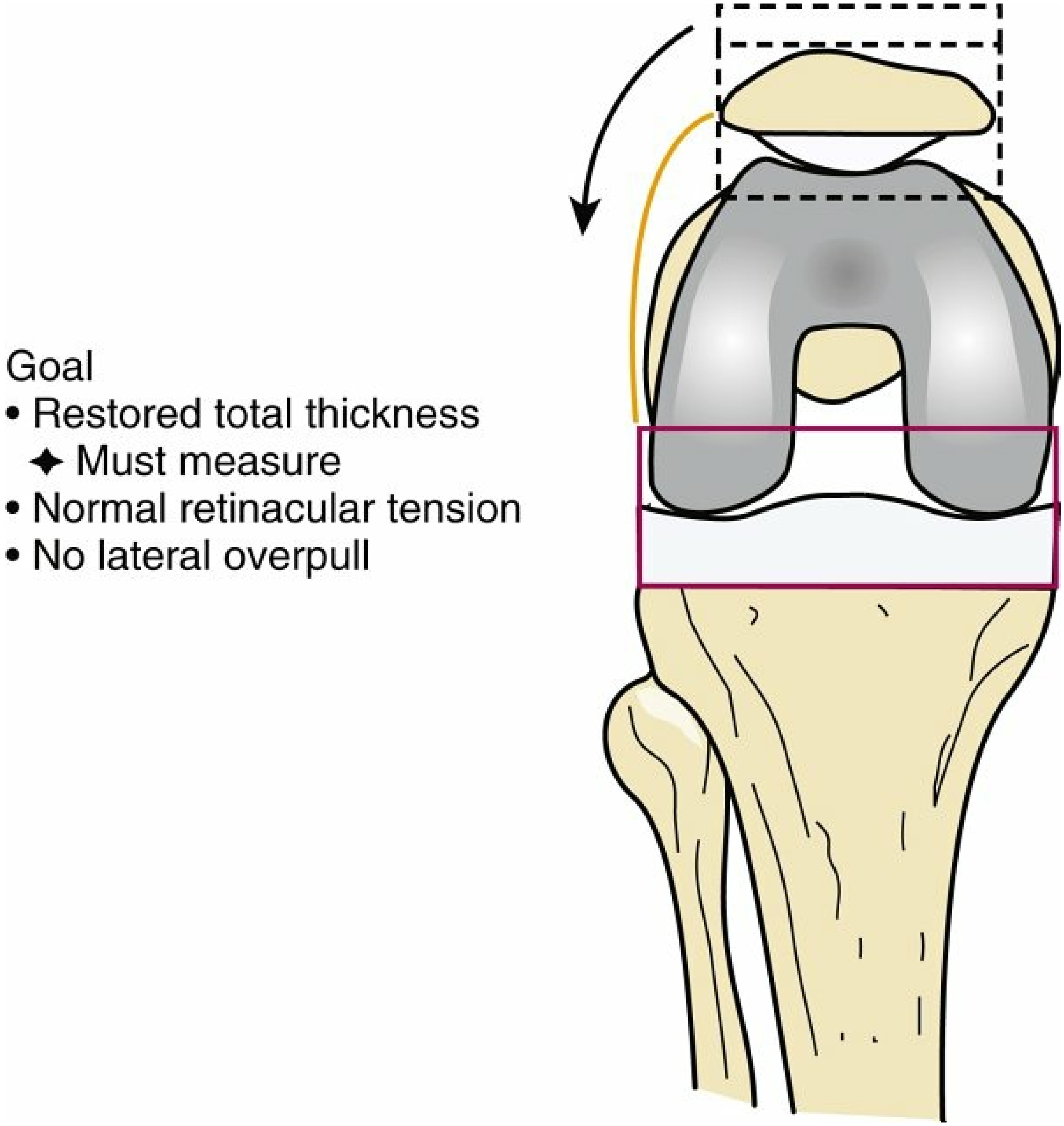


FIG. 5.101 Diagram showing patellar height. Measuring patellar height before and after patellofemoral resurfacing is important in maintaining normal retinacular tension. Increasing patellar height *(upper box, arrow)* increases retinacular tension. This increases lateral pulling forces on patella.

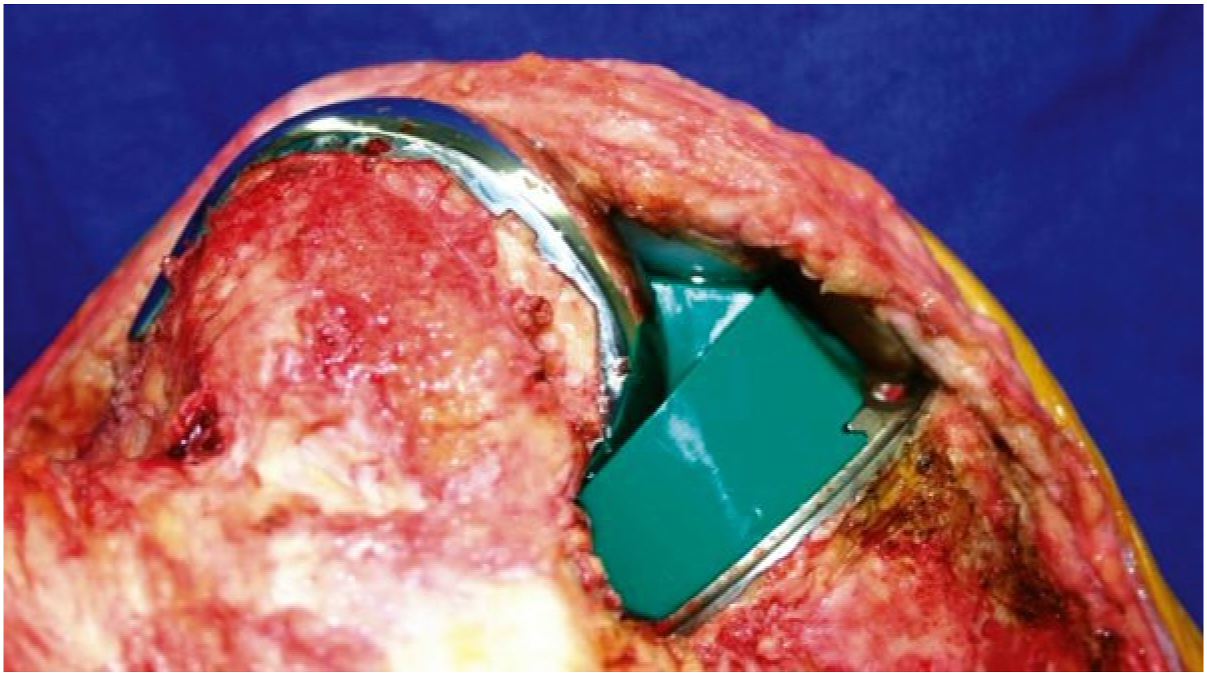


FIG. 5.102 Intraoperative photograph of TKA with patellar baja. With baja deformity, the patella component impinges upon the tibial component, limiting flexion and causing pain.

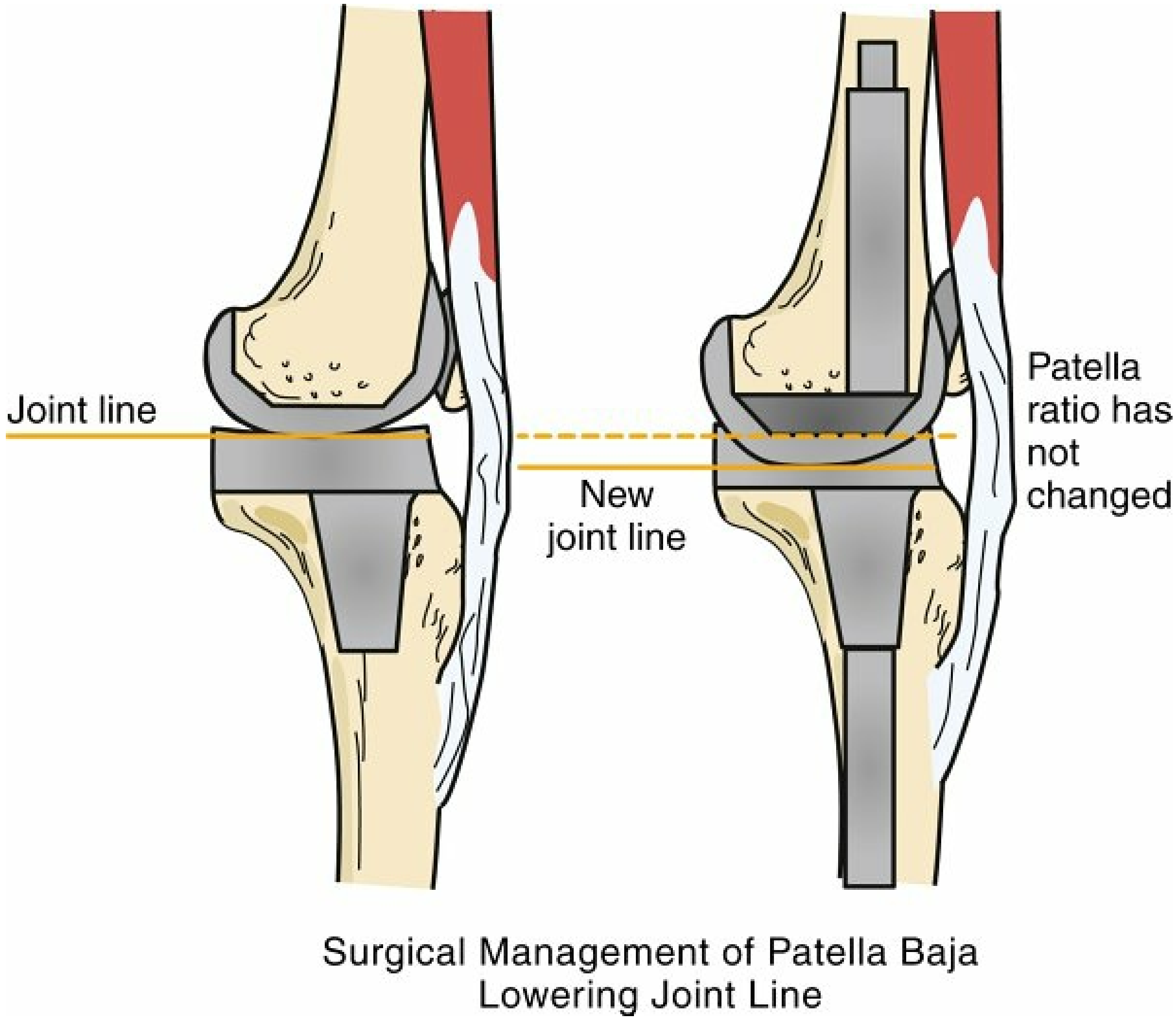


FIG. 5.103 Technique to reduce patella baja impingement in TKA. *Left,* Patella baja and starting joint line. *Right,* Lowered joint line achieved by cutting more tibial bone and adding distal femoral augmentation.

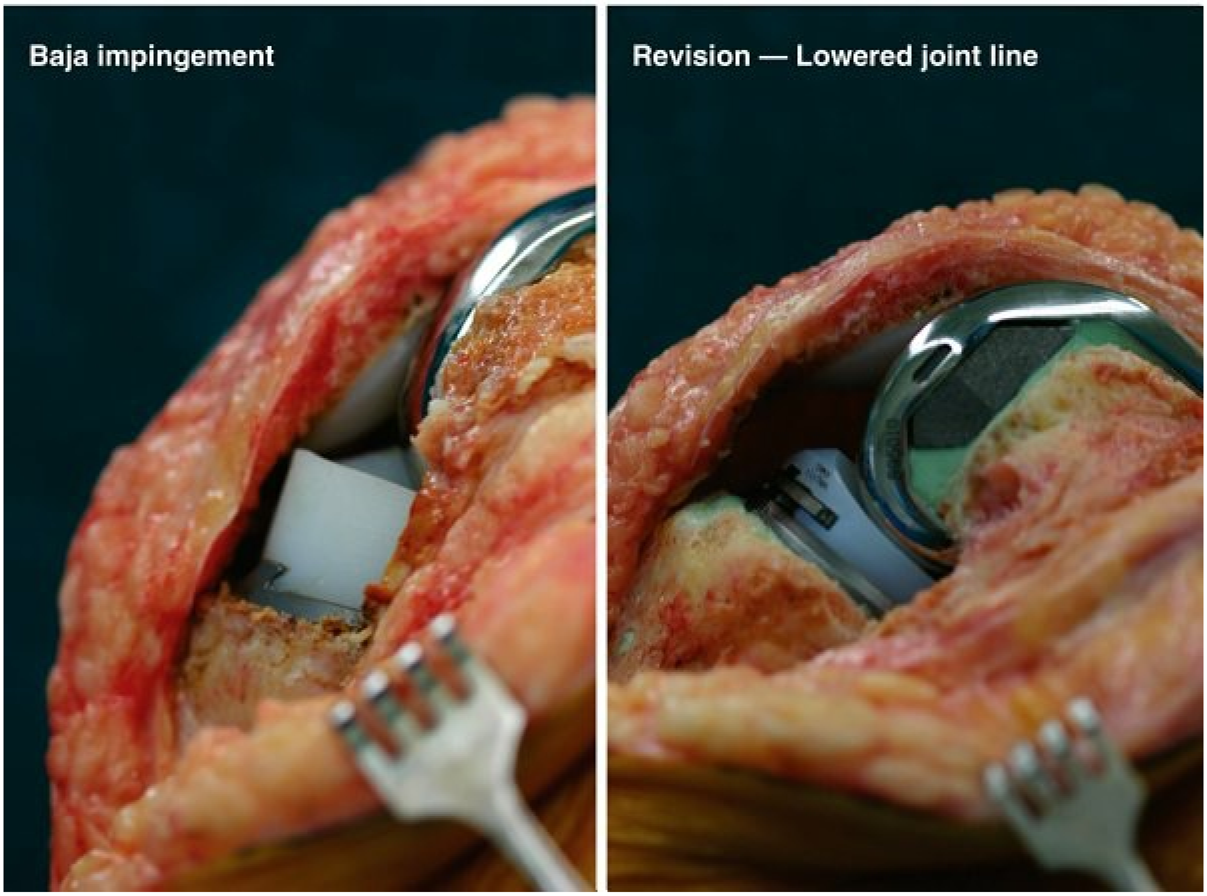


FIG. 5.104 Intraoperative demonstration of lowering joint line to correct patella baja. *Left,* Baja impingement in flexion. *Right,* Same knee after revision TKA. The joint line was lowered by making a lower tibial bone cut and reducing tibial component thickness. Note the distal femoral augmentation used to bring the femur more distal.

        - Reason: peripatellar devascularization due to lateral retinacular release
            - Disruption of lateral superior geniculate artery
- **Problems with nonresurfaced patella**
    - Anterior knee pain
        - **Incidence increases over time**.
            - Articular cartilage wears away, and there is point loading upon patellar bone.
        - Results of secondary resurfacing are variable.
            - Pain relief **not** predictable
- **Criteria for patellar nonresurfacing**
    - Noninflammatory arthritis
    - Lower activity level
    - No dysplasia or maltracking
    - No baja
- **Requirements for patellar nonresurfacing**
    - Anatomic femoral component
        - V-shaped trochlea groove to match native patella
        - Deep trochlear groove to prevent overstuffing of patellar gap

□ Circumferential denervation of patella with electrocautery

Section 17 Catastrophic Wear in TKA

Premature Failure of TKA Implant

- **Etiology is macroscopic PE failure.**
  - Problem is not a microscopic PE wear problem.
- **Patient presents with a large knee effusion that may or may not be painful.**
- **Osteolysis is present but is a secondary problem.**
- **Multiple factors are involved to create the** *perfect storm* of catastrophic wear.

Factors Involved in Catastrophic Wear

- **The factors involved in catastrophic wear of a TKA implant:**
  - PE thickness
  - Articular geometry
  - Knee kinematics
  - Surgical technique
  - PE processing
- **Polyethylene thickness**
  - Thin PE breaks.
  - To keep knee bearing contact stress below the yield strength of UHMWPE (12–20 mPA), the PE must be at least 8 mm.
  - This statement applies to "traditional" PE that is not highly cross-linked.
  - Many second-generation knee systems had PE knee inserts with a PE thickness of 4–5 mm in the thinnest region.
  - Current designs ensure that PE thickness in the thinnest areas of the insert is at least 8 mm.
- **Articular geometry (** Fig. 5.105)
  - Flat PE should be avoided.
    - Knee loads exceed yield strength of UHMWPE in flat design.
    - There is only a thin line of joint contact during loading in flat PE inserts.

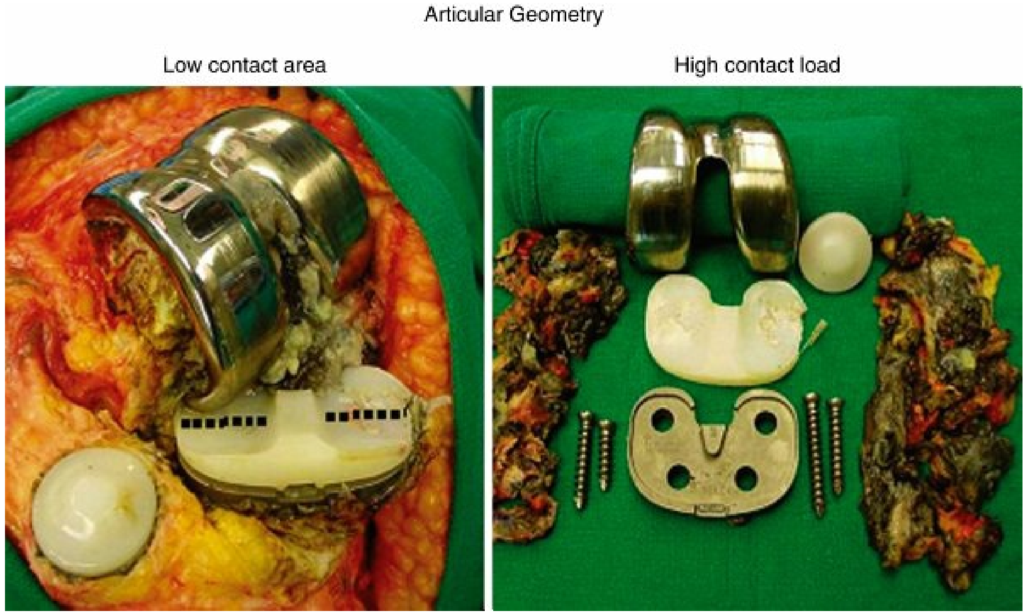


FIG. 5.105 *Left,* Intraoperative photograph of TKA with catastrophic wear after 9 years. Flat PE bearing articulating with a flat-style femoral component. This allows for only a thin line of contact *(dotted line)* during knee load. The stresses generated upon the PE are excessive, and the PE fails macroscopically. *Right,* Inflammatory debris removed at the time of revision.

- A thin line of contact results in high contact loads to PE.
- □ Goals of current tibial articular designs
  - Maximize contact area.
  - Minimize contact loads (i.e., force/area).
  - Best design is biplanar congruency (Fig. 5.106).
    - Congruent design in both coronal *and* sagittal planes

- **Knee kinematics**
  - □ Sliding wear is bad for PE.
  - □ Sliding wear occurs when the ACL is sacrificed.
    - When the ACL is removed and the PCL remains, the femur slides across the tibial PE during flexion and extension.
    - Sliding movements are most pronounced in a cruciate-retaining knee design with a flat PE insert.
    - Sliding movements are least pronounced in a posterior stabilized or anterior stabilized knee design with a congruent PE insert.
    - In laboratory testing sliding wear across the tibia created severe surface and subsurface cracking with high wear.
  - □ Current knee prosthetic systems are designed to minimize tibial sliding wear.
- **Surgical technique**
  - □ A tight flexion gap hastens sliding wear effect.
    - Stress is amplified with
      - Tight PCL

- Anterior tibial slope (Fig. 5.107)

- **Polyethylene processing**
  - Fabrication
    - Ram bar extruded PE is not good.
      - Variation in PE quality within the bar
    - Calcium stearate additive is bad.
      - Causes fusion defects in PE
    - Best PE fabrication process: direct compression molding
      - PE powder is placed into a mold, heated, and compressed, creating an implant directly from the mold.

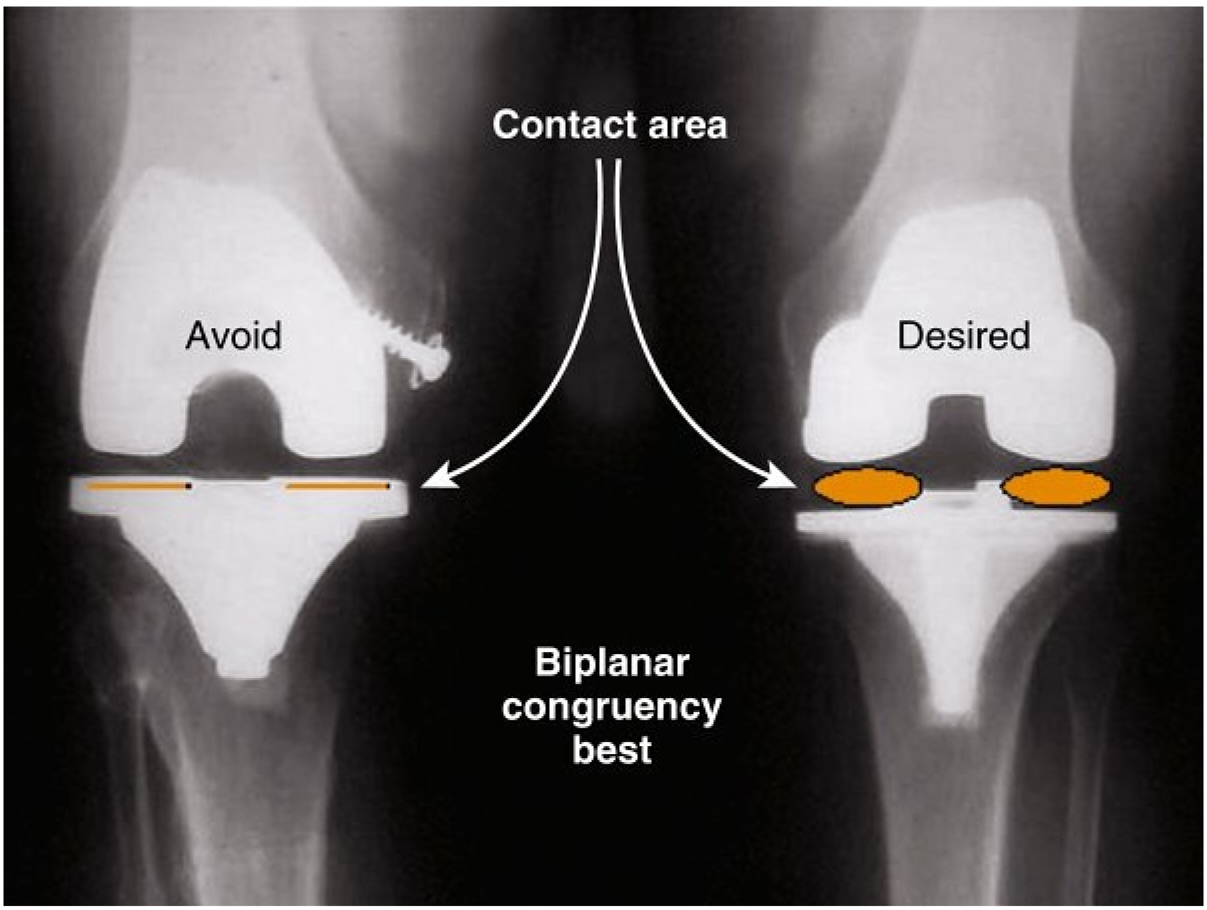


FIG. 5.106 Radiograph showing two different articular bearing designs in TKA. Left knee has a flat bearing design in the coronal plane. The contact area is a line, and contact loads are high. Right knee has a congruent design in the coronal plane. The contact area of this design is an ellipse, and the contact loads are low.

  - Sterilization
    - Irradiated PE in air is bad.
      - Oxidized PE chains
      - Reduced mechanical strength of PE
  - Machining (cutting-tool effect)
    - The cutting tool used to machine PE microscopically stretches PE chains (Fig. 5.108).

- Amorphous areas are stretched.

- The cutting-tool stretch effect is most pronounced 1–2 mm *below* the cut surface of the PE.
- The stretched PE chains are more susceptible to radiation, resulting in greater oxidation in this region.
- The clinical finding of the PE stretch/oxidation effect is the classic white band of oxidation in the subsurface of the PE (Fig. 5.109).

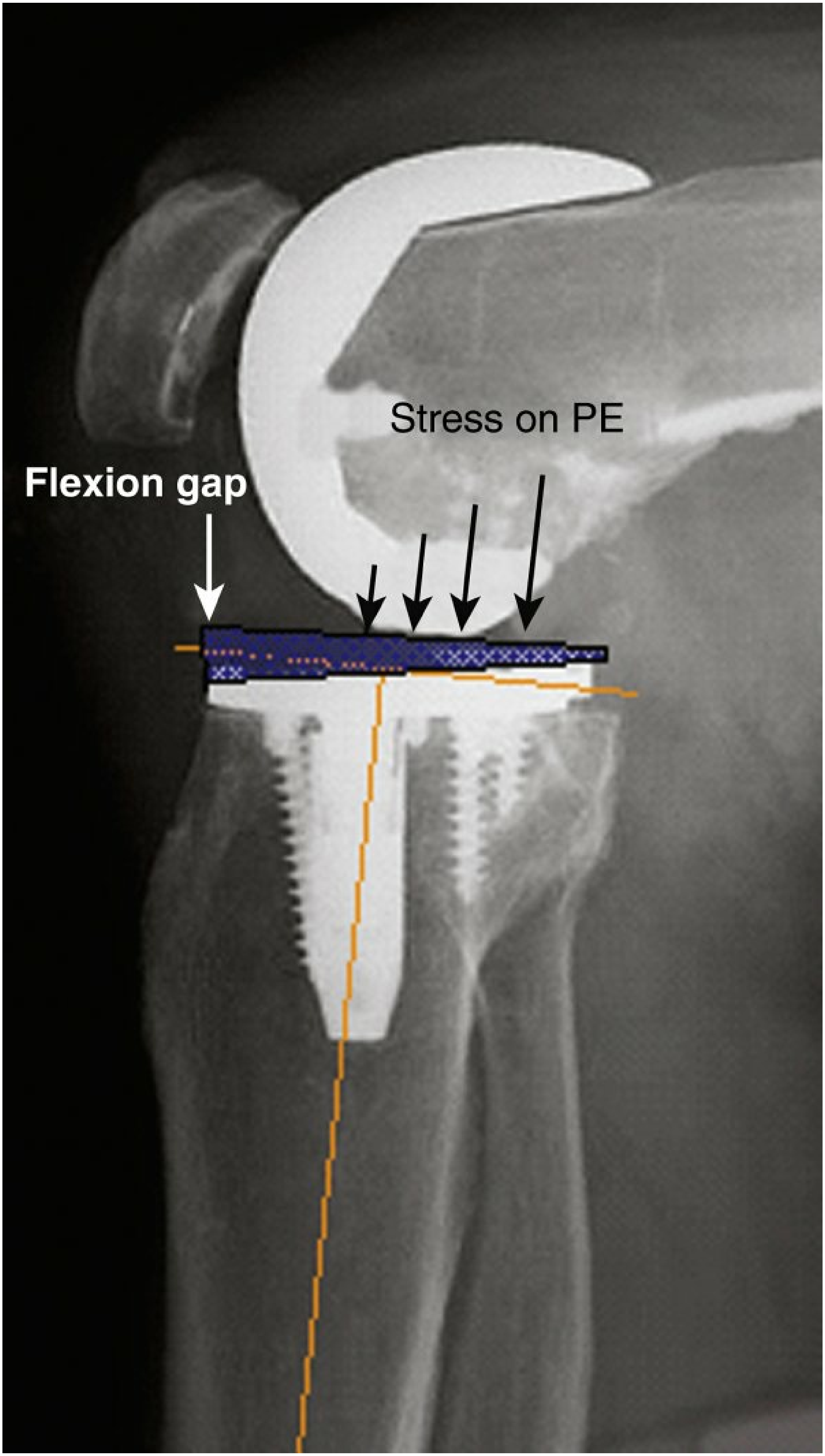

Stress on PE
Flexion gap

FIG. 5.107 Radiograph demonstrating effect of anterior slope on PE stress loads. In this radiograph, the *gold lines* define a neutral tibial slope. Compared with the neutral slope line, the tibial component is positioned with an anterior slope. As the knee flexes, the flexion gap *(triangle)* becomes smaller. Consequently, at end flexion the contact stresses on the PE become excessively high *(arrows)*.

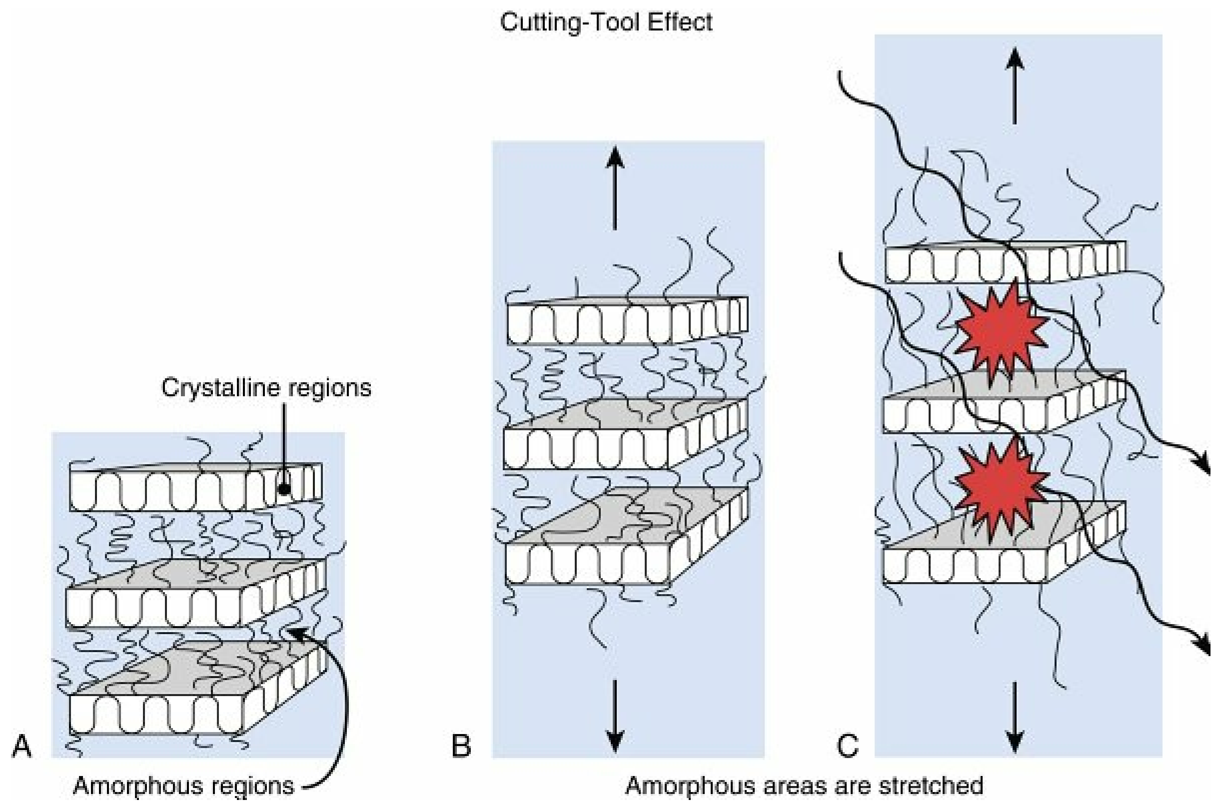


FIG. 5.108 (A) Diagram of a classic UHMWPE bearing in two forms. It consists of crystalline regions that are rigid and amorphous regions that interconnect with the crystalline regions. (B) When a cutting tool machines the PE at the surface, the cutting tool stretches the PE. The deformity occurs by stretching the PE chains in the amorphous regions. This increased strain makes these regions more susceptible to oxidation. (C) When implants are irradiated, the irradiation causes chain scission in the susceptible amorphous regions that are stretched. The machining stretch effect is most pronounced in the PE 1–2 mm below the surface of the cut PE.

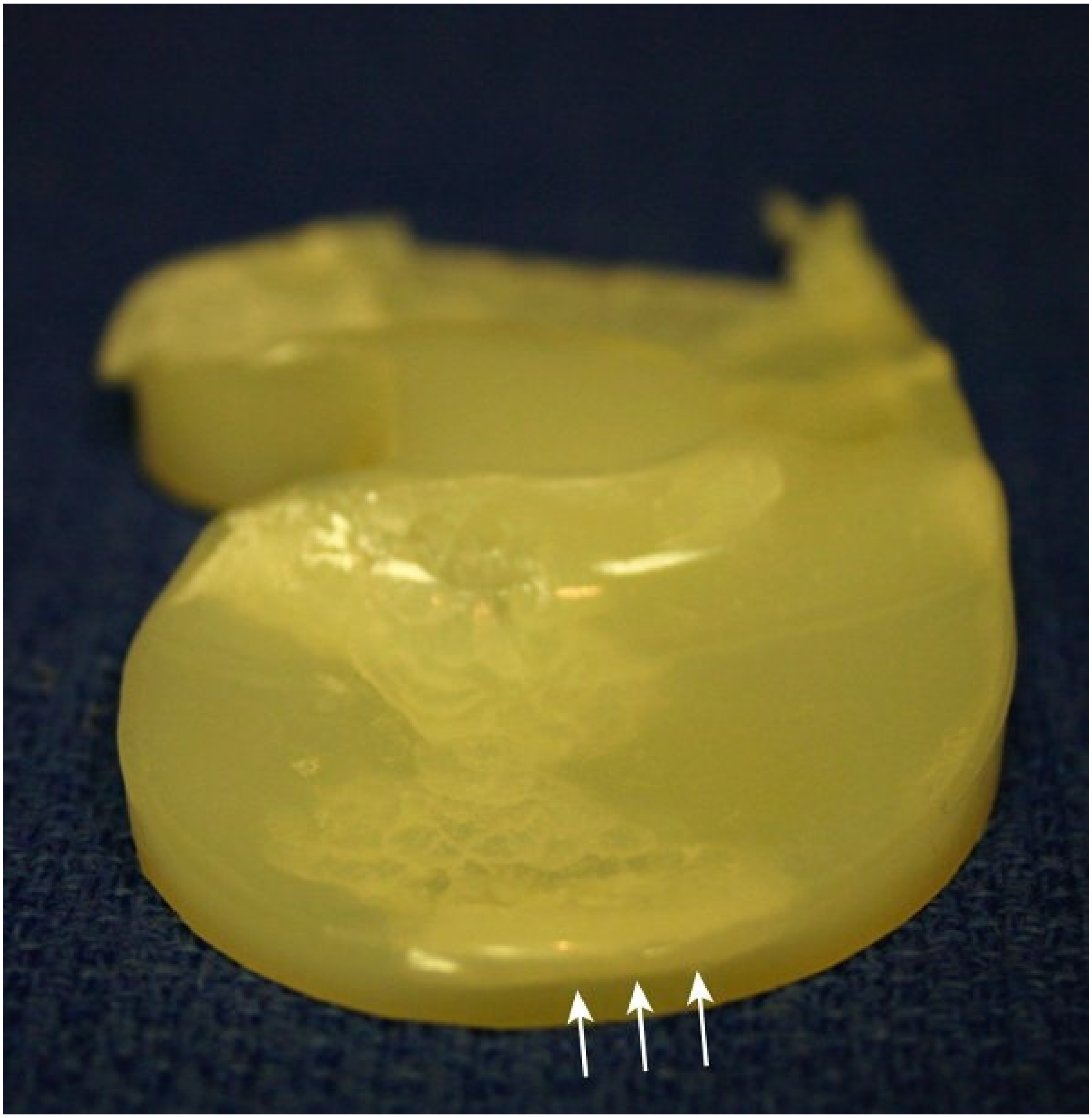


FIG. 5.109 Retrieved PE knee insert after 9 years in vivo. Note classic white band of oxidation located 1–2 mm below machined surface of PE *(arrows).* The knee was revised for catastrophic wear.

Catastrophic PE Failure

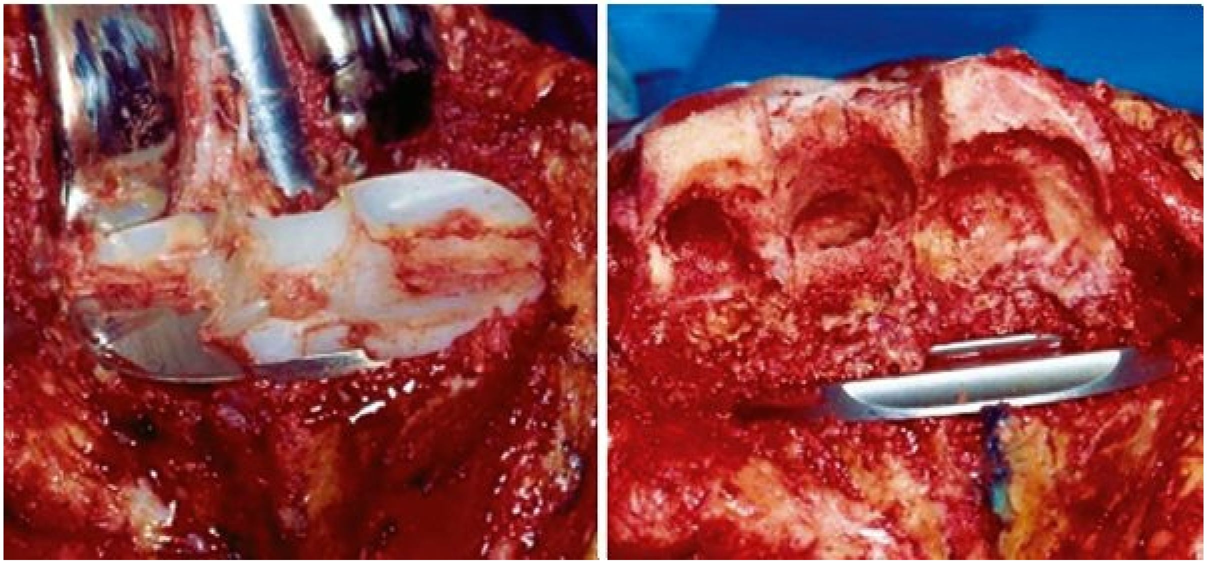


FIG. 5.110 Intraoperative photographs of 8-year-old TKA in 58-year-old man. Patient presented with painless effusion. *Left,* Complete macroscopic failure of PE bearing. *Right,* Effect of osteolysis in femur. Reconstruction required extensive bone allografts and complex revision knee system.

"Perfect Storm" Scenario for Catastrophic Wear (Fig. 5.110)

- **Metal-backed tibial baseplate with bone-conserving tibial bone cut**
  - □ Thin PE, 5 mm
- **Flat bearing design in coronal plane**
  - □ Low contact area (a line)
  - □ High contact load
- **PCL retention with flat PE insert**
  - □ High sliding wear
- **Ram bar PE with calcium stearate additive**
  - □ Fusion defects in PE
- **γ-Irradiation sterilization in air (i.e., oxygen)**
  - □ Weakening of mechanical properties of PE
- **Machined PE surface**
  - □ Cutting-tool stretch effect upon PE

Measures to Mitigate Catastrophic PE Wear

- **PE thickness at least 8 mm (for traditional PE)**
- **Congruent bearing design**
  - □ High contact area
  - □ Low contact load
- **Sliding wear on tibia minimized**
  - □ PCL substitution *or*
  - □ PCL *accepting* prosthesis

        - PCL is used as a static stabilizer only (seen with anterior stabilized knee).
- **Direct compression–molded PE bearing**
    - No machining of articular surface
- **Inert PE irradiation**
    - γ-Irradiation sterilization in an oxygen-free environment
    - Quality packaging to minimize on-the-shelf oxidation
        - Packaging must keep oxygen from diffusing back into PE through it
- **Oxygen scavengers embedded in PE material**
    - Reduces effect of in vivo oxidation
    - Vitamin E is currently the most commonly added antioxidant.

Section 18 Glenohumeral Arthritis

Introduction

- **Etiology**
  - Primary osteoarthritis (OA)
  - Postdislocation/instability (dislocation arthropathy)
  - Posttraumatic
  - Postsurgical (typically capsulorrhaphy arthropathy)
  - Rotator cuff deficiency (cuff tear arthropathy)
  - Chondrolysis
  - Rheumatoid disease
  - Osteonecrosis
  - Neuropathic arthritis (Charcot arthropathy)
  - Septic arthritis
- **Primary OA**
  - More common in women and patients older than 60 years
  - **Classic features are joint space narrowing and inferior humeral head osteophyte.**
  - First radiographic sign may be fixed posterior humeral head subluxation, which is due to tight anterior capsule and decreased external rotation.
  - **Results in classic posterior glenoid wear**
- **Dislocation arthropathy**
  - Due to articular cartilage damage from shear and impaction
  - Increased age, posterior dislocation, and associated glenoid fractures associated with higher incidence
    - A number of dislocations and surgical stabilization have not been found to be associated.
  - **The 25-year follow-up data for primary anterior dislocations have shown an incidence of 56% of radiographically evident arthrosis at final follow-up.**
- **Capsulorrhaphy arthropathy**
  - Due to overtightening of capsule and resultant abnormal translation of the humeral head on the glenoid away from the capsulorrhaphy side
  - Subscapularis transfer or imbrication is also a cause, but these procedures are rarely performed.
  - Often associated with severe posterior glenoid erosion
- **Cuff tear arthropathy (CTA)**
  - Incidence of arthropathy in patients with significant rotator cuff tears is approximately 4%–20%.
  - Due to a complex series of events that culminate in a loss of the

concavity-compression effect of the glenohumeral joint. This loss results in nutritional and biomechanical alterations that cause loss of both articular cartilage and humeral head bone density. **Superior migration of the humeral head occurs**, leading to abutment against the coracoacromial arch and further degenerative changes.

- **Chondrolysis**
  - Recently characterized entity that typically occurs after shoulder arthroscopy
  - Etiology is uncertain.
    - Associated with use of **radiofrequency energy, continuous postoperative anesthetic infusion,** low-grade infection, bioabsorbable suture anchors, and contrast medium
  - Manifests as worsening pain and gradual reduction in ROM
  - Almost complete dissolution of articular cartilage on humeral head and glenoid
    - Classically differentiated from primary OA by an absence of osteophyte formation until late in the process
  - Arthroplasty for chondrolysis improves pain and ROM but increases rate of reoperation (25%).
- **Rheumatoid disease**
  - Shoulder affected in 90% of patients with rheumatoid disease
  - Concomitant rotator cuff tears often present
  - Erosive nature of rheumatoid disease results in **central glenoid wear** (compared with posterior glenoid wear in OA) and subsequent medialization of the humeral head.
- **Osteonecrosis**
  - May be traumatic or nontraumatic
    - Traumatic causes most frequently due to three- or four-part humeral head fractures.
    - 15%–35% incidence of osteonecrosis for three-part fracture and **90% for four-part fracture**
    - Nontraumatic causes are the same as for other anatomic areas; include steroid use, alcohol use, metabolic problems, infection, HIV/AIDS, and hemoglobinopathies.
  - Staging of osteonecrosis in humeral head is similar to that in femoral head.
- **Neuropathic arthropathy**
  - Loss of trophic and protective effects of the shoulder nerve supply
  - Most commonly due to syringomyelia (syrinx), followed by leprosy. Other causes include CNS disorders and diabetes.
  - Results in severe destructive arthropathy
  - Mainstay of treatment is conservative, addressing neurosurgical intervention early.

History and Physical Examination

- **Progressively worsening shoulder pain**
- **Loss of ROM, particularly loss of external rotation due to anterior and inferior capsular ligament contraction**
- **Assessment of strength of rotator cuff musculature is important.**
  - **Subscapularis integrity should be very carefully evaluated**.
- **Significant clinical overlap with other shoulder conditions; radiographs are essential for diagnosis.**

Imaging

- **The etiology of glenohumeral arthritis can often be determined from radiographs (** Fig. 5.111).
- **True AP and axillary views** are the most important.
- **Primary OA**
  - **Posterior glenoid wear**
  - Central humeral head wear (Friar Tuck pattern)
  - Inferior humeral head osteophyte (goat's beard)
  - Posterior humeral head subluxation
- **Rheumatoid disease**
  - **Central glenoid wear**
  - Medialization of humeral head with loss of humeral head offset
  - Significant osteopenia within the humeral head and glenoid
  - Osteophytes are infrequent.
  - Periarticular erosions
- **CTA**
  - **Proximal migration of the humeral head**
    - Decreased acromiohumeral distance
  - Femoralization of proximal humerus
    - Humeral head becomes more rounded as the tuberosities erode from chronic abrasion against the coracoacromial arch.
  - Acetabularization of coracoacromial arch
    - Acromion undersurface becomes sclerotic and concave from the humeral head abrasion.
- **CT is an important adjunct,** particularly to determine glenoid morphology and remaining glenoid bone stock (Fig. 5.112).
  - Particularly useful in preoperative planning and determining need for possible glenoid augmentation
  - **Normally the glenoid is 3 degrees retroverted and the humerus is approximately 20–30 degrees retroverted.**
  - Walch classification used for primary OA (Fig. 5.113)

- **MRI is used particularly to determine rotator cuff integrity.**
    - 5%–10% incidence of full-thickness rotator cuff tears in primary OA; 25%–50% in rheumatoid disease

Treatment

- **Treatment for shoulder arthritis is similar to treatment of knee and hip arthritis. Nonoperative modalities include activity modification, NSAIDs, physical therapy focusing on capsular stretching, and corticosteroid injections.**
- **In broad terms, surgical treatment options can be separated according to whether the rotator cuff is intact.**
    - **Intact rotator cuff:** shoulder hemiarthroplasty, hemiarthroplasty with biologic glenoid resurfacing, total shoulder arthroplasty (TSA)
    - **Deficient rotator cuff:** hemiarthroplasty, reverse total shoulder arthroplasty (rTSA)
- **Contraindications to shoulder arthroplasty**
    - **Nonfunctioning deltoid** and rotator cuff deficiency
    - Intractable instability

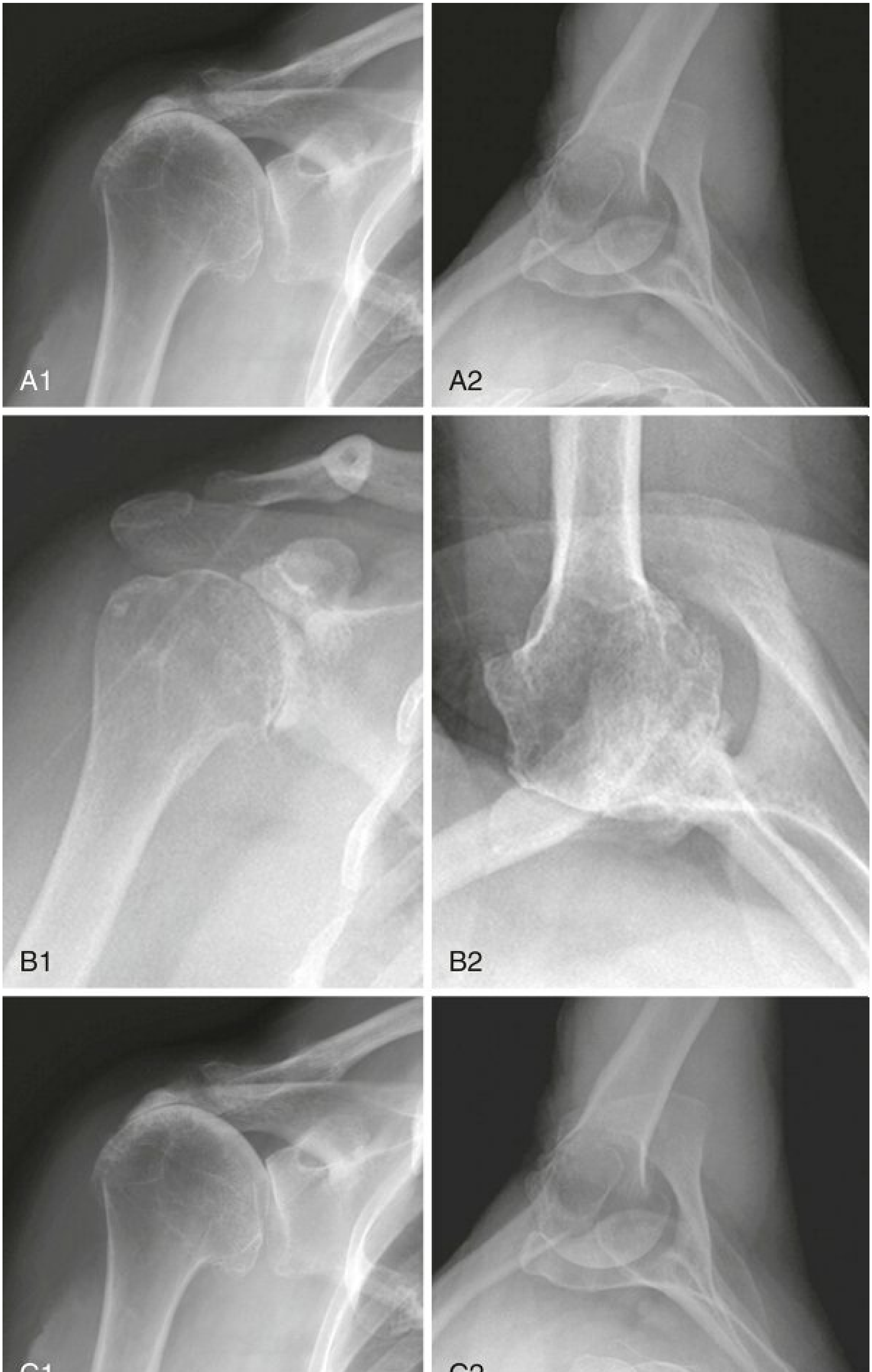


FIG. 5.111 Radiographic features of glenohumeral arthritis based on etiology (A to C).

From Gartsman GM, Edwards TB: *Shoulder arthroplasty,* Philadelphia, 2008, Saunders, Figs. 6-1 and 24-5; Miller MD, Thompson SR: *DeLee & Drez's orthopaedic sports medicine,* ed 4, Philadelphia, 2015, Saunders, Fig. 56-4; and Brower AC, Flemming DJ: *Arthritis in black and white*, ed 3, Philadelphia, 2012, Saunders, Figs. 6-1 and 6-3.

- Active infection
- Charcot arthropathy
- Poor patient compliance

- **Nonarthroplasty surgical interventions for shoulder arthritis are generally reserved for relatively young patients.**
  - Comprehensive arthroscopic management (CAM procedure) consists of glenohumeral débridement, capsular release, and removal of humeral osteophytes.
  - Shoulder arthrodesis remains an alternative for failed prosthetic reconstructions, combined rotator cuff and deltoid deficiency, paralytic disorders, brachial plexus palsies, infection, and intractable instability in a patient who is not a candidate for rTSA.
    - **Position of fusion: 30 degrees of abduction, 30 degrees of forward flexion, 30 degrees of internal rotation**

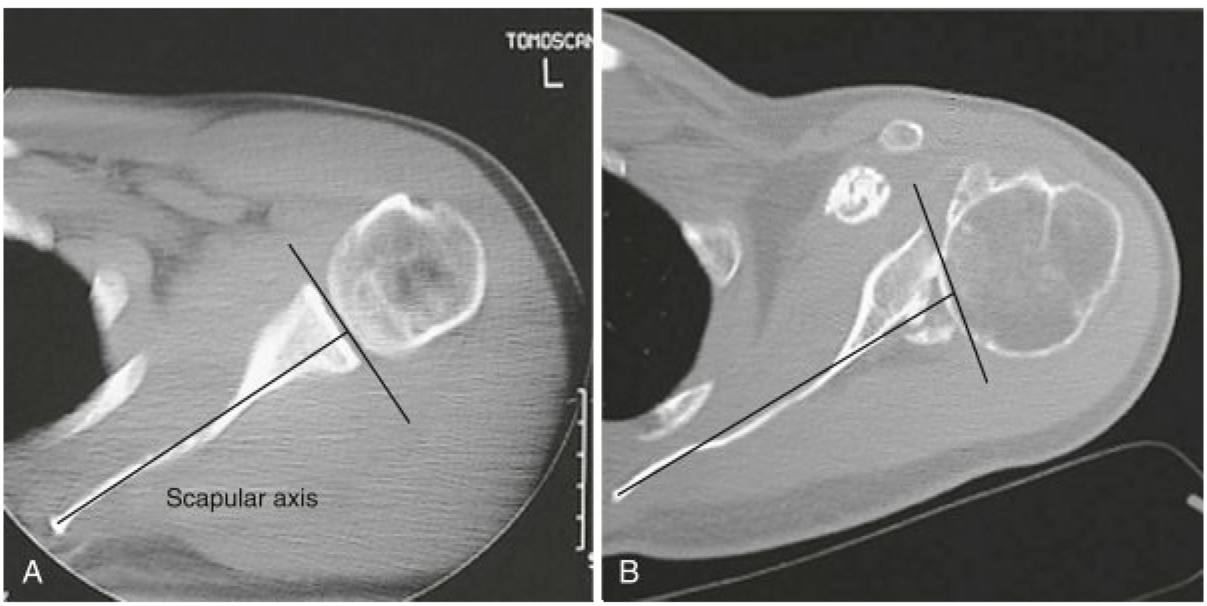


FIG. 5.112 CT scans demonstrating glenoid version. (A) Neutral glenoid version. Version is determined by drawing a line along the scapular axis and a line from anterior glenoid to posterior glenoid. Normal version is neutral to slight anteversion. (B) Glenoid retroversion in a patient with osteoarthritis. Note the significant amount of posterior glenoid wear and posterior displacement of humeral head.

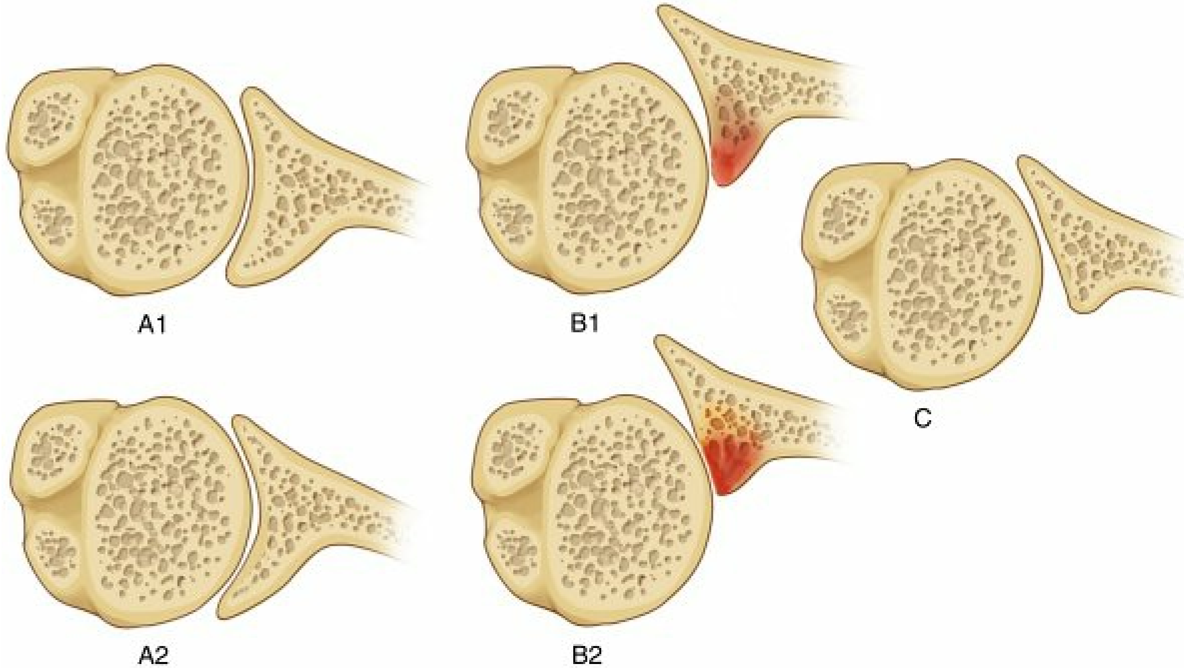


FIG. 5.113 Walch classification of glenoid morphology
From Miller MD, Thompson SR: *DeLee & Drez's orthopaedic sports medicine,* ed 4, Philadelphia, 2015, Saunders, Fig. 56-6.

Section 19 Shoulder Hemiarthroplasty

- Shoulder hemiarthroplasty involves replacement of the humeral head only.

Indications

- **Best indications:**
    - **Young patient with early-stage osteonecrosis** before degenerative changes occur on glenoid side
    - **Head-splitting proximal humerus fracture in younger patient with reconstructible tuberosities**
- **Indications are decreasing because of the better long-term results of TSA than with hemiarthroplasty as well as the advent of reverse shoulder arthroplasty for cuff tear arthropathy.**

Requirements

- **Normal glenoid bone stock and anatomy**
- **Normal or near-normal glenoid articular cartilage**

Complications

- **Late glenoid pain**
    - As glenoid surface wears, pain increases.
- **Eccentric glenoid bone loss complicating revision surgery**

Conversion From Hemiarthroplasty to TSA

- **Can be difficult, and pain relief is not always predictable.**

Hemiarthroplasty for Cuff Tear Arthropathy

- **In general, a reverse total shoulder arthroplasty (rTSA) is now preferred over shoulder** hemiarthroplasty for CTA.
    - Hemiarthroplasty possibly better if preoperative forward flexion is greater than 90 degrees.
- **However, if a hemiarthroplasty is selected, the following technical issues apply**
    - Use of anatomic head sizing and avoidance of “overstuffing” with a large head

- Overstuffing is associated with increased pain, stiffness and accelerated glenoid arthrosis.

□ Preservation of the coracoacromial ligament

- If the coracoacromial ligament is removed, the anterior acromial arch is disrupted.
- The humeral head can escape and dislocate anterosuperiorly.

Section 20 Total Shoulder Arthroplasty

Introduction

- **Involves glenoid resurfacing and humeral head replacement (** Fig. 5.114)
- **Indicated for shoulder arthritis with intact and functional rotator cuff**
- **Preferred procedure for shoulder OA** and inflammatory arthritis
  - Better pain relief than with hemiarthroplasty
  - Results of hemiarthroplasty conversion to TSA show variable satisfaction
  - Problems with hemiarthroplasty conversion to TSA
    - Severe glenoid bone loss; results in compromised or difficult glenoid component fixation
    - Unpredictable pain relief
    - Unpredictable final shoulder ROM

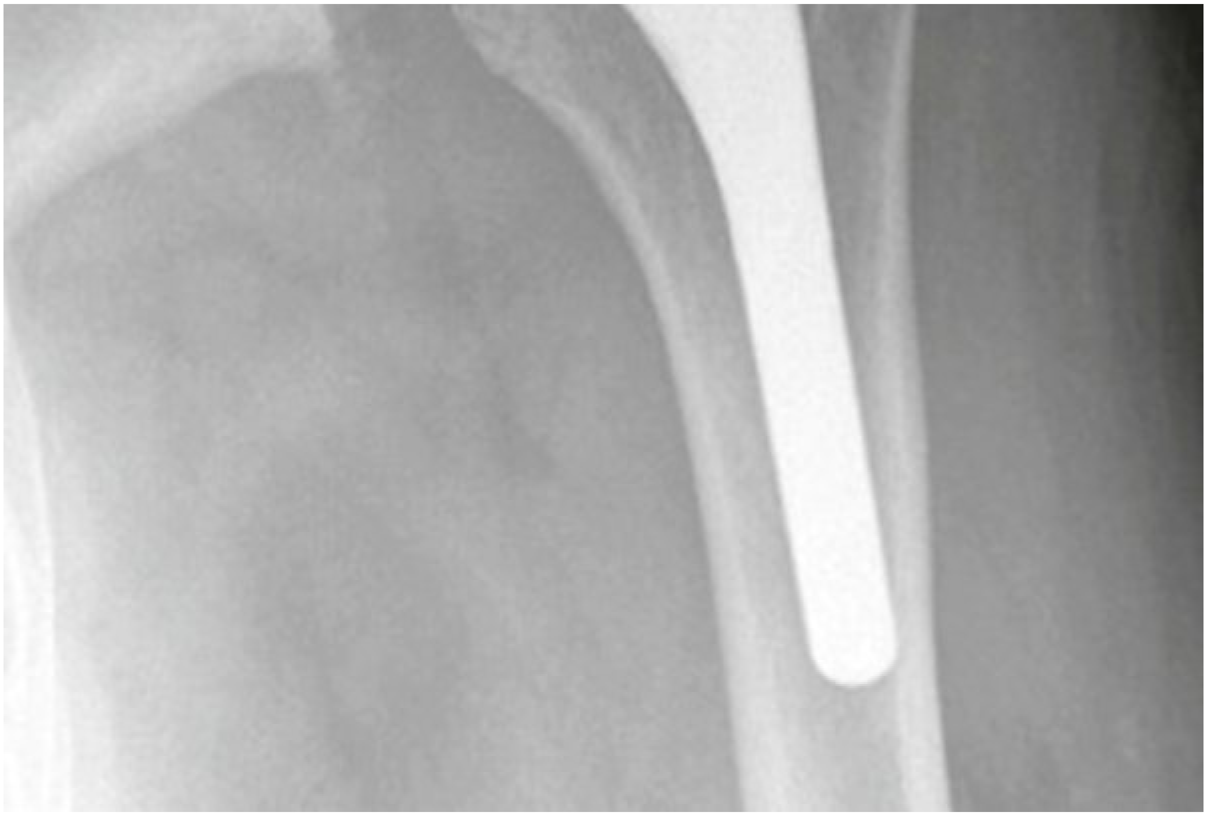


FIG. 5.114 AP radiograph of total shoulder arthroplasty for primary osteoarthritis. (From Miller MD, Thompson SR: *DeLee & Drez's orthopaedic sports medicine,* ed 4, Philadelphia, 2015, Saunders, Fig. 56-10.)

Requirements

- **Rotator cuff must be intact and functional**.
- **Isolated reparable supraspinatus tear without retraction is acceptable condition for which to proceed with TSA, although later trend is to consider reverse replacement for this problem.**
  - **Incidence of full-thickness rotator cuff tears in patients undergoing TSA is 5%–10%**.

Component Positioning

- **Humeral stem is positioned in retroversion.**
  - Accepted range: 25–45 degrees of retroversion
  - Excessive humeral bone removal during humeral neck osteotomy places the rotator cuff at risk of injury.
  - Less humeral retroversion required if glenoid must be retroverted.
- **Glenoid is positioned in neutral**.
  - Glenoid retroversion should be avoided.
  - Eccentric posterior glenoid wear management
    - From 0 to 15 degrees of retroversion can be managed with eccentric glenoid reaming.

- Retroversion of greater than 15 degrees may require posterior glenoid bone grafting or augmented glenoid component. Alternatively, a reverse shoulder arthroplasty may be used.

Rehabilitation

- **Excessive passive external rotation exercises should be avoided**.
- **Excessive passive external rotation results in tear and pull-off of subscapularis tendon from lesser tuberosity.**
  - Classically caused by patient pushing self up from a low chair
  - Manifests as weakness in belly-press test, inability to perform lift-off test, and higher amount of passive external rotation than in the uninvolved shoulder
  - Results in anterior shoulder instability, the most common instability pattern after TSA
  - Diagnosis is with ultrasound or anterior subluxation on x-ray.
  - Treatment of subscapularis pull-off is early surgical exploration and repair of the detached subscapularis tendon. In some cases, repair must be augmented with transfer of pectoralis major tendon.

Complications

- **Implant loosening**
  - Primarily due to glenoid-sided failure
  - Humeral-sided loosening: RA, AVN, infection
- **Arthrofibrosis**
- **Anterior instability, subscapularis failure**
- **Axillary, musculocutaneous nerve injury**
- **Infection**
  - Associated with male gender and young patient age
  - *Propionibacterium acnes* and *Staphylococcus* spp. are the most common pathogens.

Section 21 Reverse Total Shoulder Arthroplasty

Introduction

- **Involves insertion of the following implants (** Fig. 5.115)
  - A porous-coated, cementless baseplate is secured to the glenoid with a central screw and multiple peripheral screws.
  - A glenosphere (i.e., ball) is assembled to baseplate.
  - A humeral stem is inserted into canal (cemented or cementless technique).
  - A humeral PE socket is assembled to the humeral stem.
- **Resolves problem of superior migration of humeral head with CTA**
  - As deltoid contracts, the humerus rotates around glenosphere. **Elevation power is provided by the deltoid.**
    - Translational force of the deltoid is converted to rotational motion.
  - Deltoid power and efficiency are improved by increasing humeral offset via medialization of the center of rotation.
    - Longer fulcrum

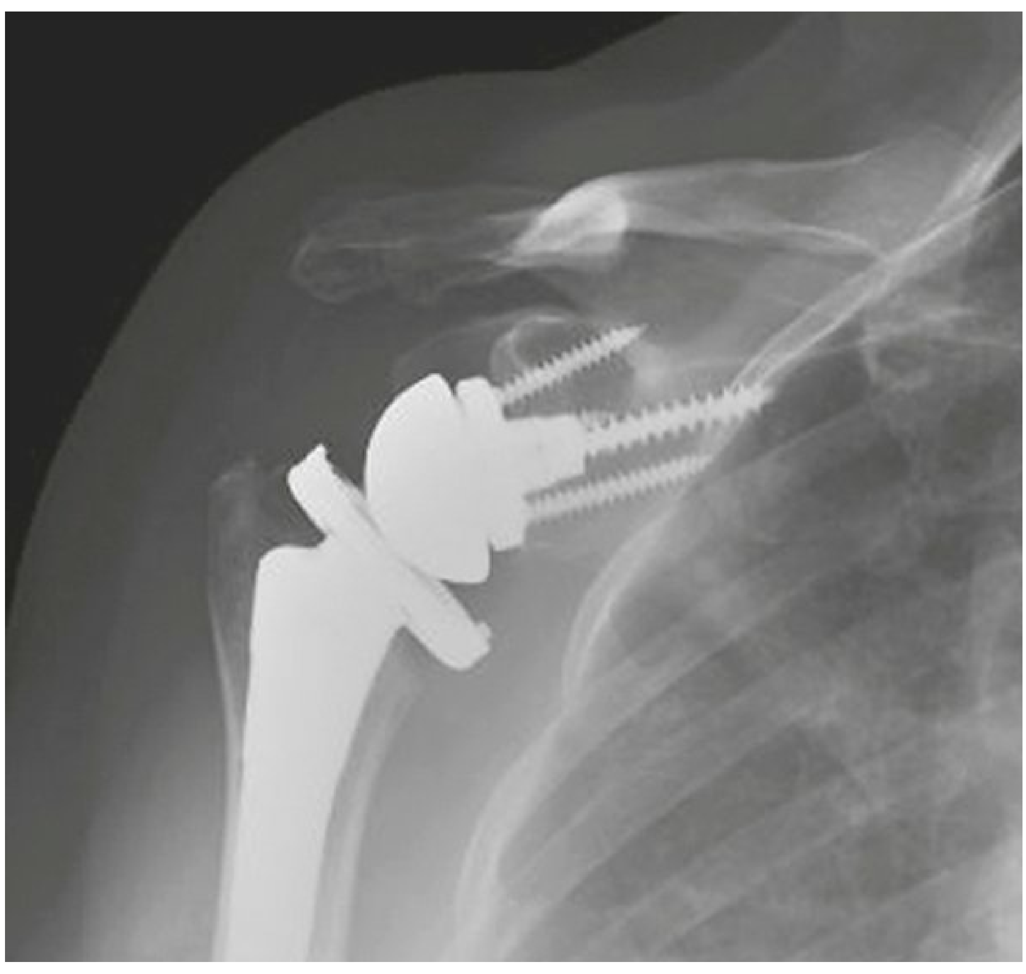


FIG. 5.115 Radiograph of a reverse total shoulder arthroplasty (rTSA). In the rTSA system, a porous-coated glenoid baseplate is inserted into the glenoid and secured with a central screw and peripheral screws. A glenosphere (i.e., ball) is attached to the baseplate. A humeral stem is placed into the humerus. A PE cup is then assembled to the proximal humeral stem via a Morse taper junction. Note inferior tilt of glenoid component, which aids in deltoid tensioning.

- **An rTSA (when indicated) is best treatment for CTA.**
    - Better functional ROM than with hemiarthroplasty
    - Better pain relief than with hemiarthroplasty

Requirements

- **Intact axillary nerve**
- **Full function of the deltoid muscle**
- **Adequate glenoid bone stock**
    - Soft tissue tension is adjusted by varying the length of the glenosphere and humeral socket.
    - Stability is provided by
        - Deltoid tensioning
            - Adjustment of humeral offset
            - Glenoid tilt
        - Head diameter
            - Larger diameter is more stable.
        - Component positioning

Component Positioning

- **Glenosphere must be positioned as low as possible** on the glenoid.
    - Minimizes risk for scapular notching by humeral socket
- **Glenoid baseplate (and glenosphere) should be tilted inferiorly 10–15 degrees.**
    - Is key to enhancing deltoid tensioning and thus providing implant stability.
- **Humeral stem is positioned in retroversion.**
    - 25–40 degrees of retroversion preferred

Complications

- **Dislocation of an rTSA most commonly is anterior.**
  - Mechanism of dislocation is shoulder hyperextension and external rotation. In this position, the humeral socket levers posteriorly and dislocates.
  - Classically results from pushing up on chair armrest
  - Occurs in approximately 9% of patients; decreased rates seen with modern designs
  - With Grammont (medialized) prosthesis, subscapularis insufficiency is a risk factor for instability. With lateralized prostheses, subscapularis repair is no longer considered necessary.
  - Lesser risk factors include proximal humeral nonunion, proximal humeral bone loss, prior failed arthroplasty, and preoperative fixed glenohumeral dislocation.
- **Scapular notching (** Fig. 5.116)
  - Historically extremely common; rates are lower with more modern implants

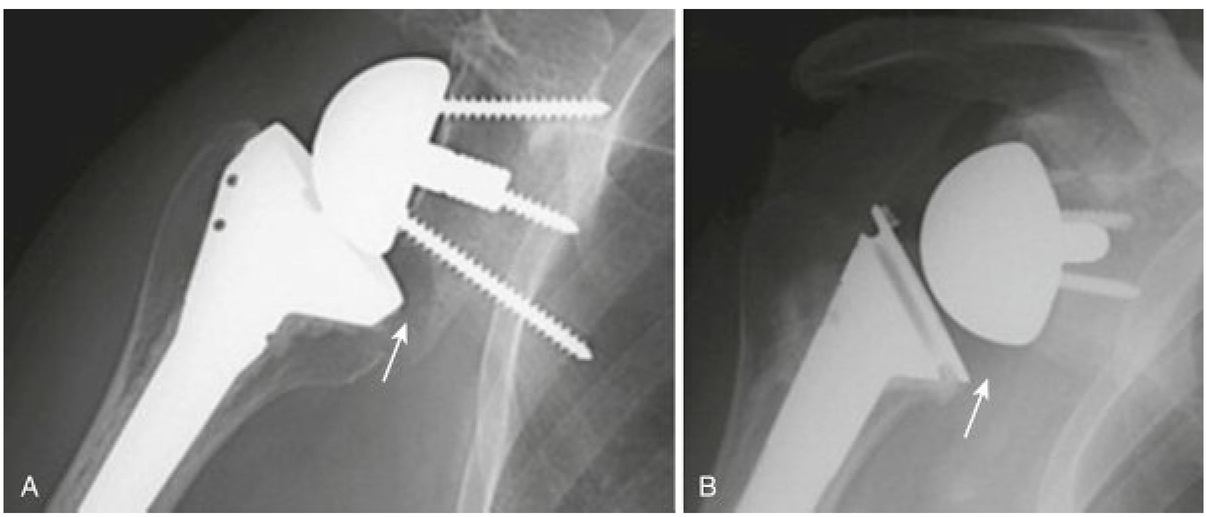


FIG. 5.116 Scapular notching in reverse shoulder arthroplasty. (A) A typical varus implant without scapular notching *(arrow)*. (B) A typical valgus implant showing scapular notching *(arrow)*.
From Jarrett CD et al: Reverse shoulder arthroplasty, *Orthop Clin North Am* 44:389–408, 2013, Fig. 8.

    - Incidence between 50% and 90% traditionally
  - Results from repeated contact between inferior scapular neck and humeral component (or humerus), more commonly seen with medialized (Grammont-style) prostheses
  - Clinical presentation is variable.
    - Pain
    - Fracture
    - Levering and dislocation

- Notching may be minimized by
  - Positioning of glenoid baseplate (and glenosphere) as low (inferior) as possible on glenoid bone
  - Use of lateralized implant design
  - Optimization of glenosphere head length, which pushes humeral socket away from scapula
  - Adequate glenosphere inferior tilt
  - Larger glenosphere size.

- **Fractures**
  - Scapular spine, acromion, humeral shaft
- **Infection**
  - Associated with prior failed arthroplasty and age younger than 65
  - To date, diabetes, smoking, obesity, and inflammatory arthropathy have *not* been associated with increased rates of infection.

Section 22 Infection in Shoulder Arthroplasty

Introduction

- **Periprosthetic shoulder infections are unlike infections in hip and knee arthroplasty.**
- **Clinical presentation and diagnostic evaluation are different.**

Common Organisms

- ***P. acnes*** and coagulase-negative *Staphylococcus* are increasingly recognized and common causes of shoulder arthroplasty infection.
- *Staphylococcus aureus* still the most common
- **Incision of dermal sebaceous glands may be a source of** *P. acnes.*
    - Colonization in males more common than in females

History and Physical Examination

- **Pain is the most common complaint.**
- **A persistent draining sinus is second most common.**
- **Stiffness, erythema, effusion, fever, chills, and night sweats are other common presentations.**
- **Risk factors for infection are** *unlike* those for THA and TKA.
    - Postoperative hematoma, young age, male gender, arthroplasty for trauma, and revision surgery have been the only identified risk factors.

Investigations

- **Radiographs are essential to exclude other causes.**
    - Signs of infection include effusion, endosteal scalloping, periprosthetic radiolucent lines, and bony resorption.
- **Bone scans should not be routinely obtained; their efficacy has not been demonstrated.**
- **Serology**
    - ESR and CRP values have not demonstrated sufficient sensitivity or specificity to suggest periprosthetic shoulder infection.
- **Joint aspiration**
    - No universal guidelines on when to aspirate a suspected infected shoulder arthroplasty
    - Synovial leukocyte counts above 500 cells/μL have been found to be

suggestive, but this level is not universally accepted.
  - Newer investigations have suggested a role for synovial α-defensin measurements, but the procedure is investigational.
  - Synovial fluid culture is critical.
- **There is an increasing role for arthroscopy when aforementioned investigations are inconclusive.**

Microbiology

- **Synovial tissue cultures are the gold standard for diagnosis of infection.**
- **Cultures should be held for 14 to 28 days to detect *P. acnes***. Cultures should be on aerobic, anaerobic, and broth media.
- **At surgery, it has been recommended that at least four different specimens be obtained.**
- **No current association between intraoperative frozen-section findings (e.g., >5 neutrophils per high power field) and diagnosis of periprosthetic shoulder infection**

Management

- **Surgical options**
  - Antibiotic suppression, irrigation and débridement with component retention, resection arthroplasty, one-stage revision, two-stage revision, fusion, and amputation
  - Acute infections may respond to incision and drainage.
  - Chronic infections are optimally treated with two-stage (component extraction with antibiotic spacer placement, followed by delayed reimplantation) revision surgery. Some later studies demonstrate efficacy with single-stage revision.
- **Antibiotics**
  - Generally guided by culture results and consultation with infectious disease physicians

Testable Concepts

Section 1 Evaluation of the Adult Patient with Hip Pain

- Impingement test result is positive when pain is reproduced by flexion of the hip to 90 degrees followed by adduction and internal rotation.
- Radiographs are the standard imaging modality.
- MRI may be indicated for suspected osteonecrosis, labral pathology in the absence of significant arthritis, gluteus medius tears, and possible stress or insufficiency fractures.

Section 2 Structural Hip Disorders in the Adult Hip

- Dysplasia typically involves a shallow acetabulum with lateral and anterior uncoverage of the femoral head.
- Surgical correction of the dysplastic acetabulum is usually done with a periacetabular osteotomy, which keeps the posterior column intact.
- The majority of patients with femoroacetabular impingement have both cam and pincer impingement.
- Surgical treatment of FAI varies according to pathoanatomy; labral repair or reconstruction is preferable to labral resection when possible.
- Total hip arthroplasty is the treatment of choice for both dysplasia and FAI when significant DJD is present.

Section 3 Osteonecrosis of the Hip

- End-stage result of vascular occlusion of the juxtaarticular sinusoids adjacent to the femoral head.
- Staging is performed with the modified Ficat system.
- Joint-preserving strategies such as core decompression and free vascularized fibular grafting should be reserved for precollapse disease.
- Transient osteoporosis of the hip shows diffuse signal change on MRI and is treated nonoperatively.

Section 4 Treatment of Hip Arthritis

- Conservative management includes activity modification, weight loss, NSAIDs, and intraarticular steroid injections; evidence does not support routine use of glucosamine sulfate.
- Arthroscopy has limited indications in patients with arthritis; preoperative joint

space narrowing is negative predictor of good clinical outcome.

- Hip arthrodesis is largely a historic procedure as THA technology has improved.
- Subsequent conversion of hip arthrodesis to THA has high complication rate, and function depends on integrity of abductors.
- Hemiarthroplasty is not routinely used for arthritis and is relegated to fracture treatment in an elderly, low-demand patient.

Section 5Total Hip Arthroplasty

- Different surgical approaches have different advantages and disadvantages.
- The posterior approach remains the most popular, although it has the highest rate of dislocation.
- The direct anterior approach has seen increased popularity, although has a higher rate of femoral problems, including fracture and loosening.
- Cementless fixation is preferred for the acetabular component; both cement fixation and cementless fixation may give durable results for the femoral component.
- Bone ingrowth requires live host bone, an appropriate ingrowth surface on the implant, and initial rigid fixation; motion of the prosthesis within the bone will lead to fibrous fixation or encapsulation.
- Hydroxyapatite is an osteoconductive surface coating that may shorten the time to biologic fixation.
- Femoral stress shielding leads to loss of proximal bone density and results from modulus mismatch between stem and femoral bone.
- Femoral stem breakage occurs from cantilever bending.

Section 6Revision THA

- Start-up pain is the most common initial presentation of implant loosening.
- Segmental acetabular bone deficiency is loss of main bony support for acetabular cup.
- Hemispheric porous cup with multiple screw fixation is most common solution and is used in the majority of acetabular revision cases.
- Modular porous metal constructs are increasingly being used for cases of severe bone loss; augments and cup-cage constructs can help achieve stability and porous bone ingrowth for a durable long-term solution.
- Custom triflange cups may be used in cases with severe bone loss in which defect-matching techniques (such as modular metal constructs) are limited.
- Screws placed into the anterior-superior quadrant (the so-called zone of death) risk laceration to the external iliac artery and veins, which can be fatal.
- Pelvic discontinuity, which occurs when the superior aspect of the pelvis is separated from the inferior pelvis, is a challenging problem.

- Most femoral revisions are performed with a cementless diaphysis-engaging implant; tapered fluted modular titanium stems have become the mainstay for treatment and are more commonly used than extensively porous-coated cylindrical stems.

Section 7Articular Bearings and Corrosion in THA

- Irradiation of PE creates free radicals, which result in cross-linking.
- Highly cross-linked polyethylene is associated with less wear and osteolysis but has the disadvantage of reduced mechanical properties.
- Submicron-sized PE particles are phagocytized by macrophages, leading to osteolysis; bone resorption is mediated via RANKL attachment to its receptor on the osteoclast.
- Volumetric wear is the main determinant of the number of PE particles produced.
- With HCLPE, wear rates tend to remain below the osteolytic threshold even with large femoral heads (36 mm or greater).
- Treatment of PE wear involves head and liner exchange when the implants are well fixed and well positioned; dislocation is the most common postoperative complication.
- Metal-on-metal bearings are rarely used because of increased rates of failure; reaction to metal debris can lead to adverse local soft tissue reactions, including pseudotumors; implant malposition, including a vertical acetabular component position, has been associated with higher rates of failure.
- Metal debris from metal-on-metal bearings is processed by the T lymphocyte; ALVAL is the common histologic finding.
- Standard evaluation for a painful MOM THA includes serum cobalt and chromium levels as well as MRI with MARS.
- Ceramic-on-ceramic bearings have been associated with squeaking.
- Dual-mobility components increase the impingement-free range of motion as well as the jump distance, which should decrease the rate of dislocation.
- Trunnion corrosion (trunnionosis) results from fretting corrosion and metal ion release at the modular junction between the femoral head and stem; patients may experience adverse local soft tissue reactions and pseudotumors; treatment involves revision of the metal femoral head to a ceramic head with a titanium sleeve adaptor.

Section 8Periprosthetic THA Fracture

- Intraoperative fracture is more common with cementless implants; a calcar crack may be treated with cerclage wires if stem remains stable.
- Early postoperative fracture is often a result of unrecognized intraoperative fracture.

- Vancouver classification is used to guide treatment.
- A loose stem requires revision to a new femoral component; if the stem remains well fixed, ORIF of the fracture is performed.

Section 9THA—Miscellaneous

- Risk for sciatic nerve palsy increases with lengthening of the leg by more than 3–5 cm.
- A nerve palsy that develops postoperatively may be due to hematoma, for which emergency evacuation is required.
- There is no effective treatment for heterotopic ossification in the early postoperative period once the process has started; resection may be performed later, once the process is mature or stable on serial radiographs.
- Iliopsoas impingement is a cause of groin pain following THA and may be confirmed with an injection.

Section 10 THA—Joint Stability

- Primary arc of hip motion must be centered within patient's functional range to avoid impingement.
- Best stability is achieved by maximizing head/neck ratio; large femoral heads have a greater jump distance.
- **Abductor complex is key to hip stability.**
- Patients with fixed spinopelvic alignment during movement from standing to sitting position are at increased risk for instability.
- The treatment of instability involves identifying the reason for dislocation; malpositioned implants should always be revised; constrained liners should be reserved as a last resort for patients with soft tissue dysfunction.

Section 11 Knee Arthritis Assessment

- Best view to image arthritis in midflexion (which is common) is weight-bearing knee at 45-degree angle, imaged posterior-to-anterior with x-ray plate positioned parallel to tibia.
- This is the best view when standing films do not reveal notable narrowing and the patient has significant pain.
- Varus thrust: knee pushes outward with stance phase, overloads medial compartment, and increases cartilage degeneration in medial compartment (also called adductor moment of force, as tibia is in adduction relative to femur).

Section 12 Knee Arthritis Treatment

- Based on AAOS's *Treatment of Osteoarthritis of the Knee: Evidence-Based Guideline*, 2nd edition; only five recommended treatment modalities (before knee arthroplasty) meet consensus guidelines: patient-guided self-management programs focusing on knee strength, balance and agility, weight loss (when BMI ≥ 25), NSAIDs, tramadol therapy, and valgus osteotomy for medial compartment disease.
- Contraindications to UKA: inflammatory arthritis, significant fixed coronal plane deformity (deformity must be correctable on clinical exam), previous meniscectomy in opposite compartment, ACL deficiency, flexion contracture greater than 10 degrees, and tricompartmental arthritis.
- TKA (**not** patellofemoral arthroplasty) is recommended choice in patients older than 50 years for isolated patellofemoral arthritis.

Section 13 Total Knee Arthroplasty

- To correct varus deformity, a medial compartment release is needed.
    - Superficial MCL is the key structure for medial compartment release.
    - Posterior oblique portion is tight in extension—release needed for medial extension tightness
    - Anterior portion is tight in flexion—release needed for medial flexion tightness
- To correct valgus deformity, a lateral compartment release is needed.
    - Iliotibial band and popliteus are the key structures for lateral compartment release
    - Iliotibial band is tight in extension—release needed for lateral extension tightness.
    - Popliteus is tight in flexion—release needed for lateral flexion tightness.
- McPherson rule for balancing the gaps (review table for gap scenarios)
    - Symmetric gap problem—tibia adjusted first
    - Asymmetric gap problem—femur adjusted first
- Perioperative nerve blocks
    - Femoral nerve block—**motor** and sensory block—knee will buckle with walking
    - Adductor nerve block—sensory block only—knee will not buckle with walking
- The deformity most likely to cause peroneal nerve palsy in TKA is a combined valgus flexion deformity.
    - When nerve palsy is identified postoperatively, the first treatment is to remove compressive wraps and flex the knee.
- With a lateral retinacular release in TKA, the artery at risk for transection is the lateral superior genicular artery; increases risk for osteonecrosis of the patella.
- For arthrofibrosis following primary TKA, manipulation of the knee should be

performed between 4 and 12 weeks.

- Osteolysis in TKA manifests later in life of implant (7–15 years); radiographs show round lytic lesions behind implant (most common site is behind posterior femoral condyle).
- Periprosthetic femur fracture treatment
    - If implants are mechanically loose: revision TKA and ORIF of fracture
    - If implants are mechanically stable: ORIF with premolded supracondylar plate (submuscular plating lowers nonunion rate)
    - Fracture resection with endoprosthetic hinged TKA is an acceptable alternative when the fracture is highly comminuted and the patient is elderly and/or the bone is significantly osteoporotic.
- Periprosthetic joint infection: a draining sinus is an **absolute** diagnosis of a chronic PJI.
- Medial gastrocnemius rotational flap is the workhorse for deficiencies about the knee—used to cover medial and anterior deficiencies.
- Lateral gastrocnemius rotational flap is used to cover lateral soft tissue deficiencies—risk with its use is peroneal nerve palsy from traction of the flap.

Section 14 TKA Design

- Painful TKA due to **flexion instability** is characterized by knee effusion, chronic pain, inability to climb stairs with reciprocal gait, inability to arise from low chair, and buckling of knee.
- Femoral cam jump occurs in **posterior stabilized** knees when the flexion gap is left too loose.
    - Closed reduction maneuver: with use of anesthesia, the knee is positioned at 90 degrees of flexion off the table (dependent dangle), and an anterior drawer maneuver is performed.
- Patella clunk syndrome occurs in **posterior stabilized knee designs** when scar tissue superior to the patella gets caught in box as the knee moves from flexion into extension.
    - Scar catches in box then releases with a clunk.
    - Treatment is removal of suprapatellar scar nodule.
- A constrained nonhinged TKA has a high central post that **substitutes for MCL and LCL** function—a standard posterior stabilized post is *not* constrained.
    - Constrained high-post knee system requires medullary stem support in femur and tibia to help distribute the load forces to bone, which are increased when a constrained post is used.
- In a hinged TKA, the femoral and tibial components are linked with a connecting bar and bearings.
    - Main indications for a hinged TKA are global instability and hyperextension instability.

- Hyperextension instability is an **absolute** indication for a hinged TKA.

Section 15 Revision TKA

- Periprosthetic joint infection is currently the number one reason for revision within the first 2 years of a primary TKA.
- Smooth radiolucent lines around the cement mantle and metallic implants on radiographs suggest aseptic loosening.
- Irregular marginal erosions around the cement mantle and metallic implants on radiographs suggest a **chronic** infection.
- If two or more longitudinal incisions are present in the anterior knee, the most lateral incision should be chosen for the revision procedure.
- Difficult exposure sequence: (1) extended proximal arthrotomy; (2) external rotation of tibial bone from soft tissue envelope; (3) lateral knee débridement; (4) lateral retinacular release (only if needed); (5) quadriceps tendon snip—transverse snip at most proximal region.

Section 16Patellar Tracking in TKA

- The main causes of patellar maltracking are internal rotation of either the femoral or tibial component and medialization of either the femoral or tibial component.
- If maltracking is seen intraoperatively with implants in place, the tourniquet should be released first and reevaluation should be performed before any changes are made.

Section 17Catastrophic Wear in TKA

- Etiology is **macroscopic** PE failure due to excess PE loading
- Factors leading to catastrophic wear:
  - PE thickness—PE must be at least 8 mm.
  - Articular geometry—flat PE should be avoided. Congruent bearing designs are better.
  - Knee kinematics—sliding wear, which occurs when the ACL is sacrificed, is bad for PE. Current prosthetic systems are designed to minimize tibial sliding wear.
  - Surgical technique—a tight flexion gap significantly increases stresses to PE.
  - PE processing—the best fabrication process is direct-compression molding. Irradiated PE in air is bad as it reduces mechanical strength of PE.

Section 18Glenohumeral Arthritis

- Etiology is multifactorial and includes primary and secondary causes.
- Primary OA involves posterior glenoid wear and inferior humeral head osteophyte.
- Rheumatoid disease frequently affects the shoulder, often manifesting as rotator cuff tears, and its erosive nature leads to central glenoid wear.
- Rotator CTA shows superior migration of the humeral head.
- It is critical to assess for rotator cuff function, particularly the subscapularis, in the evaluation of a patient with glenohumeral OA.
- True axillary and AP views are the most important imaging studies; CT and MRI can be helpful for evaluating bony deformity and rotator cuff integrity, respectively.
- Nonoperative treatment of shoulder arthritis is similar to that for hip and knee OA.

Section 19Shoulder Hemiarthroplasty

- Best indications are young patient with early-stage osteonecrosis before degenerative changes occur on glenoid side and head-splitting proximal humerus fracture in younger patient with reconstructible tuberosities.
- Late glenoid pain is a frequent complication.
- In general, reverse shoulder replacement is now the favored treatment for rotator CTA.

Section 20Total Shoulder Arthroplasty

- TSA is the preferred treatment for shoulder OA in a patient with an intact rotator cuff.
- Incidence of full-thickness cuff tears with primary glenohumeral OA is low (5%–10%).
- The glenoid component should not be placed in retroversion; numerous strategies exist to address excessive retroversion, including high side-reaming, bone grafting, and augmented components.
- Rehabilitation after TSA should avoid excessive passive external rotation and active internal rotation early on to protect the subscapularis repair.
- Complications of TSA include injury to the musculocutaneous and axillary nerves, subscapularis failure, and glenoid more often than humeral loosening.

Section 21Reverse Total Shoulder Arthroplasty

- Involves placing a baseplate and glenosphere on the glenoid side and a humeral tray and stem on the humeral side.
- Medializes the center of rotation of the shoulder and resolves the problem of superior migration.
- Elevation power is provided by the deltoid, so an intact axillary nerve is required.
- Component position largely focuses on the glenosphere, which must be placed as inferiorly as possible and with slight inferior tilt to enhance deltoid tension and avoid scapular notching.
- The most common location of instability after rTSA is anterior; the classic mechanism is pushing up from a chair.
- Rates of scapular notching were historically quite high; more modern lateralized prostheses have reduced this risk.
- Periprosthetic fractures can occur, most importantly in the acromion and scapular spine, owing to tension on the deltoid.

Section 22Infection in Shoulder Arthroplasty

- Periprosthetic shoulder infections manifest differently from periprosthetic hip and knee infections.
- *P. acnes* and coagulase-negative *Staphylococcus* are the most common organisms; cultures should be held for 14–28 days to allow growth.
- Postoperative hematoma, young age, male gender, arthroplasty for trauma, and revision surgery have been the only identified risk factors.
- Serum laboratory tests and aspiration with analysis of synovial fluid are key in the workup, but neither is sufficiently sensitive or specific. The role of arthroscopy in diagnosing infection is increasing.
- Tissue culture is the gold standard for diagnosis.
- Management options include antibiotic suppression, irrigation, and polyethelene exchange for acute infections, one-stage revisions and two-stage revisions.
- Antibiotic choices are guided by culture results.

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CHAPTER 6

Disorders of the Foot and Ankle

Anish R. Kadakia, and Amiethab A. Aiyer

Biomechanics of the Foot and Ankle

- **Primary functions of foot and ankle: to provide weight-bearing support and forward ambulation**

Anatomy

- **Ankle**
  - Ankle mortise formed by tibial plafond, medial malleolus, and lateral malleolus (Fig. 6.1)
    - Mortise articulates with dome of talar body.
    - Mortise widens and ankle becomes more stable in dorsiflexion owing to shape of talar dome (wider anteriorly and narrower posteriorly).
      - Mortise widens 1 to 1.5 mm during motion from plantar flexion to dorsiflexion.
      - Medial/superior clear spaces appear wider with the foot in plantar flexion.
    - A simplified model of the ankle joint has a horizontal axis from anteromedial to posterolateral and a coronal axis from superomedial directed distally and laterally to the tip of the fibula (between the malleoli) (Fig. 6.2).
    - Responsible for most sagittal plane motion of foot and ankle
      - 23 to 48 degrees plantar flexion
      - 10 to 23 degrees dorsiflexion
    - Also contributes to inversion/eversion and rotation
  - Distal tibiofibular joint
    - Distal fibula—convex medial surface

- Incisura fibularis—concave surface of distal lateral tibia
- Fibula rotates (≈2 degrees) within incisura during ankle motion and ambulation. Ankle dorsiflexion results in external rotation and proximal translation of fibula.

□ Ligamentous anatomy (Fig. 6.3)

- Lateral ankle ligaments function as restraints to varus/inversion forces at ankle.

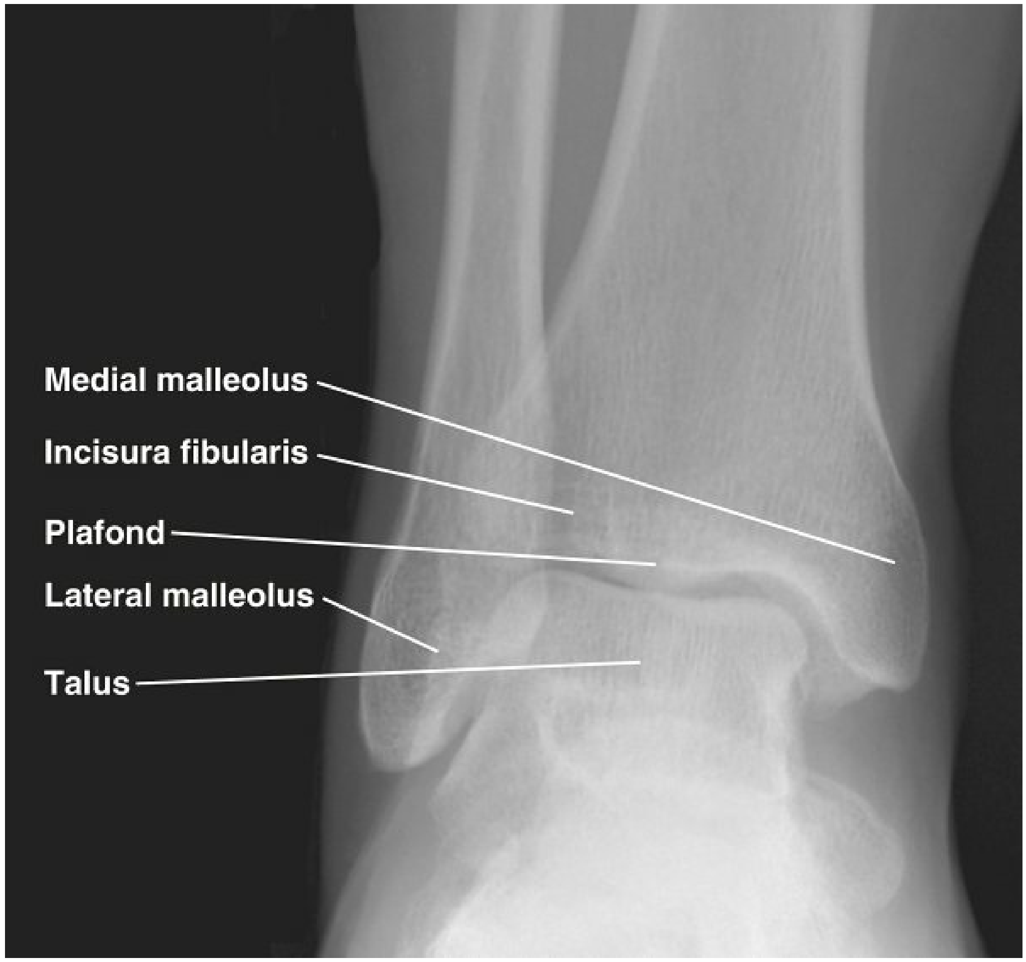


FIG. 6.1 Anteroposterior radiograph of the ankle.

- Anterior talofibular ligament (ATFL) originates from anteroinferior aspect of lateral malleolus (1 cm proximal to its tip) and extends to lateral aspect of talar neck.
- Calcaneofibular ligament (CFL) extends from tip of lateral malleolus to lateral aspect of calcaneus.
- Posterior talofibular ligament (PTFL) extends from posterior lateral malleolus to posterolateral talus.
- ATFL is the weakest ankle ligament; PTFL is the strongest.
- Distal tibiofibular joint (ankle syndesmosis) and fibula provide stability against lateral talar translation.
- Deltoid ligament complex—primary ankle stabilizer during stance
    - Deep deltoid ligament extends from apex of

medial malleolus to medial talar body and functions primarily to resist lateral talar translation and external rotation.
- Posterior deep deltoid is the most important component.
- Superficial deltoid ligament extends from distal medial malleolus to navicular bone, sustentaculum tali of calcaneus, medial talus, and spring ligament. Functions primarily to resist valgus/eversion ankle forces (i.e., talar tilt).

- **Hindfoot and midfoot**
  - Hindfoot consists of talus, calcaneus, and cuboid; subtalar, calcaneocuboid (CC), and talonavicular (TN) joints are included (Fig. 6.4). Hindfoot functions primarily in inversion and eversion.
    - Inversion motion is normally greater than eversion.
      - This is the reason why valgus deformities of the tibia are better tolerated.
    - Limited eversion accommodation contributes to stiffness and disability derived from even a mild cavovarus foot deformity.
    - Spring ligament connects calcaneus to navicular along the medial hindfoot.
      - Supports the talar head and is incompetent in adult-acquired flatfoot deformity
    - Subtalar joint motion is interrelated to tibial rotation.
      - Internal tibial rotation results in subtalar eversion.
        - Late heel strike and foot flat
      - External tibial rotation results in subtalar inversion.
        - Initial heel strike and toe-off

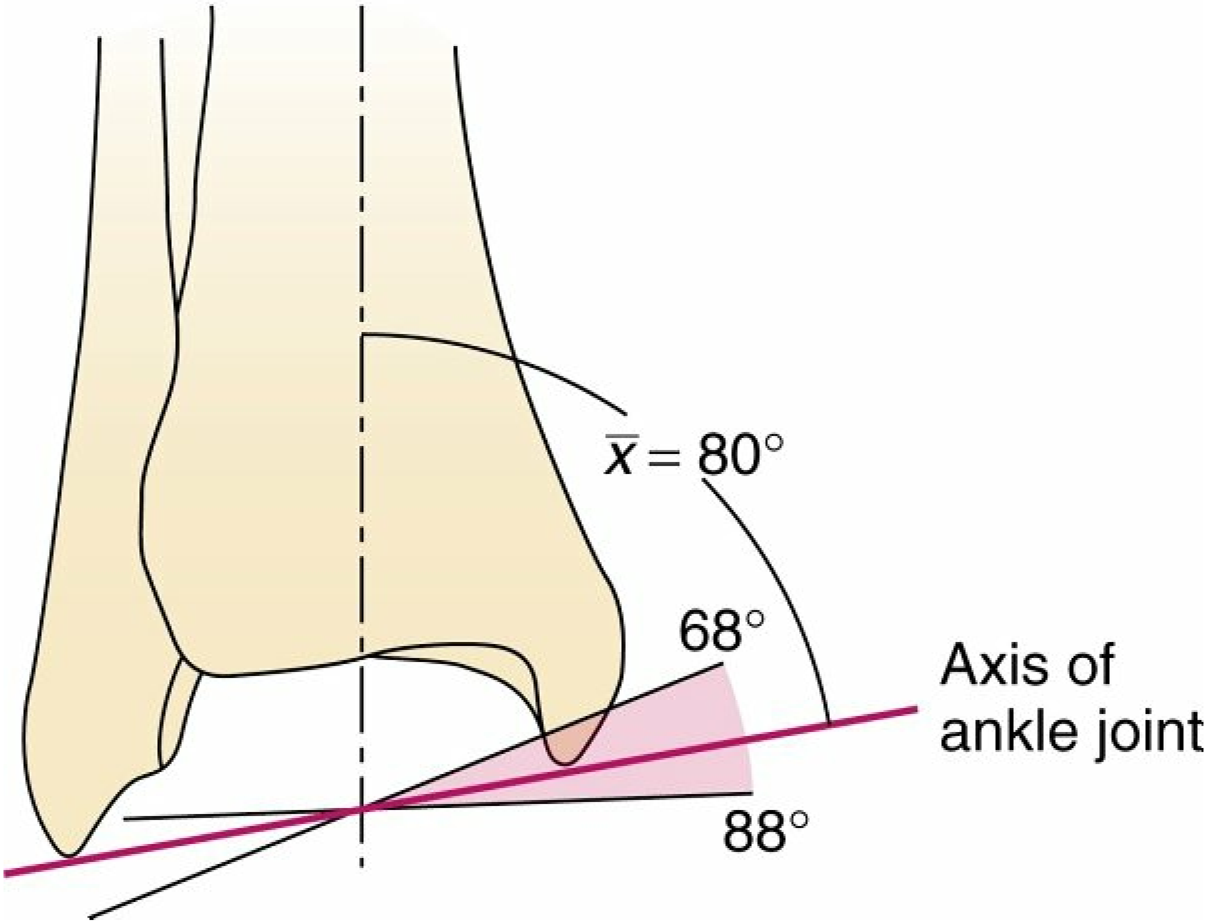
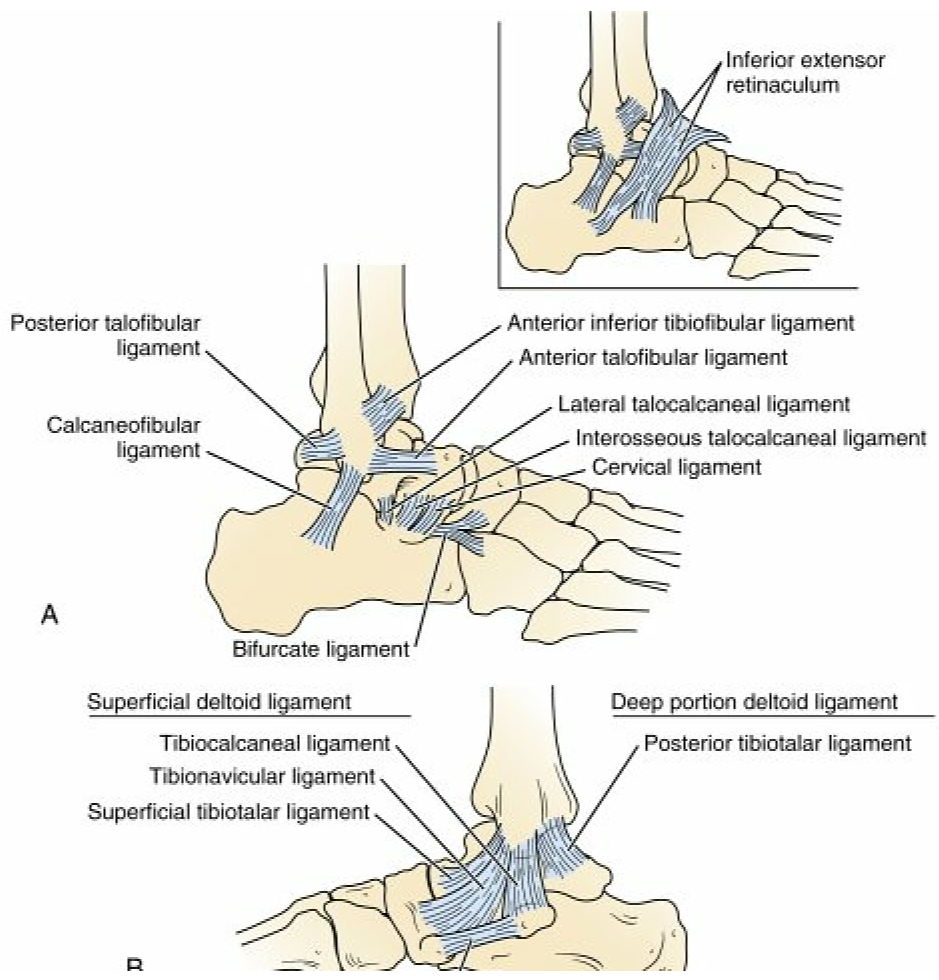


FIG. 6.2 Angle between the axis of the ankle joint and the long axis of the tibia.
From Hsu J et al: *AAOS atlas of orthoses and assistive devices,* Philadelphia, 2008, Elsevier.



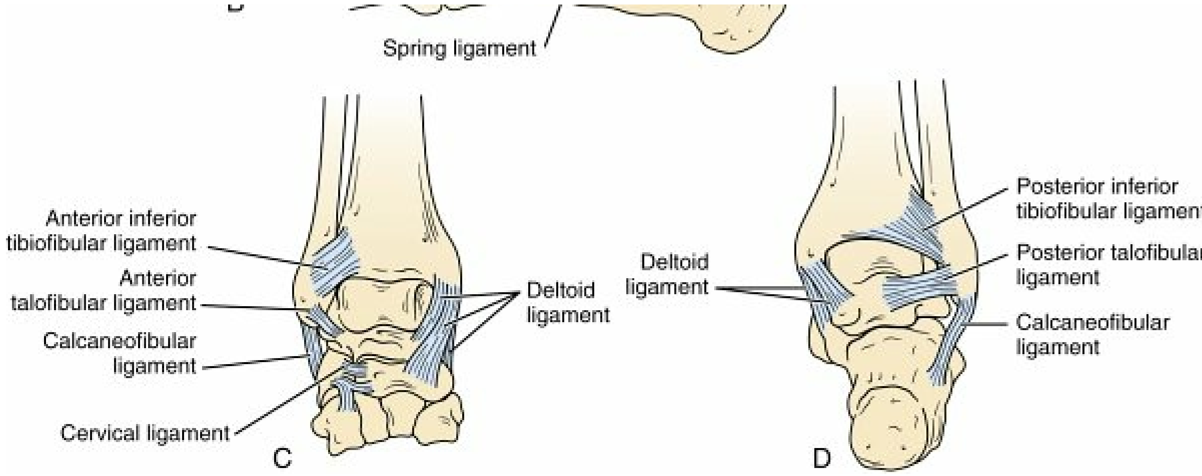


FIG. 6.3 Ligaments of the ankle and subtalar joint. (A) Lateral view. (B) Medial view. (C) Anterior view. (D) Posterior view.
From Miller MD: *Core knowledge in orthopaedics—sports medicine,* Philadelphia, 2006, Elsevier.

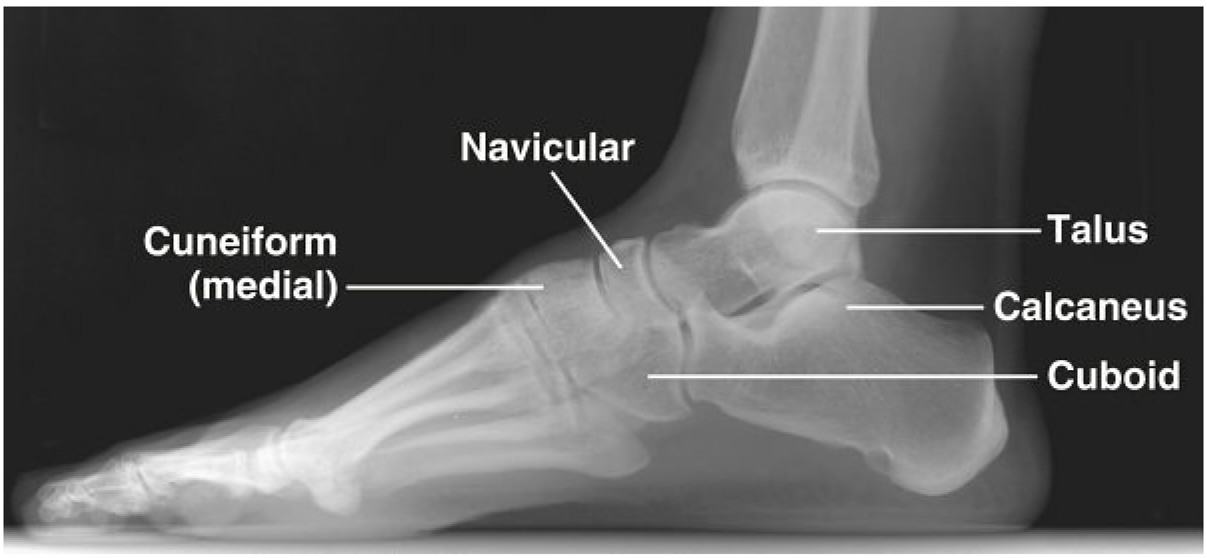


FIG. 6.4 Lateral radiograph of the foot.

- □ Midfoot begins at articulation between navicular and cuneiforms, along with cuboid and fourth and fifth metatarsals. Midfoot also includes tarsometatarsal (TMT) joints.
  - Midfoot functions in adduction and abduction.
  - CC and TN joints are collectively referred to as the *midtarsal*, *transverse tarsal*, or *Chopart joint.*
    - This joint is important for providing hindfoot and midfoot stability to produce a rigid lever at heel rise.
      - During foot flat (hindfoot valgus, forefoot abduction, and dorsiflexion of ankle), the transverse tarsal joints are parallel and supple, adapting to uneven ground.

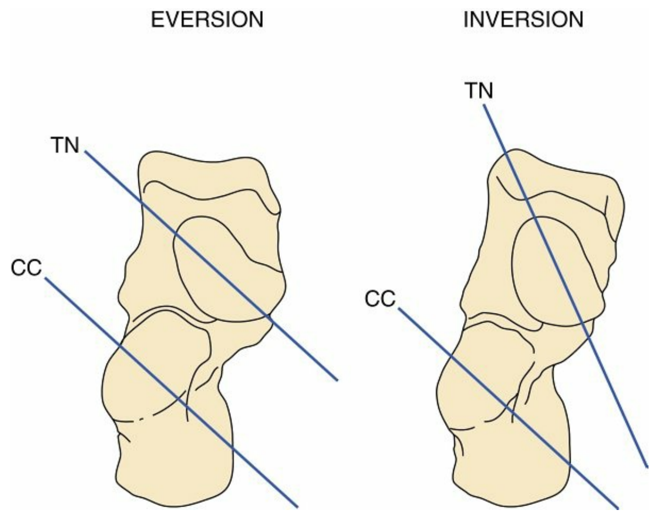


FIG. 6.5 Function of the transverse tarsal joint. When the heel is everted, the transverse tarsal joints are parallel and unlocked, allowing the foot to be supple and pronate and accommodate to the floor. When the heel is inverted (varus), the transverse tarsal joint is divergent and locked, allowing for a stable hindfoot/midfoot complex for toe-off.

  - During toe-off (hindfoot varus, forefoot adduction, and plantar flexion of ankle), these joints become divergent and lock, providing stiffness to the foot for forward propulsion (Fig. 6.5).
  - Failure of posterior tibial tendon (PTT) to lock transverse tarsal joints is the biomechanical etiology for lack of a heel rise in patients with PTT dysfunction (PTTD).
- Midfoot provides an important bridge between hindfoot and forefoot, giving both flexibility and stability necessary for normal gait and other activities.
- Ligamentous stability to midfoot is provided through longitudinal and transverse ligaments on plantar and dorsal aspects of each joint.
  - Plantar ligaments are thicker and stronger than their dorsal counterparts.
  - Primary stabilizer of longitudinal arch is the interosseous ligaments, *not* the plantar fascia; plantar fascia is

a secondary stabilizer.

- Lisfranc joint complex has a specialized bony and ligamentous structure, providing stability to this joint.
    - The second metatarsal extends more proximally than surrounding metatarsals. This "keystone" effect imparts inherent bony stability.
    - Dorsal and plantar ligaments extend from the second metatarsal to each of the three cuneiforms.
    - Largest and strongest of these ligaments is the Lisfranc ligament, which travels from medial cuneiform to the base of the second metatarsal.
        - Three parts (dorsal, plantar, interosseous); interosseous is strongest

- The midfoot is also divided into three columns.
    - Medial column includes the first metatarsal, the medial cuneiform, and the navicular.
    - Middle column includes the second and third metatarsals, the middle cuneiform, and the lateral cuneiform.
        - Rigidity of the middle column allows for a rigid lever arm during push-off.

FIG. 6.6 Anteroposterior radiograph of the foot.

- Lateral column includes the fourth and fifth metatarsals and the cuboid.
  - Sagittal mobility of the lateral column imparts flexibility necessary for walking on uneven ground.
- Mobility of the midfoot (dorsiflexion/plantarflexion)
  - First tarsometatarsal joint has 3.6 degrees, second tarsometatarsal has 0.6 degrees, third tarsometatarsal has 1.6 degrees
  - Lateral column has the most sagittal mobility (≈10 degrees) and the middle column has the least
  - Foot has longitudinal and transverse arches, with arch stability provided by a combination of the bony architecture, ligamentous attachments, and muscle forces.
  - Stability of the midfoot allows for push-off during gait and other activities.

- **Forefoot**
  - Forefoot includes all structures distal to the TMT joints (Fig. 6.6).
  - First metatarsal is the widest and shortest and bears 50% of the weight during gait.
  - Second metatarsal is usually the longest and experiences more stress

than the other lesser metatarsals.

- Second metatarsal is more commonly involved in stress fractures.

□ Lesser toes are controlled by a delicate muscle balance.

- Extrinsic muscles
  - Extensor digitorum longus (EDL)
  - Flexor digitorum longus (FDL)
- Intrinsic muscles
  - Metatarsophalangeal (MTP) flexion
  - Proximal interphalangeal (PIP) extension
    - Interossei (dorsal to the distal transverse intermetatarsal ligament)
    - Lumbricals (plantar to the distal transverse intermetatarsal ligament)

□ Passive restraints

- Plantar plate—disrupted in a hammer toe and crossover toe
  - Most important stabilizer of the lesser MTP joint
- Extensor hood—primary distal insertion point of the long extensors, which function to extend MTP joint but *not* PIP joint
- Joint capsule
- Collateral ligaments

□ Intrinsic tendons pass plantar to MTP joint axis proximally (providing a flexion force) and pass dorsal to the axis distally (providing an extension force).

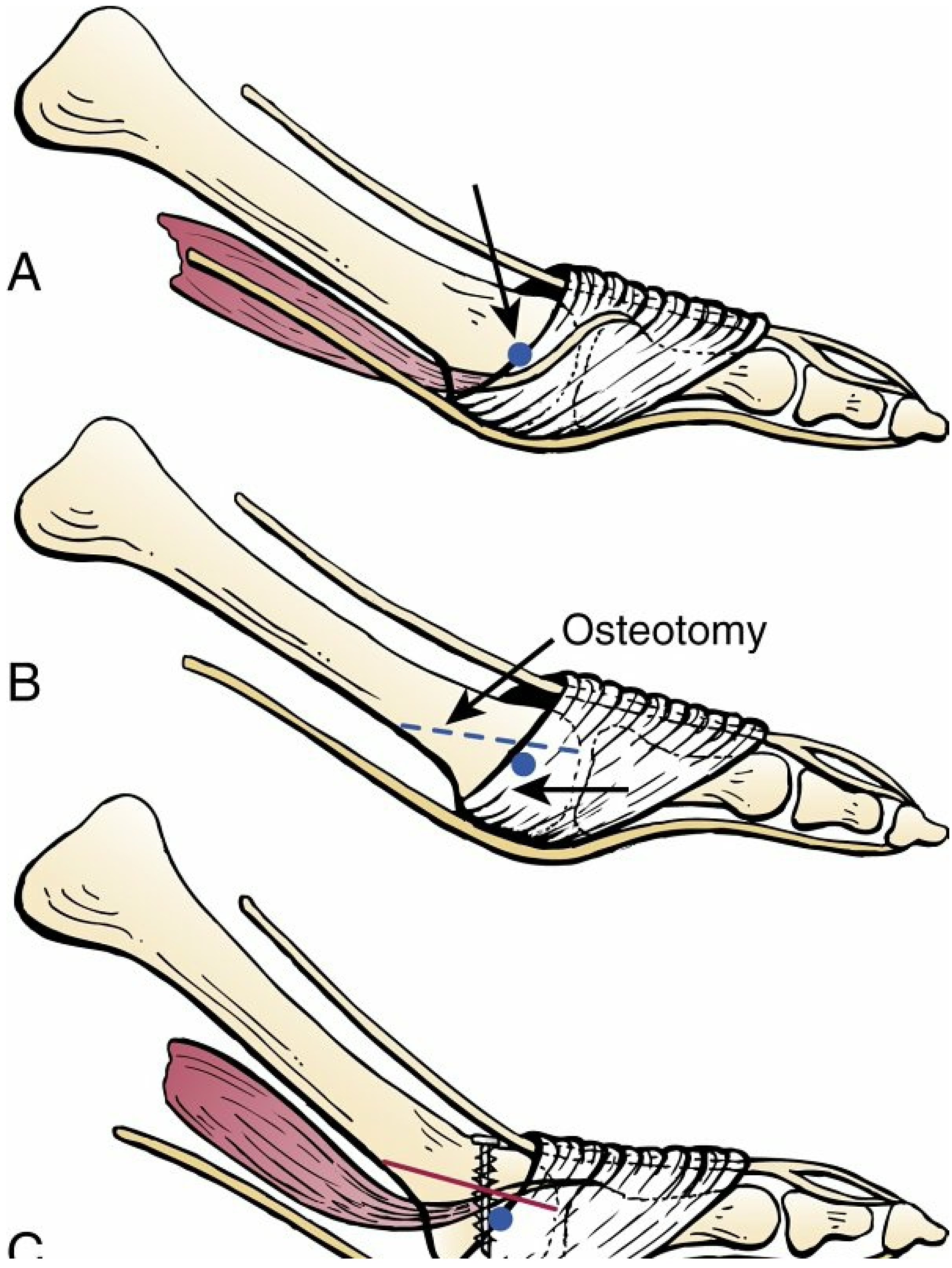
- Plantar migration of this metatarsal head after a Weil (oblique shortening) osteotomy leads to a relatively dorsal position of the intrinsic tendons. The tendons now lie dorsal to the axis of rotation, leading to a "floating" toe (Fig. 6.7).
- Loss of intrinsic function, as seen in hereditary motor sensory neuropathy or diabetic neuropathy, predictably leads to claw toes.

Foot Positions Versus Foot Motions

- **Foot positions are defined differently from foot motions.**
- **Foot positions are:**
  - Varus/valgus—hindfoot
  - Abduction/adduction—midfoot
  - Equinus/calcaneus—ankle
- **Foot motions in the three axes of rotation are illustrated in** Fig. 6.8 and summarized in Table 6.1.
  - The critical assessment is to determine the relationship of the forefoot to the hindfoot.
    - If the heel is in a neutral position (subtalar neutral), the forefoot should be parallel with the floor to meet the ground flush (plantigrade).
    - If the first ray is elevated, the forefoot is in varus position. If the first ray is flexed, the forefoot is in valgus position (see Fig. 6.3). This should not be confused with hindfoot varus or valgus.
    - Example: in a long-standing flatfoot deformity the heel is valgus and the forefoot has compensated by going into varus or supinating to keep the foot flat to the ground.
      - Once the heel has been corrected, the elevated first ray can be easily seen (Fig. 6.9).

Gait Cycle

- **One full gait cycle from heel strike to heel strike is termed a** *stride.*
  - Each stride is composed of a stance phase (heel strike to toe-off; 62% of cycle) and a swing phase (toe-off to heel strike; 38% of cycle) (Fig. 6.10).
- *Walking* is defined by a period of double-limb support in addition to there always being one foot in contact with the ground throughout the gait cycle.



A
B
Osteotomy
C

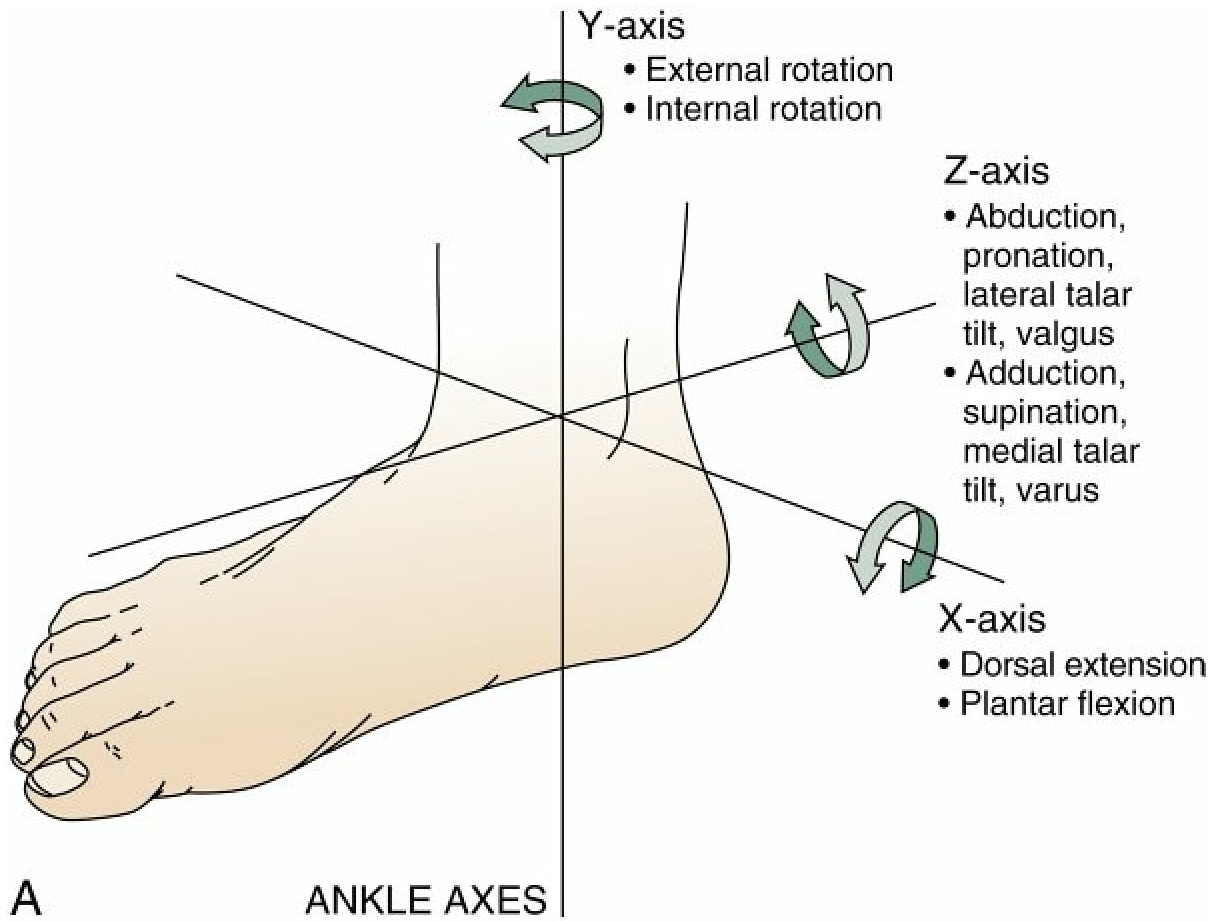
FIG. 6.7 Axis of the metatarsophalangeal joint before and after Weil osteotomy. (A) Lesser metatarsal before osteotomy; note that intrinsic tendons are plantar to the axis. (B) Osteotomy is above the center of the metatarsal head. (C) Following the osteotomy and proximal translation of the capital fragment, the intrinsic tendons course dorsal to the axis of rotation. This change can lead to metatarsophalangeal joint dorsiflexion.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

Table 6.1

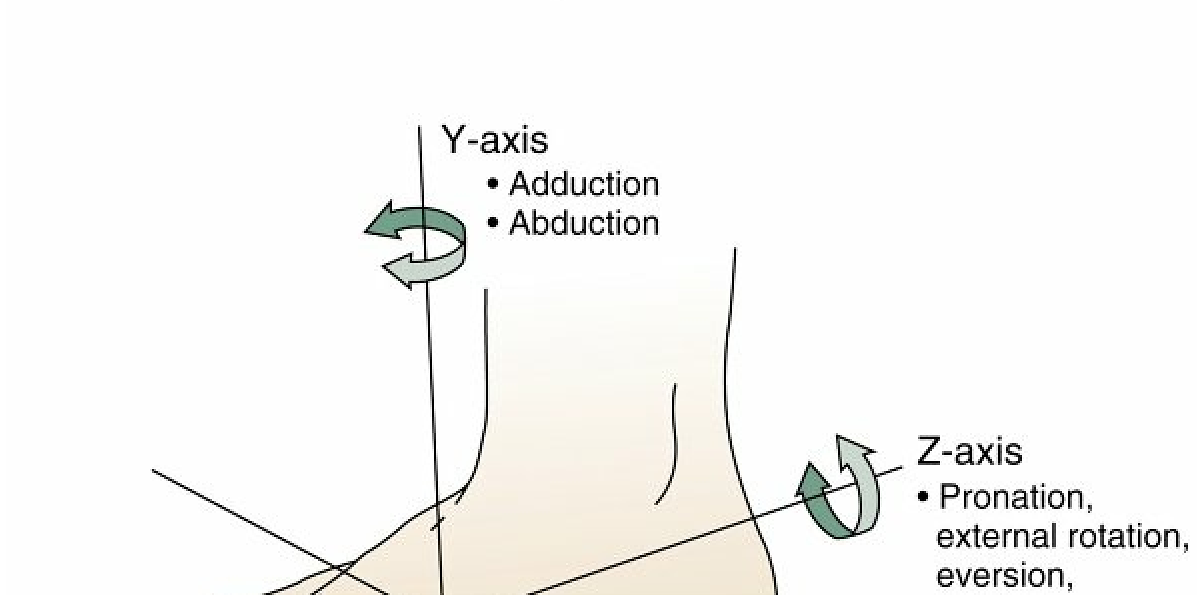
Motions of the Foot and Ankle.

Plane of Motion	Motion
Sagittal (x-axis)	Dorsiflexion Plantar flexion
Frontal (coronal) (z-axis)	Inversion Eversion
Transverse (y-axis)	Forefoot/midfoot Adduction Abduction Ankle/hindfoot Internal rotation External rotation
Triplanar motion	Supination Adduction Inversion Plantar flexion Pronation Abduction Eversion Dorsiflexion

- **Ground reaction forces are approximately 1.5 times body weight during walking and 3 to 4 times body weight during running.**
  - This difference is due to the increased load after the float phase of running, in which there is no foot in contact with the ground.
  - As the speed of gait increases, the stance phase decreases.



Y-axis
• External rotation
• Internal rotation
Z-axis
• Abduction, pronation, lateral talar tilt, valgus
• Adduction, supination, medial talar tilt, varus
X-axis
• Dorsal extension
• Plantar flexion
A
ANKLE AXES



Y-axis
• Adduction
• Abduction
Z-axis
• Pronation, external rotation, eversion,

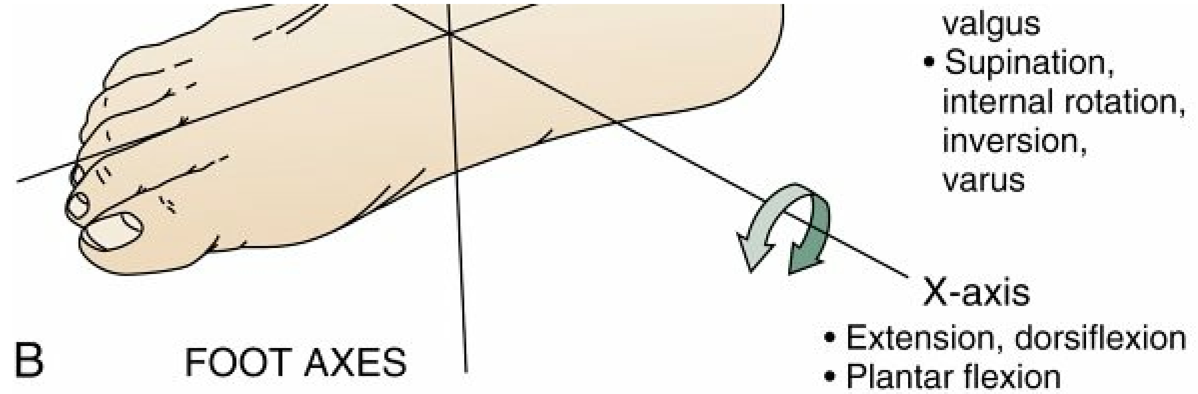


FIG. 6.8 Axes of rotation of the ankle (A) and foot (B).
From Myerson MS: *Foot and ankle disorders,* Philadelphia, 2000, Elsevier.

- **Soft-tissue contributions to gait mechanics**
  - Swing phase
    - Anterior tibialis—contracts concentrically
      - Loss of function results in footdrop and steppage gait.
  - Heel strike
    - Anterior tibialis—contracts eccentrically
      - Controls the rate at which foot strikes the ground. In patients with footdrop, the rapid strike of the foot can result in a loud "slap" during heel strike.
    - Hindfoot—locked/inverted at initial strike; passively everts during transition from heel strike to foot flat
      - Allows for energy absorption. Failure of hindfoot eversion in patients with cavovarus deformity increases forces to lateral foot, resulting in stress fractures (fifth metatarsal), callus formation, and ankle instability.
  - Foot flat
    - Gastrocnemius-soleus complex—eccentric contraction
      - Controls forward progression of body over the foot
      - Loss of function results in a calcaneus gait with heel pain
    - Hindfoot—unlocked/everted for ground accommodation
      - At terminal stance, the FDL tendon is most active
  - Toe-off
    - Gastrocnemius-soleus complex—concentric contraction
    - In addition, as foot progresses from heel strike to toe-off, the following changes allow foot to convert from a flexible shock absorber to a rigid propellant:
      - Plantar fascia, which attaches to plantar medial heel and runs the length of the arch to the bases

of each proximal phalanx, is tightened as MTP joints extend. The longitudinal arch is accentuated.

  - This is called the *windlass mechanism* (Fig. 6.11).

- Hindfoot supinates, with firing of the PTT.
- Transverse tarsal joint locks and provides a rigid lever arm for toe-off.
  - Insufficiency of the PTT will limit the ability to lock the transverse tarsal joint.

Physical Examination of the Foot and Ankle

Inspection

- **Foot and ankle should be inspected for:**
  - Symmetry
  - Calluses—areas of abnormally increased pressure
  - Signs of peripheral vascular disease—lack of hair, increased skin pigmentation (hemosiderin deposition)
  - Swelling—symmetric (likely systemic etiology) versus asymmetric (trauma, venous thrombosis, cellulitis, osteomyelitis, focal musculoskeletal etiology) (Fig. 6.12)
  - Ecchymosis—plantar ecchymosis associated with TMT injury (Lisfranc injury) (Fig. 6.13)
  - Alignment
    - Neutral
    - Cavovarus—elevated longitudinal arch with hindfoot varus and plantar-flexed first ray (Fig. 6.14)
      - Plantar flexion of the first ray is secondary to imbalance between the peroneus longus and tibialis anterior tendon
    - Pes planovalgus—flat longitudinal arch with hindfoot valgus (Fig. 6.15)
      - Differentiation between hindfoot-driven and midfoot-driven etiology required
        - Midfoot driven secondary to degenerative joint disease (DJD) or chronic Lisfranc injury
          - Treatment—midfoot fusion with realignment
        - Hindfoot driven (adult) secondary to PTTD (most common)
          - Treatment—FDL tendon transfer with medial slide calcaneal osteotomy or triple arthrodesis

FIG. 6.12 This patient presented with chronic osteomyelitis of the leg, with a past medical history significant for diabetes mellitus and peripheral vascular disease. Note the lack of hair growth in distal half of leg along with significant swelling of the limb.

- Hindfoot driven (pediatric) secondary to abnormal skeletal development
  - Treatment—lateral column lengthening

Gait Evaluation

- **Steppage gait—increased knee and hip flexion during swing phase to ensure toes clear the floor (** Fig. 6.16)
  - Secondary to footdrop (peroneal nerve palsy or neuropathy, tibialis anterior tendon rupture)
- **Calcaneus gait—increased ankle dorsiflexion during heel strike**
  - Secondary to triceps surae (gastrocnemius-soleus) weakness
- **Antalgic gait—shortened stance phase on the affected side**
  - Secondary to pain, most commonly DJD
  - Short stance phase minimizes amount of time pressure is placed on affected limb, decreasing pain.

Vascular Examination

- **Palpation for dorsalis pedis and posterior tibial pulses; if not present, noninvasive studies should be considered.**
- **Predictive for healing**
  - Doppler ultrasonography
    - Triphasic waveforms are normal.

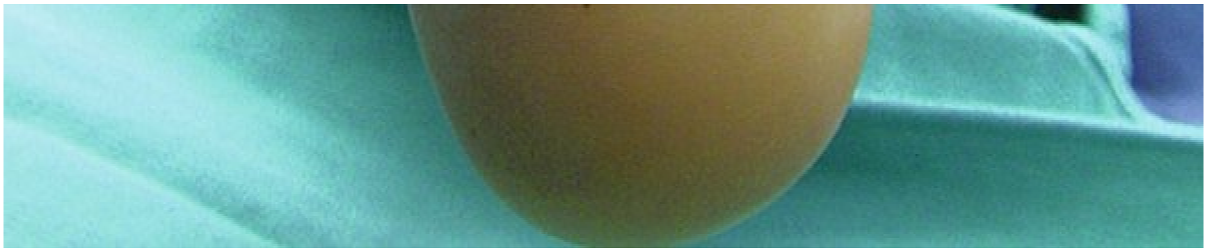


FIG. 6.13 Plantar ecchymosis is noted in a patient with a Lisfranc (tarsometatarsal) injury.

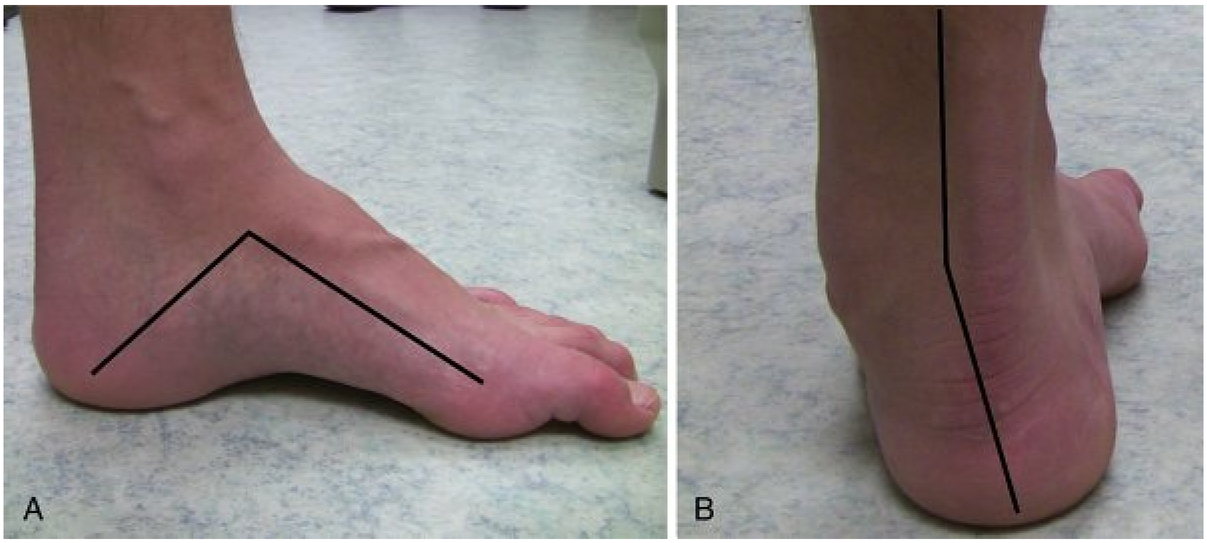


FIG. 6.14 Note the plantar-flexed first ray (A) and varus position of the hindfoot (B) in a patient with a cavovarus deformity.

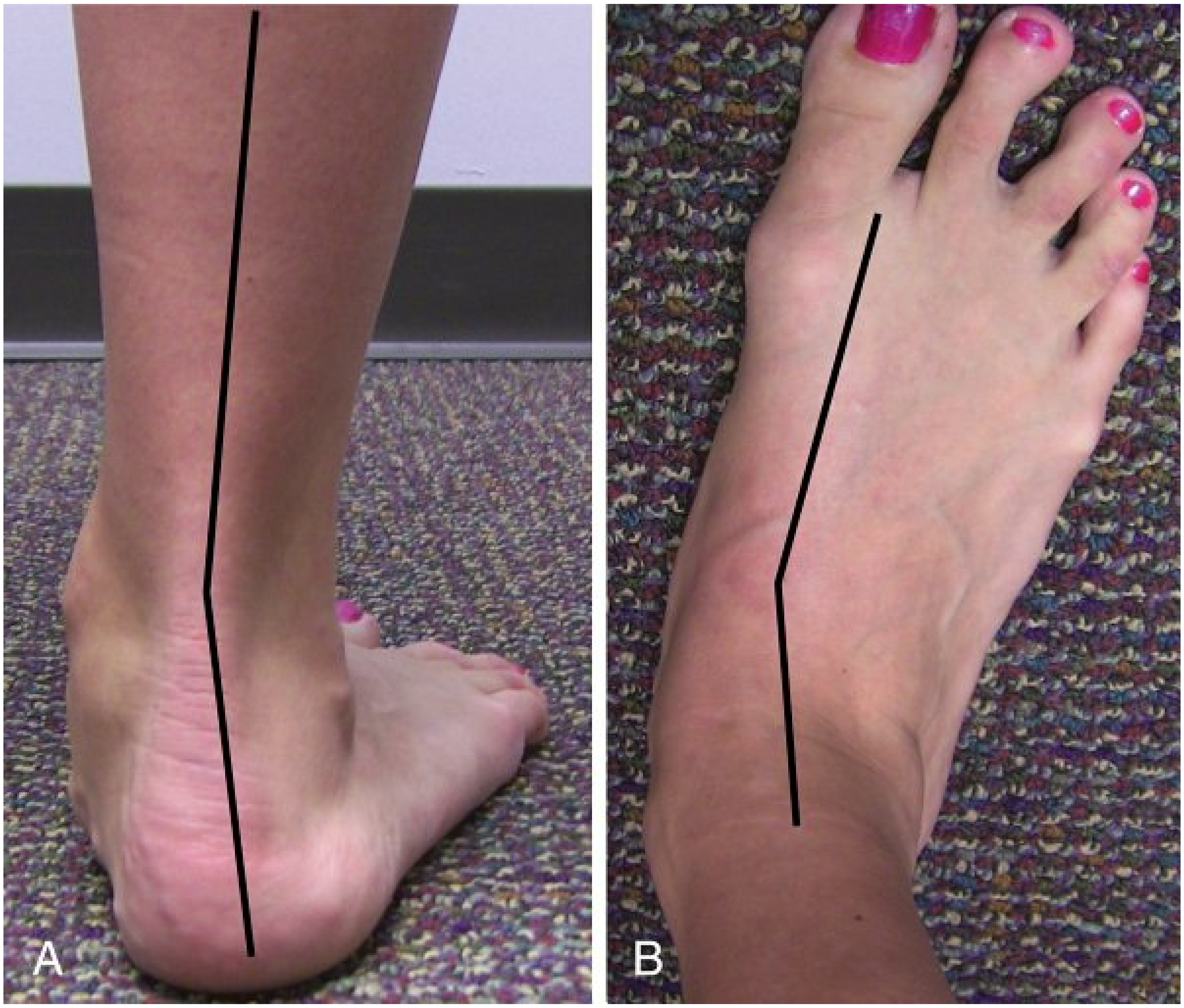


FIG. 6.15 Valgus position of the hindfoot (A) with forefoot abduction (B) in a patient with a pes planovalgus deformity.

- Ankle-brachial index (ABI)
  - Greater than 0.5, with normal ranging from 0.9 to 1.3
  - Greater than 1.3 indicates inelastic vessels (calcified—common in diabetics); *not* indicative of good flow.
- Toe pressures
  - Greater than 40 mm Hg
- Transcutaneous oxygen pressures ($TcPO_2$)
  - Greater than 30 mm Hg

Neurologic Examination

- **Sensory examination should assess the following five cutaneous nerves that supply the feet (** Fig. 6.17)
  - Superficial peroneal (Fig. 6.18)
    - Medial dorsal cutaneous—dorsomedial foot
    - Intermediate dorsal cutaneous—dorsolateral foot
  - Deep peroneal—first dorsal web space
  - Sural—posterolateral border of the leg and the lateral border of the foot (Fig. 6.19)

- □ Tibial—plantar foot (Fig. 6.20)
    - • Medial calcaneal

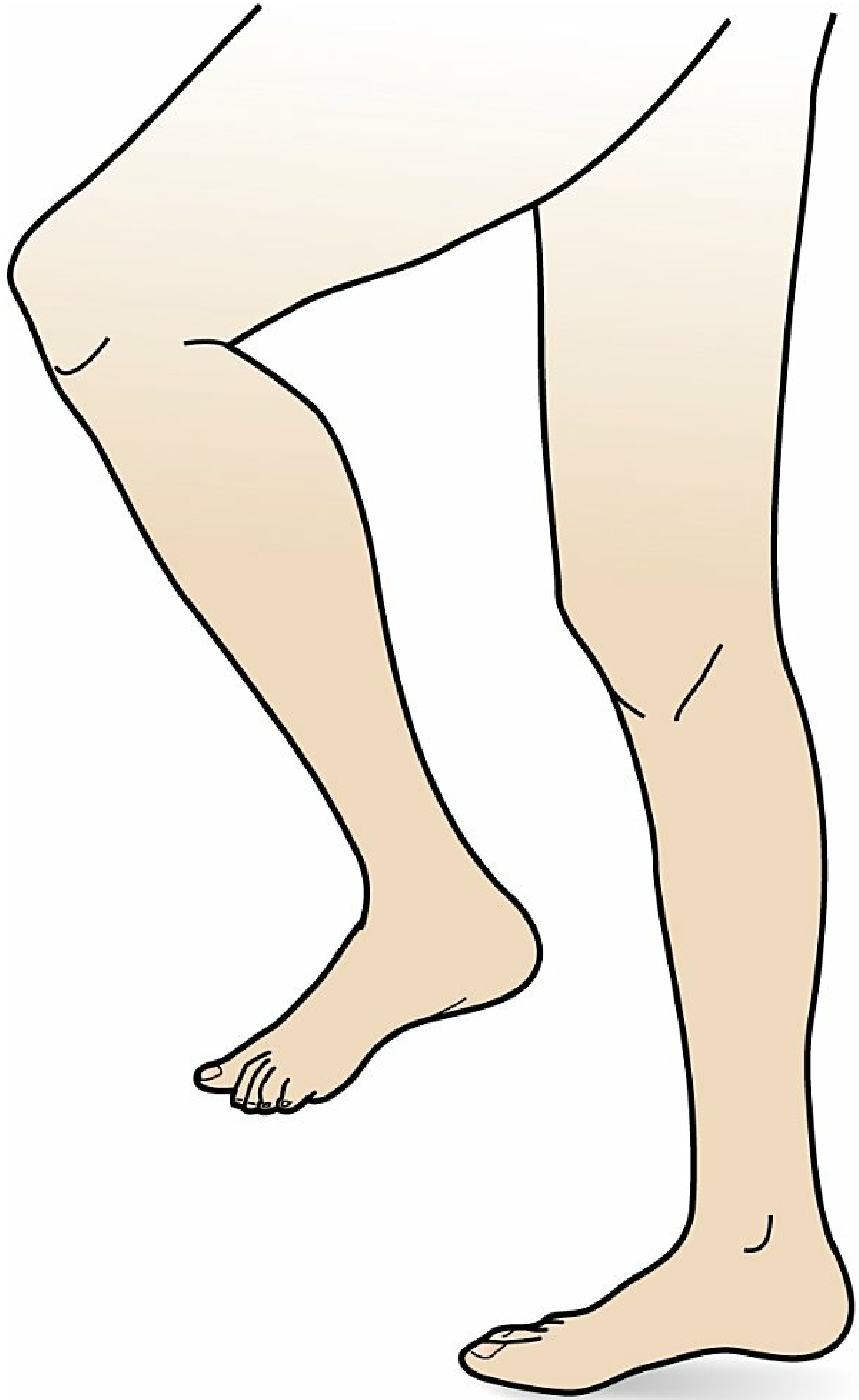


FIG. 6.16 In steppage gait, each knee is excessively raised during walking. This maneuver compensates for a loss of position sense by elevating the feet to ensure that they will clear the ground, stairs, and other obstacles. It is a classic sign of posterior column spinal cord damage from tabes dorsalis. However, peripheral neuropathies more commonly impair position sense and lead to this gait abnormality. From Kaufman D: *Clinical neurology for psychiatrists,* ed 6, Philadelphia, 2006, Elsevier.

- Medial plantar
- Lateral plantar

- Saphenous—adds sensation to anteromedial ankle

- **Inability to sense a Semmes-Weinstein 5.07 monofilament (10 g) is consistent with neuropathy.**
  - The most predictive sign for development of a foot ulceration

Motor Examination

- **In assessment of strength, the relation of the tendon with the axis of the ankle should be kept in mind. For example, if it passes medially and posteriorly, the function of that structure will be to provide plantar flexion and inversion (tibialis posterior).**
- **In assessment of motor function of the foot and ankle, the following muscles should be tested:**
  - Tibialis anterior—ankle dorsiflexion, L3–4
  - Extensor hallucis longus—great-toe extension, L4–5
  - Peroneus longus and brevis—hindfoot eversion, L5–S1
  - Posterior tibialis—hindfoot inversion, L4–5
  - Gastrocnemius complex—ankle plantar flexion, S1

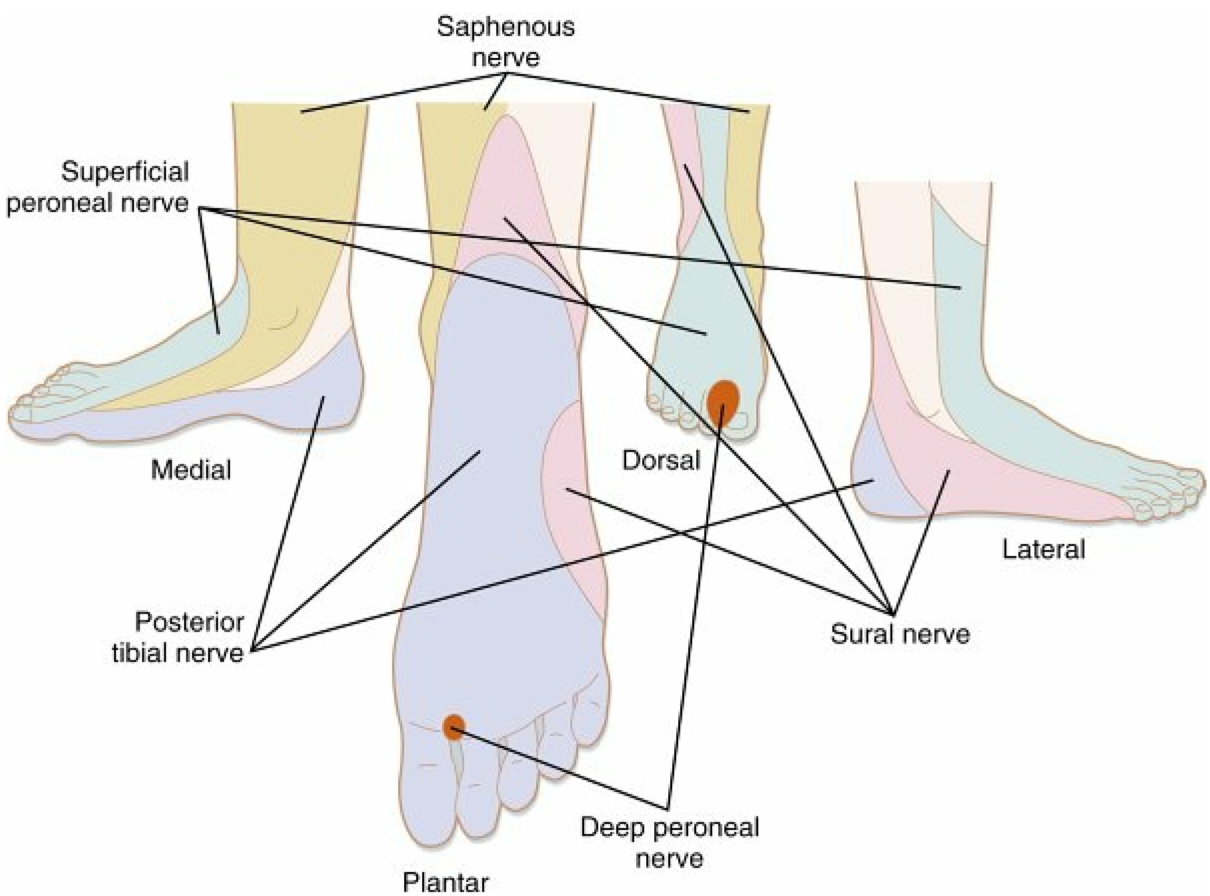


FIG. 6.17 Sensory nerve distribution of the ankle.
From Adams J et al: *Emergency medicine,* Philadelphia, 2008, Elsevier.

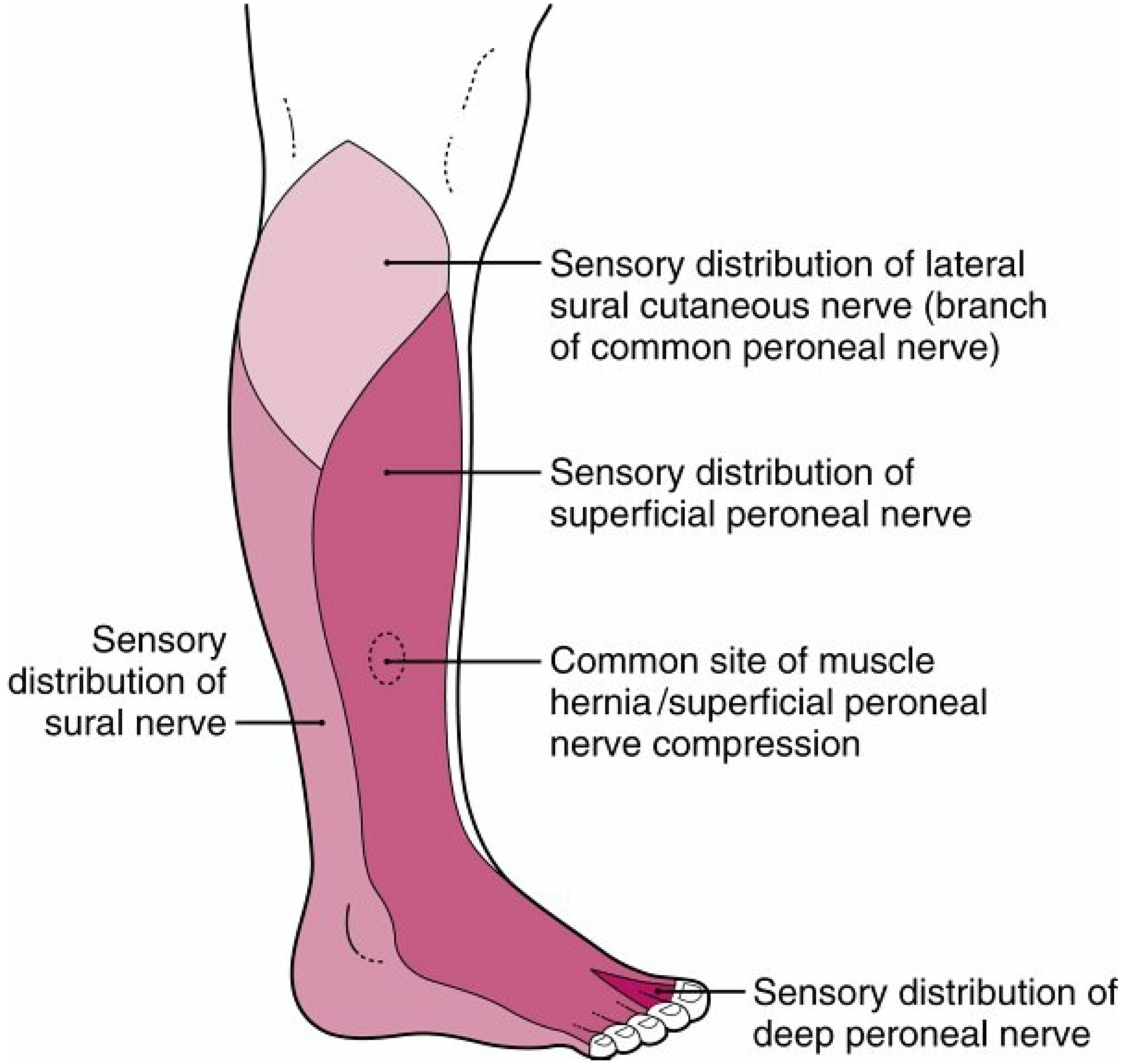


FIG. 6.18 Sensory distribution of superficial peroneal nerve. Note typical site of muscle hernia/superficial peroneal nerve compression.
From Frontera W et al: *Clinical sports medicine: medical management and rehabilitation,* Philadelphia, 2006, Elsevier.

- **It is important to remember that neurologic deficits can be secondary to more proximal pathology (e.g., central nervous system, spinal cord, nerve root).**

Palpation and Stability Assessment

- **Palpation of the tendinous and bony anatomy of the foot and ankle is facilitated by its subcutaneous nature. A detailed examination can typically reproduce the source of the patient's** pain, allowing the examiner to identify the cause without the need for supplementary studies.

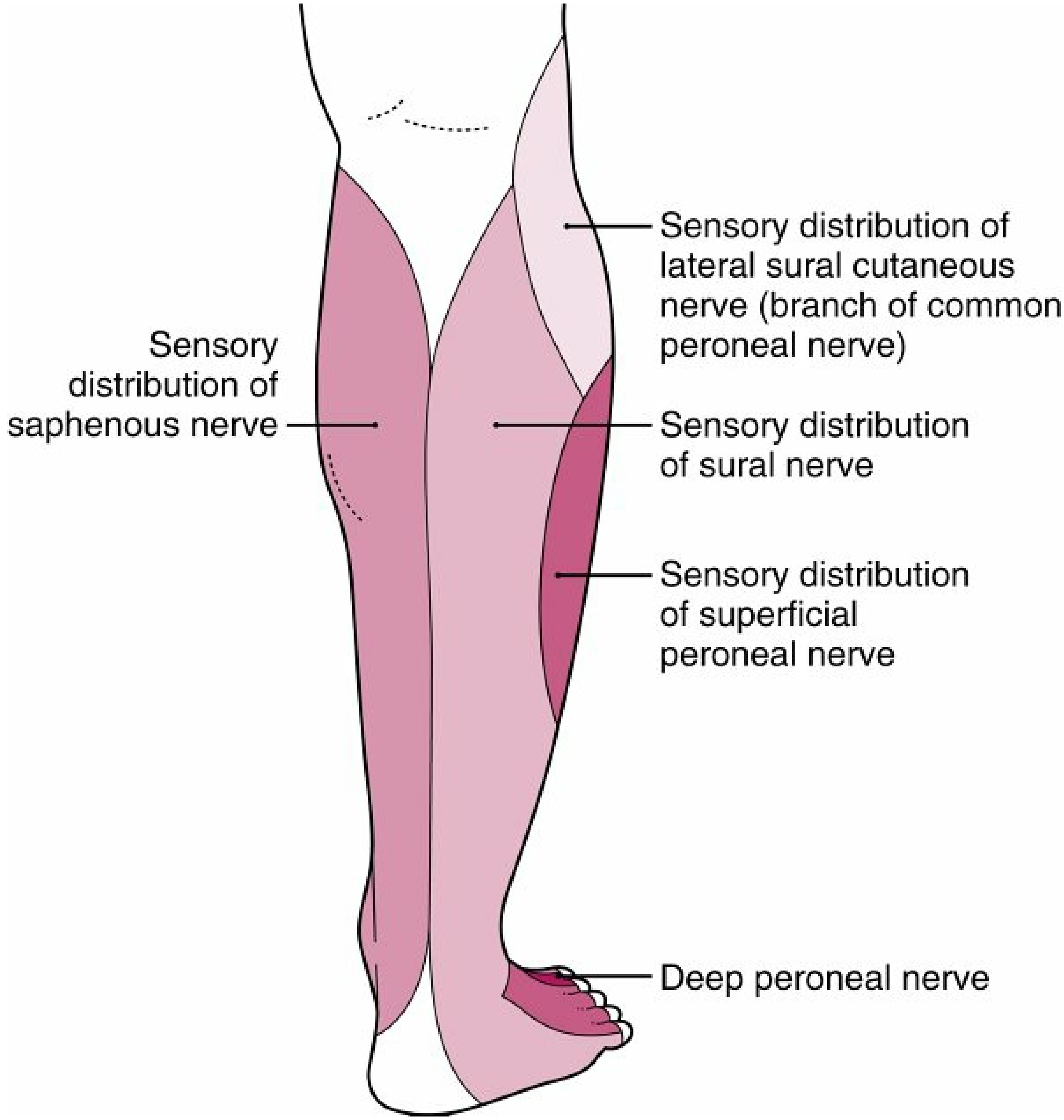


FIG. 6.19 Sensory distribution of sural nerve.
From Frontera W et al: *Clinical sports medicine: medical management and rehabilitation,* Philadelphia, 2006, Elsevier.

- **The courses of all tendons are checked both at rest and during contraction for swelling, nodules, and subluxation.**
- **Tinel sign should be sought for at the following locations:**
  - □ Tibial nerve at the tarsal tunnel
  - □ Superficial peroneal nerve as it exits the fascia of the lateral compartment (anterolateral leg)

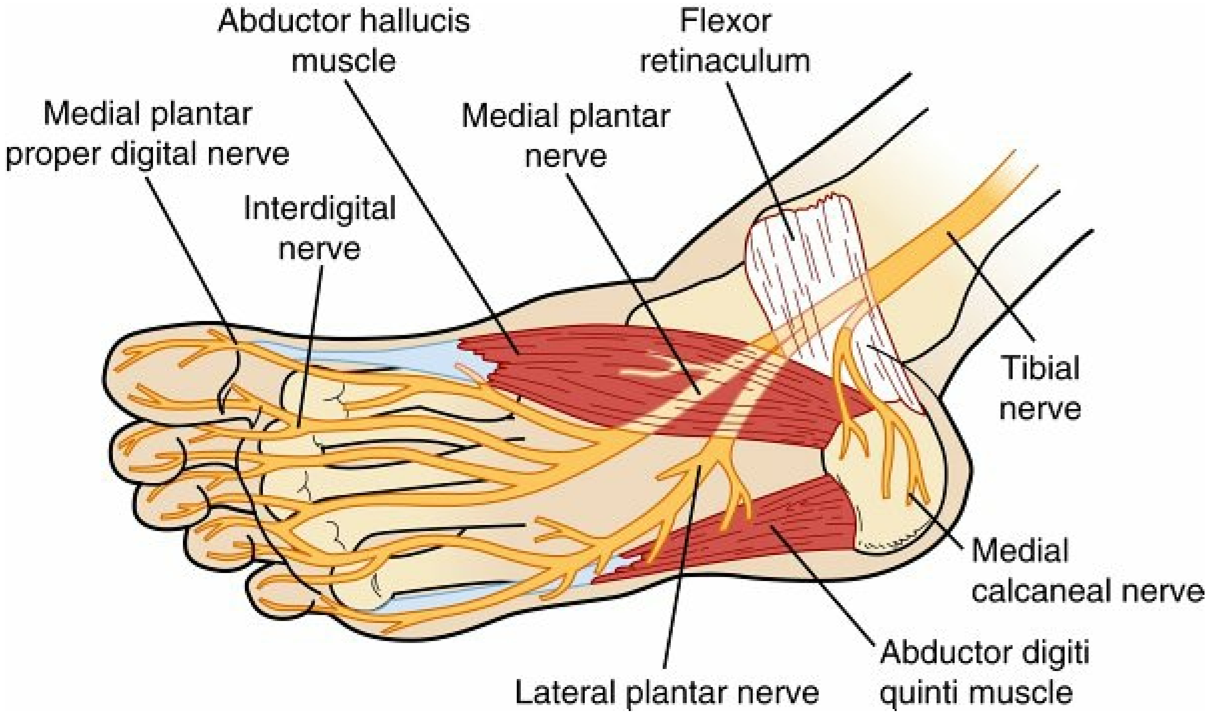


FIG. 6.20 The tarsal tunnel and its neural contents—the terminal portion of the tibial nerve, the medial plantar nerve, the lateral plantar nerve, and the medial calcaneal nerve—are illustrated, as are the digital nerves.
From Dyck P, Thomas PK: *Peripheral neuropathy,* ed 4, Philadelphia, 2005, Saunders.

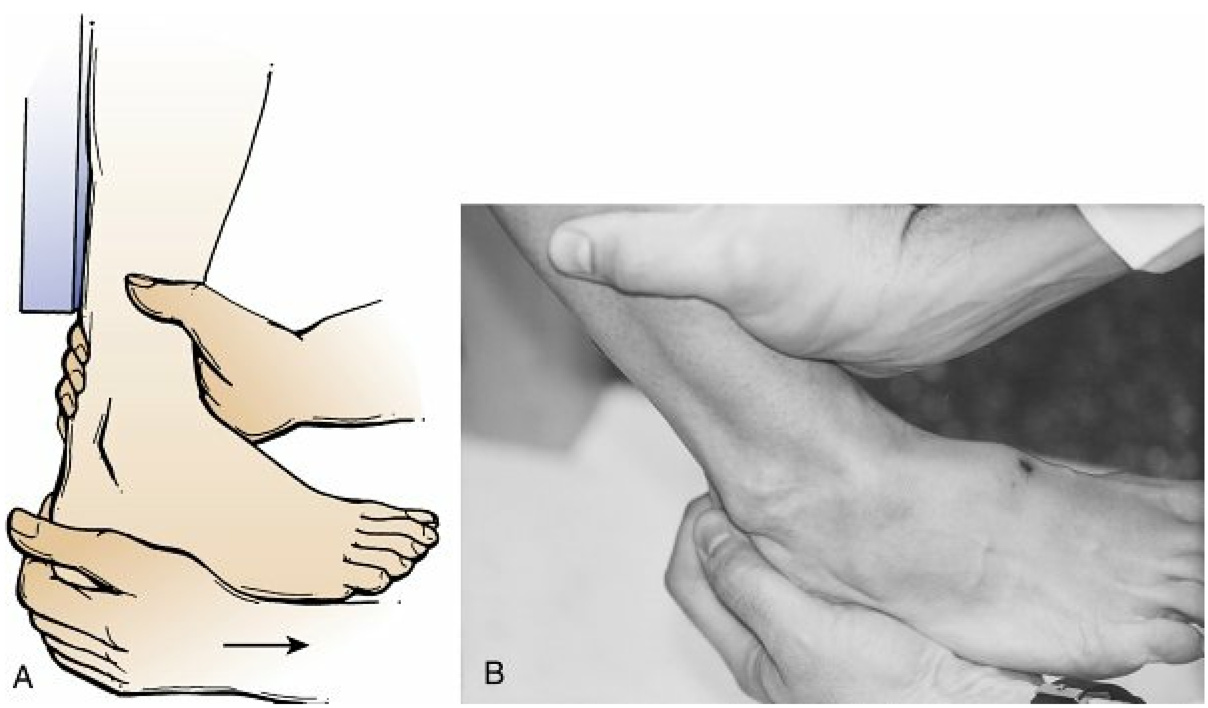


FIG. 6.21 (A and B) Anterior drawer test.
From Miller MD: *Core knowledge in orthopaedics—sports medicine,* Philadelphia, 2006, Elsevier.

- □ **Deep peroneal nerve (anterior tarsal tunnel syndrome) at the anterior ankle and hindfoot; may be compressed at inferior extensor retinaculum**

- **Web spaces can be palpated for evidence of interdigital neuromas with an associated Mulder sign.**
  - □ With dorsal pressure applied to the web space, the metatarsal heads

are compressed with the contralateral hand. An audible click along with radiating pain into the affected toes is the Mulder sign.

- **Stability of the lateral ankle ligaments can be assessed with the anterior drawer and varus talar tilt tests.**
  - Anterior drawer test (Fig. 6.21)
    - Anterior pressure on the hindfoot with the ankle in plantar flexion evaluates ATFL.
  - Varus stress test
    - Inversion of the ankle in plantar flexion evaluates the ATFL.
    - Inversion of the ankle in dorsiflexion evaluates the CFL.

Range of Motion (ROM)

- **Both passive and active ROM should be compared with contralateral side.**
- **There is a high rate of variability of normal motion of the joints of the foot and ankle, with no defined absolute normal.**
- **ROM that is limited to the contralateral side or is painful is abnormal.**
- **Increased ROM, specifically ankle dorsiflexion, is critical to identify and may be associated with an Achilles rupture.**
- **Silfverskiöld test (difference in ankle dorsiflexion with knee flexed vs. extended while hindfoot is in neutral position) can help differentiate between gastrocnemius and Achilles contractures (** Fig. 6.22).
  - Increased ankle dorsiflexion with knee flexed is indicative of an isolated gastrocnemius contracture.
  - If lack of tension on Achilles with attempted Silfverskiöld test, contracture is likely coming from the posterior capsule.

Radiographic Evaluation Of the Foot and Ankle

- **Weight-bearing views should be obtained when possible.**
- **Standard views of the ankle are:**
  - Anteroposterior (AP)
  - Lateral
    - Malleoli should be superimposed, the two sides of the talar dome should be superimposed, and the posterior fibula should intersect with the posterior tibial plafond.
  - Mortise (view of 10–15 degrees of internal rotation along transmalleolar axis)
  - Gravity, manual external rotation stress, and weight-bearing radiographs are critical in the evaluation for suspected deltoid ligament (supination–external rotation [SER] IV injury) and syndesmotic injuries (Fig. 6.23).
  - Gravity stress radiographs are equivalent to manual stress radiographs and less painful.

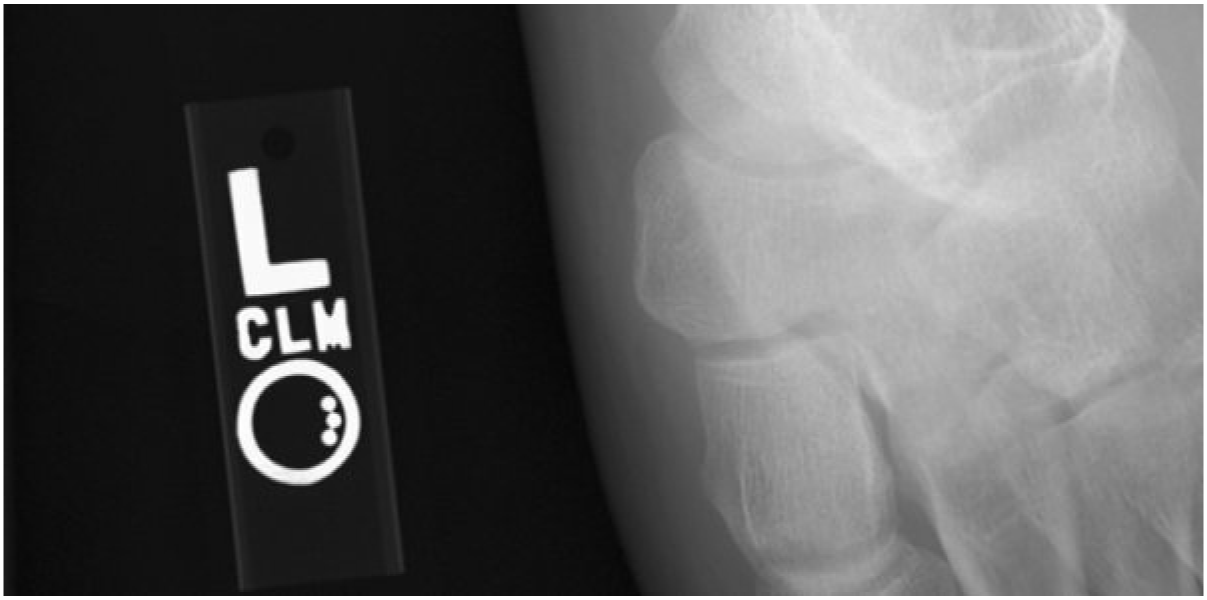


FIG. 6.23 Gravity stress ankle radiograph demonstrating that the medial clear space *(horizontal white line)* is both increased (>4 mm) and greater than the superior clear space *(vertical white line)* with associated fibular fracture displacement.

  - Anterior drawer and talar tilt views are helpful in cases of suspected ankle instability (Figs. 6.24 and 6.25).
- **Standard views of the foot should include:**
  - AP—medial and middle columns visualized
  - Lateral
    - Sagittal alignment of the foot visualized (pes planus, cavus)
    - Dorsal osteophytes are easily identified at the hindfoot/midfoot and signify early DJD.
  - Oblique—middle and lateral columns visualized
  - Special views are provided as the clinical presentation warrants (Table 6.2).
  - Comparison views of the contralateral foot or ankle are not routinely ordered but can be helpful.
    - Used primarily in the setting of a suspected ligamentous injury (syndesmotic, Lisfranc, or plantar plate of the first MTP)

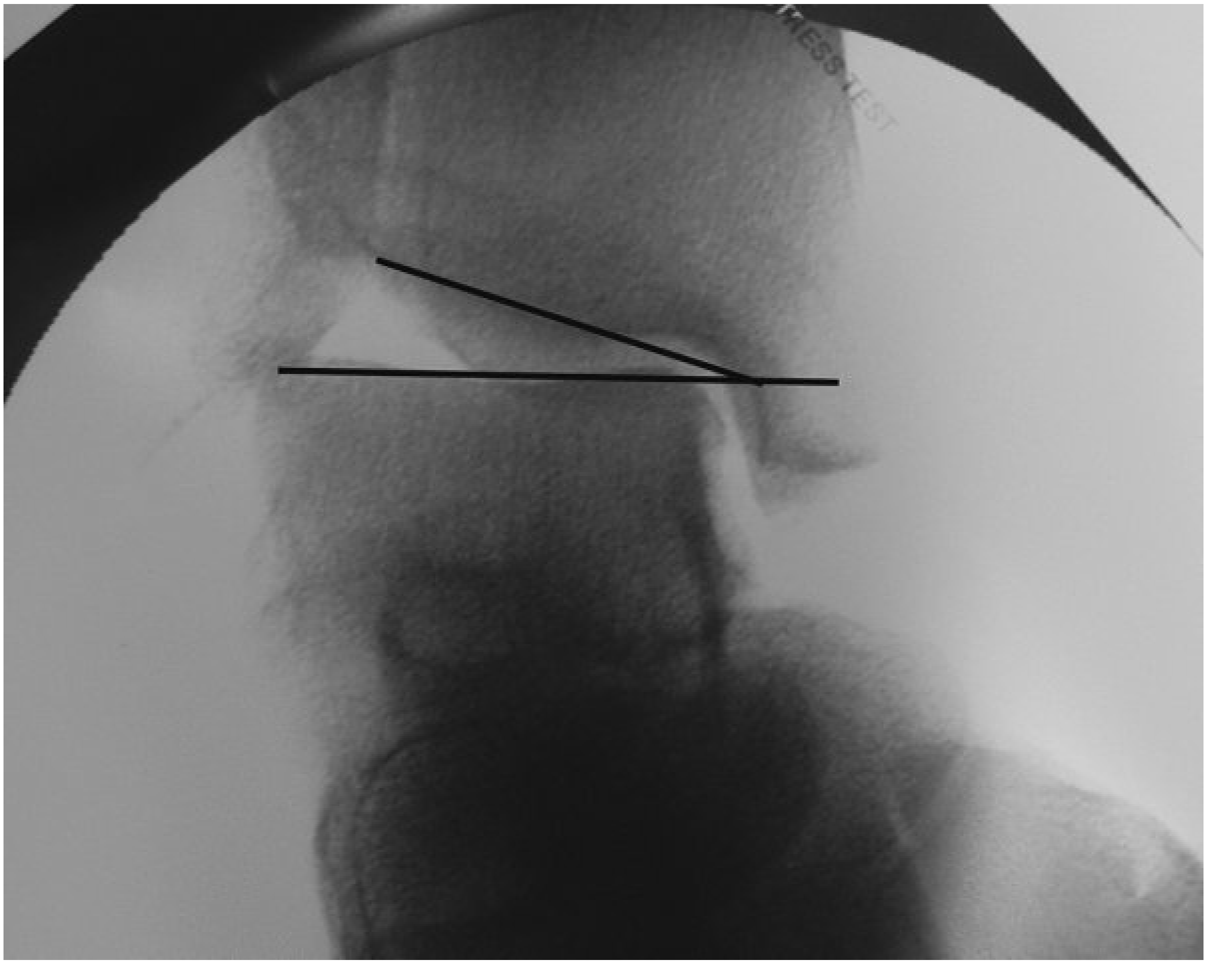


FIG. 6.24 Varus stress radiograph of a patient with significant talar tilt of more than 15 degrees.
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

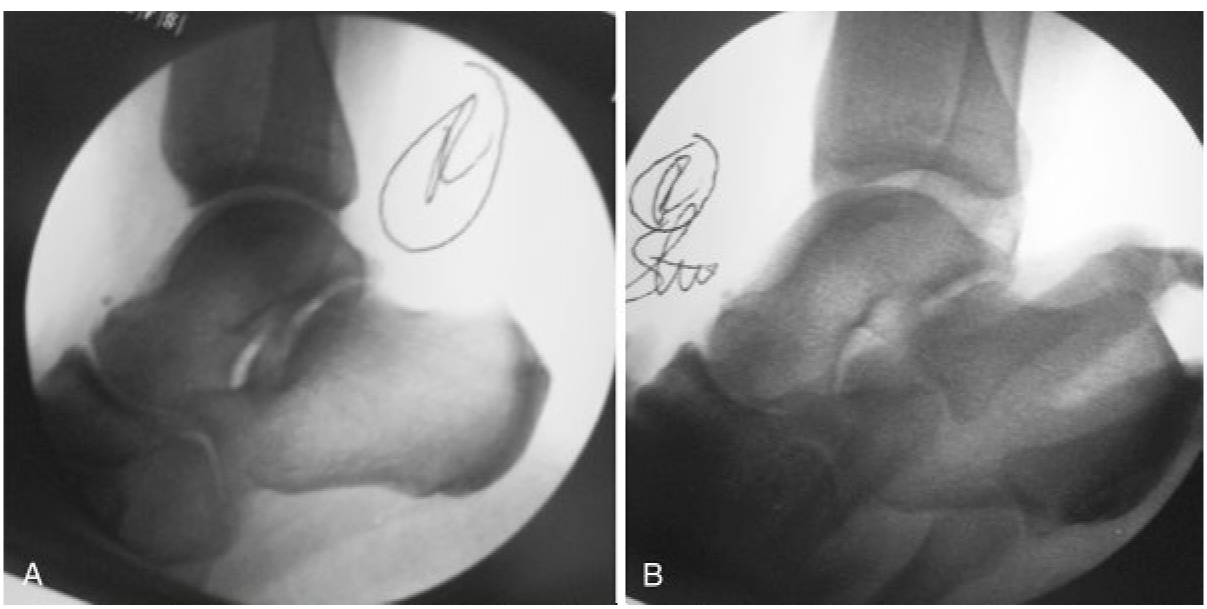


FIG. 6.25 (A) Unstressed radiograph of the ankle with the talus in normal position. (B) Anterior drawer stress radiograph demonstrating the relative anterior translation of the talus.
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

Table 6.2

Special Radiographic Views of the Foot and Ankle.

View	Specific Purpose
Canale view—15-degree internal rotation for foot	Talar neck view for fracture
Harris view—axial heel view	Calcaneus fractures
Sesamoid view—axial sesamoid view	Sesamoid fracture or arthritis
Broden view—talocalcaneal (subtalar) medial oblique views at 10-degree variations	Posterior, medial, and anterior facets of subtalar joint for fracture or arthritis

- □ Other imaging procedures
  - Computed tomography (CT) of the foot and ankle is especially useful for complex fractures (pilon, calcaneus, talus, midfoot, Lisfranc) and tarsal coalition.
  - Magnetic resonance imaging (MRI) aids evaluation of osteochondral defects, osteonecrosis, neoplasm, and other soft tissue pathologies or tendon injuries.
  - Bone scans are sensitive for identification of stress fractures.
  - Indium (In) 111–tagged white blood cell (WBC) scanning is both sensitive and specific in detection of osteomyelitis.

Adult Hallux Valgus

- *Hallux valgus* is defined as lateral deviation of the great toe with medial deviation of first metatarsal.
- **Pathophysiology: likely multifactorial**
  - Intrinsic factors such as genetic predisposition, ligamentous laxity, and predisposing anatomy (convex metatarsal head, pes planus) are contributory.
  - Extrinsic factors such as certain types of shoewear (narrow toe box, high heels) also play a role.
- **Pathoanatomy (** Fig. 6.26)
  - Medial capsular attenuation
  - Proximal phalanx drifts laterally, leading to the following conditions:
    - Plantar-lateral migration of abductor hallucis (ABH); change in position causes the muscle to plantar flex and pronate the hallux.
      - The pronation of the hallux is amplified by the proximal phalangeal attachment of the adductor hallucis (ADH).
    - Stretching of the extensor hood of the extensor hallucis longus (EHL)
    - Lateral deviation of the EHL and flexor hallucis longus (FHL), causing a muscular imbalance and deforming force for valgus progression and pronation of the great toe (Fig. 6.27)
  - First metatarsal head moves medially off the sesamoids, increasing the intermetatarsal angle (IMA).
  - Secondary contracture of the lateral capsule, adductor hallucis, and lateral metatarsal-sesamoid and intermetatarsal ligaments
- **Radiographs**
  - Multiple measurements can be obtained from standard radiographs that guide treatment options.
  - Hallux valgus angle (HVA): angle formed by line along first metatarsal shaft and line along shaft of proximal phalanx (Fig. 6.28)
    - Normal: less than 15 degrees
  - First–second IMA: angle formed by lines along first and second metatarsal shafts (Fig. 6.29)
    - Normal: less than 9 degrees
  - Hallux valgus interphalangeus (HVI) angle: angle formed by lines along shafts of the proximal phalanx and distal phalanx (Fig. 6.30)
    - Normal: less than 10 degrees
    - Associated with a congruent deformity

- Distal metatarsal articular angle (DMAA): angle formed by line along articular surface of first metatarsal and line perpendicular to axis of first metatarsal (Fig. 6.31)
  - Normal: less than 10 degrees

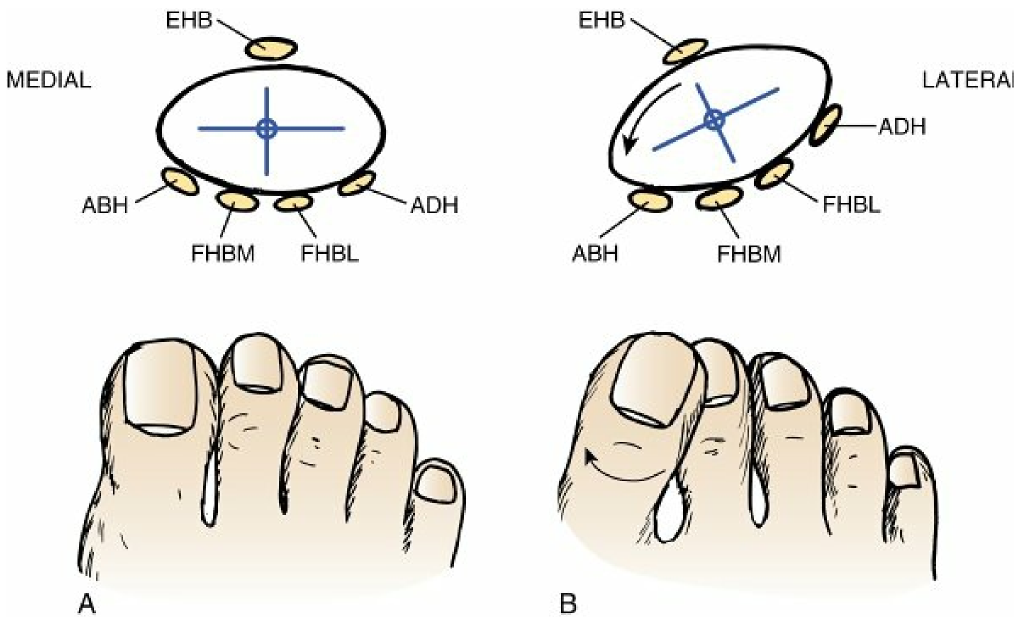


FIG. 6.26 Schematic representation of tendons around the first metatarsal head. (A) Normal articulation in a balanced state. (B) Relationship of the tendons in hallux valgus deformity. *FHBL,* Lateral head of the FHB; *FHBM,* medial head of the FHB.

From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

FIG. 6.27 Pronation of the great toe is easily noted by comparing the angulation of the nail of the great toe in relation to the floor.
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

- Increased angle associated with a congruent deformity.

□ Congruency of first MTP joint must be determined (Fig. 6.32).

- Congruency is determined by comparing the line connecting the medial and lateral edges of the first metatarsal head articular surface with the similar line for the proximal phalanx.
  - When these lines are parallel, the joint is congruent.
    - Increased DMAA
      - Distal redirectional osteotomy of the metatarsal head (medial closed-wedge osteotomy)
    - Increased HVI
      - Akin osteotomy—medial closed-wedge

osteotomy of the phalanx

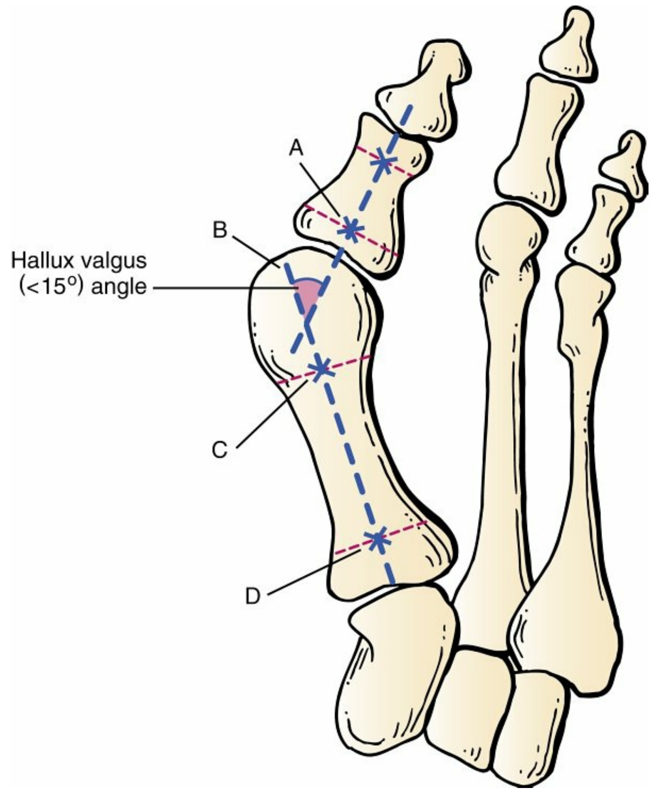


FIG. 6.28 Hallux valgus angle. Marks are placed in the middiaphyseal region of the proximal phalanx and the first metatarsal at equal distances from the medial and lateral cortices. The longitudinal axis of the proximal phalanx is determined by an axis drawn through points *A* and *B,* and the longitudinal axis of the first metatarsal is determined by a line drawn through points *C* and *D*. The hallux valgus angle is formed by the intersection of the diaphyseal axes of the first metatarsal (line *CD*) and the proximal phalanx (line *AB*).
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

- Both of these operations may be required in addition to an osteotomy of the metatarsal to correct the increased IMA. Performing these osteotomies does *not* exclude additional distal or proximal metatarsal correction.

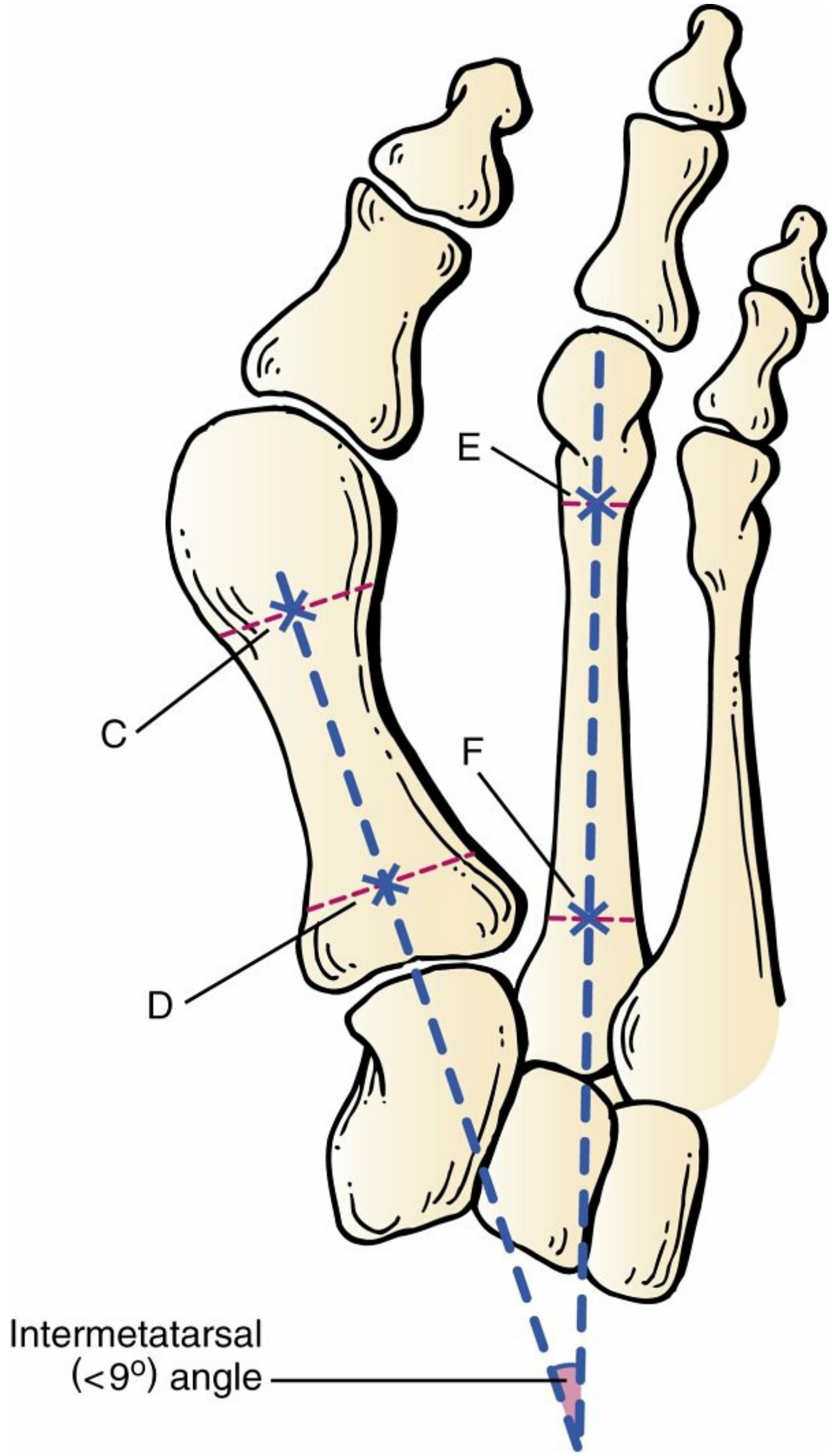


FIG. 6.29 First–second intermetatarsal angle. Middiaphyseal reference points *(X)* are placed equidistant from the medial and lateral cortices of the first (*C* and *D*) and second (*E* and *F*) metatarsals in both the proximal and distal middiaphyseal region. The longitudinal axis is drawn for both the first metatarsal (line *CD*) and the second metatarsal (line *EF*). The first–second intermetatarsal angle is formed by the intersection of these two axes (lines *CD* and *EF*).
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

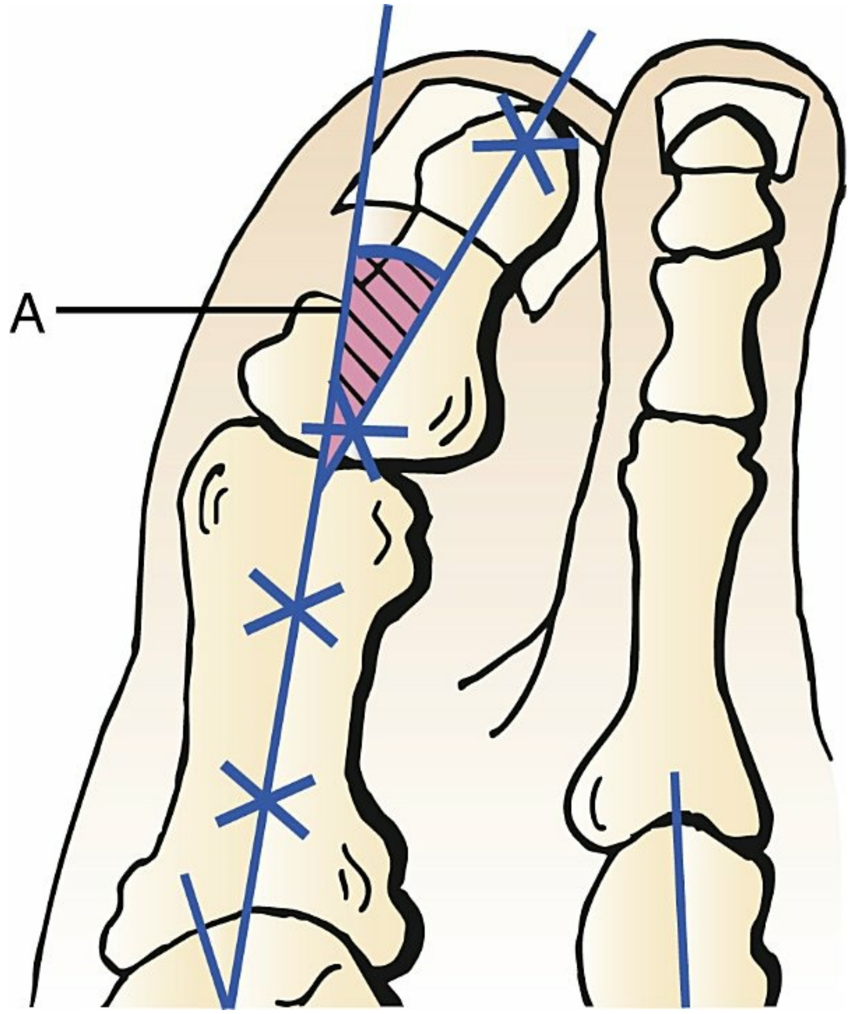


FIG. 6.30 Hallux valgus interphalangeal angle. On the proximal phalanx, reference points *(X)* are drawn at middiaphysis. On the distal phalanx reference points are placed at the distal tip of the phalanx and at the midpoint of the articular surface of the distal phalanx. A line is drawn to connect the reference points for the axes of each phalanx. Line *A* indicates the proximal phalanx axis. The intersection of the axis of the distal phalanx with the longitudinal axis of the proximal phalanx forms the hallux valgus interphalangeal angle. From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

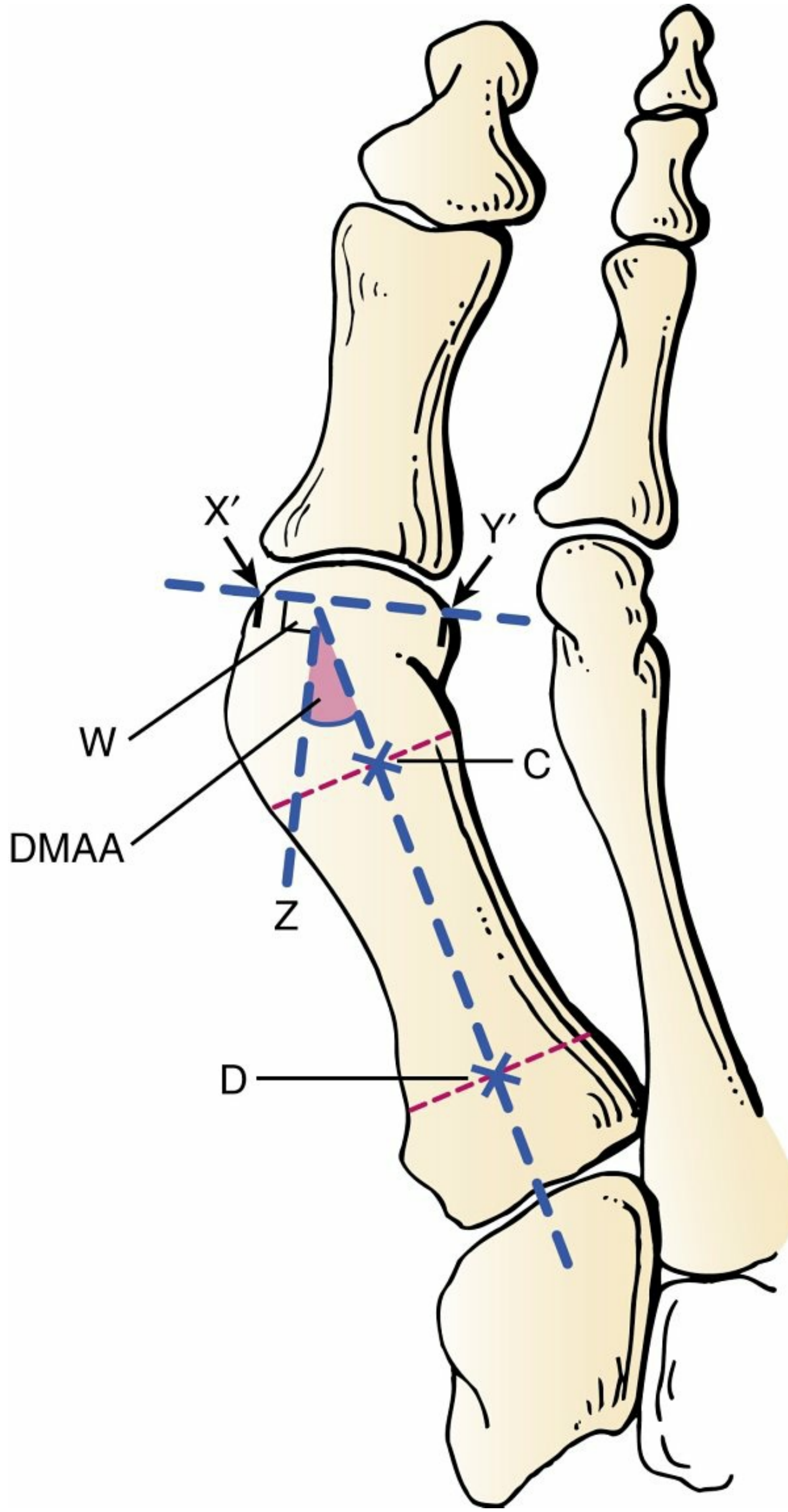


FIG. 6.31 Distal metatarsal articular angle (DMAA). The DMAA defines the relationship of the articular surface of the distal first metatarsal with the longitudinal axis of the first metatarsal. Points are placed on the most medial and lateral extents of the distal metatarsal articular surface *(X′, Y′)*. A line drawn to connect these two points defines the "lateral slope of the articular surface." Another line through points *W* and *Z* is drawn perpendicular to the first line X′Y′. A third line through points *C* and *D* (defined in Fig. 6.30) defines the longitudinal axis of the first metatarsal. The angle subtended by the perpendicular line (*WZ*) and the longitudinal axis of the first metatarsal (line *CD*) defines

the DMAA.

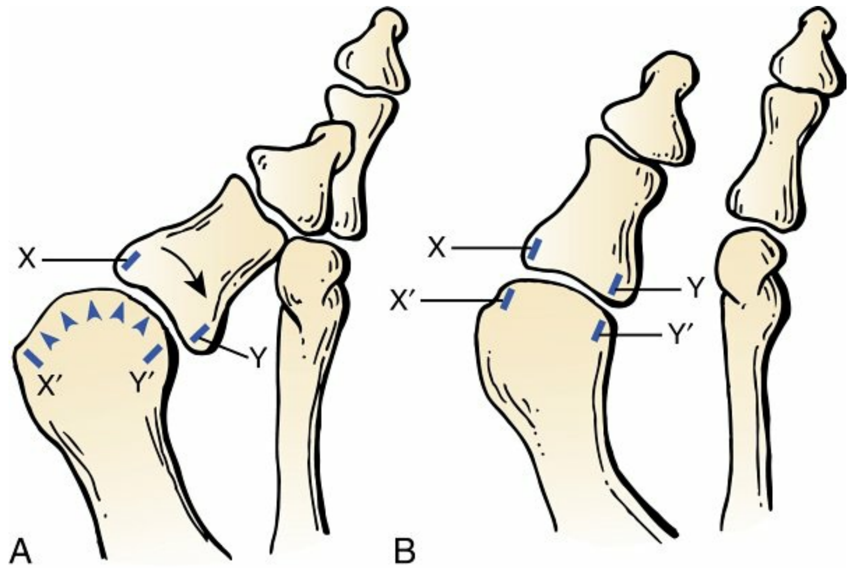


FIG. 6.32 Congruency versus subluxation. (A) Hallux valgus deformity with subluxation (noncongruent joint) is characterized by lateral deviation of the articular surface of the proximal phalanx in relation to the articular surface of the distal first metatarsal. (B) Hallux valgus deformity with a nonsubluxated (congruent) metatarsophalangeal joint is caused most often by lateral inclination of the distal metatarsal articular surface. Points *X* and *Y* determine the medial and lateral extents of the articular surface of the proximal phalanx; points *X′* and *Y′* determine the medial and lateral extents of the metatarsal articular surface. Note the lateral slope of the distal metatarsal articular surface.

FIG. 6.33 (A) Preoperative anteroposterior radiograph of a patient with a hallux valgus deformity (indicated by *white lines*) with associated stiffness and pain within the joint. (B) Postoperative radiograph demonstrates correction of both the hallux valgus deformity and the intermetatarsal angle without the need for an additional metatarsal osteotomy.

- When these lines are divergent, the joint is incongruent.
  - Patients may present with both an incongruent joint and increased DMAA or HVI in severe deformities.

□ Position of sesamoids should be noted; in more severe or chronic deformities, the sesamoids are frequently displaced laterally.

□ Presence of degenerative changes in first MTP joint and first TMT joint should be noted.

- A stiff or arthritic MTP joint requires a first MTP arthrodesis.

▪ **Nonoperative treatment**

□ Adjusting shoewear and increasing the size of the toe box may limit pain with pressure along the prominent dorsomedial eminence.

□ There is no role for "corrective" braces or splints.

▪ **Operative treatment**

□ The best indication for operative intervention is pain that has not responded to adjustments in shoewear or activity. Surgical correction of a hallux valgus deformity is *not* a cosmetic procedure.

□ The appropriate surgical procedure is determined by the abnormal radiographic angular measurements in concordance with underlying clinical abnormalities.

- The patient's physical findings and associated pathology dictate the appropriate surgical procedure regardless of the angular measurements.
  - First MTP fusion required for following conditions; IMA will correct with realignment of first MTP; concomitant metatarsal osteotomy is *not* required (Fig. 6.33).
    - Rheumatoid arthritis (RA)
    - Osteoarthritis
      - Painful or stiff first MTP—deformity cannot be passively corrected
    - Spasticity
      - Stroke
      - Cerebral palsy
  - Lapidus (first TMT realignment arthrodesis) required for:
    - Ligamentous laxity
    - First TMT DJD
- Procedures never appropriate in isolation (high recurrence rate)
  - Distal soft tissue release (modified McBride procedure)
    - Modification—retention of the lateral (fibular) sesamoid to avoid hallux varus
  - Medial eminence resection
  - Medial capsular imbrication
  - Isolated osteotomy without associated soft tissue correction
- Algorithmic approach to identifying the appropriate surgical intervention is listed in Box 6.1
  - All patients should undergo a soft tissue release with all associated osteotomies and first TMT arthrodesis (Lapidus procedure) (Fig. 6.34).
  - **IMA 13 degrees or less and HVA 40 degrees or less**
    - Distal metatarsal osteotomy (chevron)
    - Distal soft tissue release
    - Medial eminence resection and capsular repair
  - **IMA greater than 13 degrees or HVA greater than 40 degrees**
    - Proximal metatarsal osteotomy/scarf
    - Distal soft tissue release
    - Medial eminence resection and capsular repair
  - Instability of first TMT/joint hyperlaxity
    - Lapidus procedure (fusion of first TMT joint) (Fig. 6.35)
    - Soft tissue release
    - Medial eminence resection and capsular repair
  - Increased DMAA (>10 degrees)

- Distal medial closed-wedge metatarsal osteotomy in addition to what is required by angular measurements (Fig. 6.36)
- IMA 13 degrees or less and HVA 40 degrees or less
  - Distal biplanar closed-wedge metatarsal osteotomy
    - Translates and redirects the metatarsal head simultaneously.
- IMA greater than 13 degrees or HVA greater than 40 degrees
  - Proximal metatarsal osteotomy *and* distal medial closed-wedge metatarsal osteotomy

Box 6.1 Algorithmic Approach to Surgical Correction of Hallux Valgus

IMA ≤13 degrees AND HVA ≤40 degrees

Distal metatarsal osteotomy (chevron)

IMA >13 degrees OR HVA >40 degrees

Proximal metatarsal osteotomy

Instability of the first TMT/joint laxity

Lapidus (fusion of first TMT joint)

Arthritis or spasticity

First MTP fusion

Increased DMMA

Distal metatarsal redirectional osteotomy in addition to metatarsal translational osteotomy

HVI

Akin osteotomy

- Instability of first TMT/joint hyperlaxity
  - Lapidus procedure *and* distal medial closed-wedge metatarsal osteotomy
  - If there is arthritis or pain at the first TMT, consider a Lapidus procedure
- Hallux valgus interphalangeus
  - Akin osteotomy
    - Can be done in isolation if no other deformity present
    - Commonly performed in addition to procedures required to correct HVA and IMA (Fig. 6.37)

□ Operative complications

- Avascular necrosis (AVN)
  - Distal metatarsal osteotomy and lateral soft tissue release may be performed simultaneously without increased risk of AVN.
    - Intraoperative laser Doppler study demonstrated that medial capsulotomy primary is insult to metatarsal head blood flow.
    - Care must be taken with vascular pedicle dorsolaterally.
- Recurrence
  - Can occur with any procedure—highly associated with:
    - Undercorrection of IMA
    - Isolated soft tissue reconstruction (modified McBride procedure)
    - Isolated resection of the medial eminence

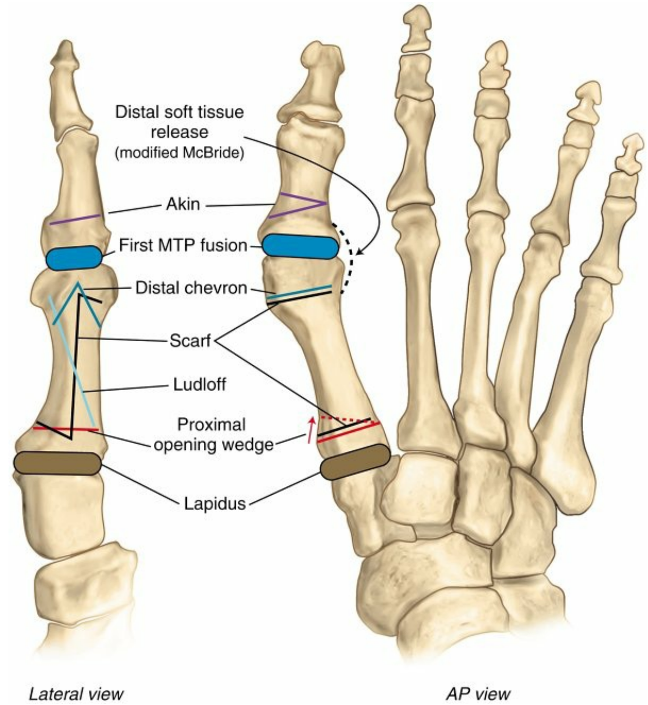


FIG. 6.34 Lateral and AP drawings delineating various surgical options for management of hallux valgus. It is important to note that a distal soft tissue release is performed in conjunction with all corrections. The exception to this is a hallux MTP joint fusion.

FIG. 6.35 (A) Preoperative radiograph of a patient with hallux valgus and first tarsometatarsal instability. (B) Correction was successfully achieved with a Lapidus procedure using two crossed screws for fixation.
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

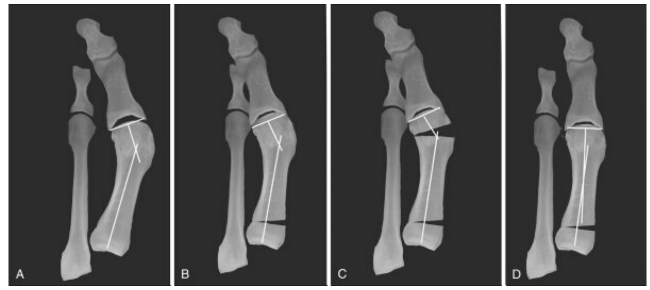


FIG. 6.36 (A) Hallux valgus deformity secondary to increased intermetatarsal and distal metatarsal articular angles. (B) Correction of the IMA with a proximal osteotomy causes the proximal phalanx to override the second toe secondary to the DMAA. (C) A distal closed-wedge osteotomy is performed. (D) With closure of the osteotomy, the phalanx is now directed parallel to the metatarsal shaft, correcting the overall deformity.

            - Persistent lateral subluxation of the sesamoids
- Dorsal malunion
    - Results in transfer metatarsalgia—highly associated with:
        - Lapidus procedure (first TMT fusion)
            - Often related to inadequate preparation of plantar joint (depth of first TMT is ≈30 mm)
        - Proximal crescentic osteotomy
- Hallux varus—associated with:
    - Resection of the fibular sesamoid (original McBride procedure)

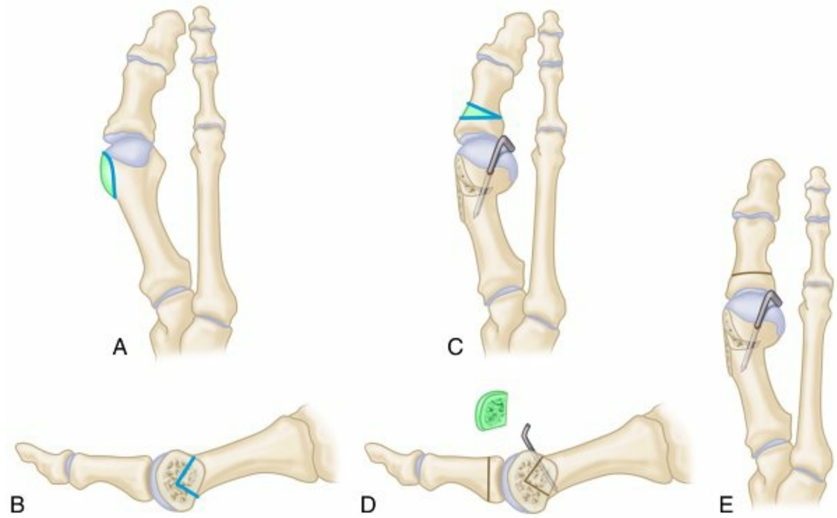


FIG. 6.37 (A) Resection of medial eminence parallel to medial border of foot. (B) Chevron osteotomy cut is made, and metatarsal head is shifted laterally 2.5 to 3 mm. (C) Osteotomy is fixed with 0.045-inch smooth pin, and protruding medial border of metatarsal is osteotomized flush with metatarsal head. (D) The Akin cut parallels concavity at base of proximal phalanx, and a 1-mm wedge of bone is removed. (E) Suture closure of Akin osteotomy corrects residual valgus of hallux.
From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier.

  - Overresection of the medial eminence
  - Excessive lateral release
  - Overcorrection of IMA
- Nonunion
  - Highest risk associated with a Lapidus procedure

Juvenile and Adolescent Hallux Valgus

- **Several critical factors separate juvenile and adolescent patients from adult patients with hallux valgus deformity.**
    - **Recurrence of the deformity after surgical correction is the most common complication (Fig. 6.38).**
    - Proximal osteotomy is performed through the medial cuneiform in the patient with an open first metatarsal physis.
        - If arthrodesis of the first TMT is required for laxity, surgical intervention is delayed until physeal closure.
    - The deformity is secondary to underlying bony and ligamentous anatomy, which must be addressed to prevent recurrence.
        - Varus of the first metatarsal with a large IMA is commonly present.
        - DMAA is typically increased.
        - HVI may be present.
        - Ligamentous laxity may be present, and a history of Ehlers-Danlos or Marfan syndrome should be elicited.
            - Examination for generalized hyperlaxity should be performed to determine whether a first TMT arthrodesis is required.
    - Family history is frequently positive for hallux valgus.
- **Operative correction**
    - Single, double, or triple osteotomies are required to correct the deformity, with application of the same principles as described for evaluation of adult hallux valgus.
    - In cases of ligamentous laxity, a first TMT arthrodesis substitutes for a proximal osteotomy to correct the IMA. The first metatarsal physeal plate must be closed.
    - Single osteotomy
        - HVI
            - Akin osteotomy
        - Increased DMAA, IMA 13 degrees or less
            - Biplanar distal chevron osteotomy for DMAA and IMA
    - Double osteotomy
        - HVI with increased DMAA, IMA 13 degrees or less
            - Akin osteotomy for HVI
            - Biplanar distal chevron osteotomy for DMAA and IMA
        - IMA greater than 13 degrees, with increased DMAA

- Biplanar distal chevron osteotomy for DMAA
  - Medial closed-wedge osteotomy needed after a proximal correction
- Open-wedge medial cuneiform osteotomy

- Triple osteotomy
  - HVI with increased DMAA, IMA greater than 13 degrees
    - Akin osteotomy for HVI
    - Biplanar distal chevron osteotomy for DMAA
    - Open-wedge medial cuneiform osteotomy

Hallux Varus

- **Etiology**
- **Medial deviation of the great toe is most often an iatrogenic deformity secondary to overcorrection of hallux valgus.**
  - Overresection of the medial eminence
  - Excessive lateral release
  - 0-degree or negative IMA (Fig. 6.39)
- **Treatment**
  - Nonoperative treatment
    - Limited to accommodation of the deformity with shoe modifications and shoe stretching
  - Operative treatment
    - Dependent on whether deformity is flexible (reducible) or rigid (irreducible)
    - Flexible deformity can be corrected with a soft tissue procedure.
      - Release of abductor hallucis muscle and fascia
      - Transfer of a portion of EHL or extensor hallucis brevis (EHB) tendon under the transverse intermetatarsal (IM) ligament to the distal metatarsal neck (taken from lateral to medial) (Fig. 6.40)
        - The distal portion of the tendon is left intact, creating a dynamic stabilizer to correct the deformity.
        - Suture button augmentation is commonly used with a tendon reconstruction but should not be utilized in isolation.
    - Fixed deformity, deformity with limited first MTP motion, joint pain, or presence of first MTP DJD is treated with a first MTP arthrodesis.

Lesser-Toe Deformities

Anatomy and Function

- **Static stability of the lesser toes is provided by the congruency of the MTP and interphalangeal joints.**
  - Plantar plate—plantar aponeurosis and capsule—provides a soft tissue block to metatarsal head depression and prevents hyperextension of the MTP joint.
  - Persistent hyperextension at MTP joint may lead to attenuation and weakening of plantar structures.
- **Dynamic stability is provided by the various tendons that insert on lesser toes (** Fig. 6.41).
  - Extensor digitorum longus: primary extensor of MTP joint
    - Runs through a sling over dorsal surface of MTP joint before splitting into a central slip that inserts on the middle phalanx and two dorsolateral slips that reconverge to insert at the base of the distal phalanx.
    - Distal extensor effect of the EDL is neutralized when the proximal phalanx is dorsiflexed, as in hammer-toe or claw-toe deformity.
    - There is no EDL to the fifth digit.
  - Extensor digitorum brevis (EDB) extends PIP joints and inserts on lateral aspects of EDL tendons on all but the fifth toe.
  - Flexor digitorum longus: primary plantar flexor of distal interphalangeal (DIP) joints as it inserts on plantar aspects of distal phalanges; also weakly plantar flexes MTP joints.
  - Flexor digitorum brevis (FDB) splits at the level of the MTP joint and inserts on plantar lateral aspects of the middle phalanges. The FDB is the primary plantar flexor of the PIP joints.
- **Intrinsic muscles of the foot include the lumbricals, which originate from the FDL tendon and insert on the extensor sheath over the MTP joints, and four dorsal and three plantar interossei muscles, which insert on the medial aspects of the proximal phalanges.**
  - These muscles act similarly to the intrinsic muscles of the hand, flexing the MTP joints and extending the PIP and DIP joints.
  - Pull of the intrinsics is plantar to the rotational axis of the MTP joints.
  - Plantar translation of the metatarsal head after a distal osteotomy of the metatarsal places the intrinsics dorsal to the axis of rotation of the MTP joint, creating the “floating toe.”

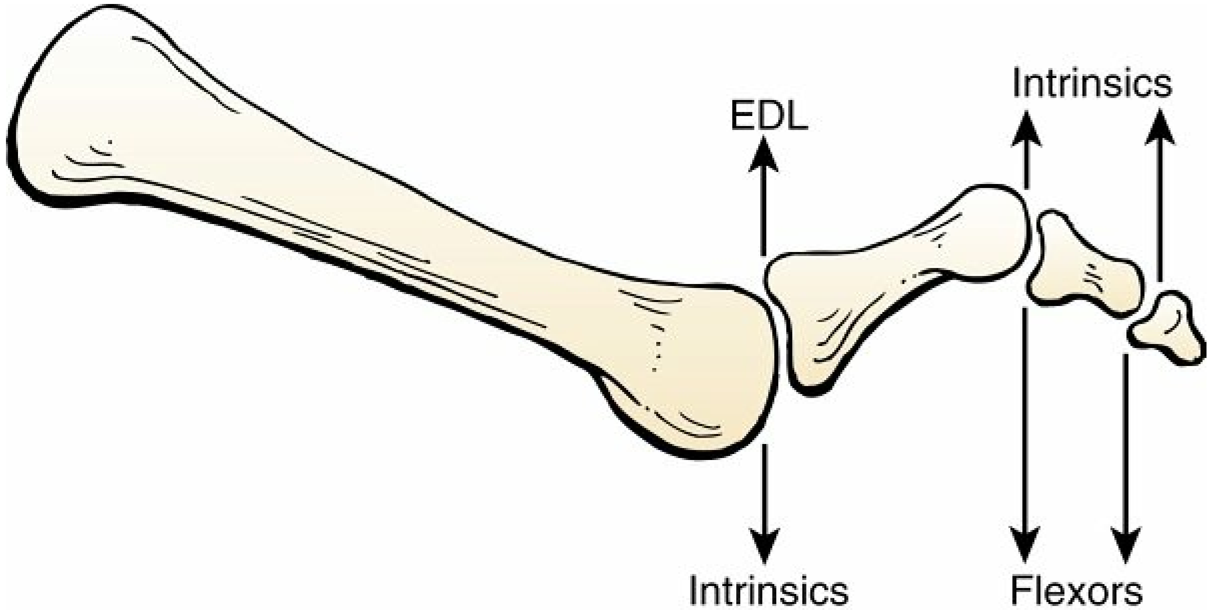


FIG. 6.41 Diagram demonstrates the relationship of the intrinsic and extrinsic muscles about a lesser toe. The smaller intrinsic muscles are overpowered by the extrinsic muscles, leading to a hammer-toe deformity.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

- **Extrinsic muscles (EDL and FDL) overpower intrinsic muscles in positioning the lesser toes in hammer- and claw-toe deformities, with the EDL driving MTP joint extension and the FDL driving PIP and DIP joint flexion.**
  - EDL is also a weak antagonist to flexion at interphalangeal joints, and likewise, the FDL is a weak antagonist to extension at MTP joint.
  - There is no flexor (FDL/FDB) attachment to the proximal phalanges.
  - Dorsiflexion of the proximal phalanx at MTP joint neutralizes these weak antagonist effects and accentuates the developing deformity.
- **Lesser-toe deformities occur much more commonly in women (up to a 5:1 ratio); difference thought to be secondary to high-fashion shoewear that constricts the forefoot and maintains the MTP joints in hyperextension.**
  - A hammer-toe deformity most commonly involves the second toe, because it is relatively longer than the other lesser toes. A short toe box causes the second toe to buckle and extend at the MTP joint.
  - Long-term positioning of the MTP joint in hyperextension will attenuate the static plantar structures, allowing depression of the metatarsal head, distal migration of the fat pad, and imbalance of the dynamic forces on the toe, as described earlier.

Deformities

- **Hammer-toe deformity**
  - The characteristic hammer-toe deformity is flexion of the PIP joint. With weight bearing, the MTP joint appears dorsiflexed; this should correct with elevation of the foot off the ground (Fig. 6.42).
    - Contracture of the FDL is responsible for the flexible

hammer-toe deformity

- The term *complex hammer toe* refers to concomitant dorsiflexion of the MTP joint that does not correct and is more appropriately termed (and treated as) a *claw toe*.
- Treatment depends on the flexibility of the deformity (Table 6.3).
  - Flexible deformity
    - Nonoperative—protective padding, tall toe-box shoes, corrective hammer-toe splints are effective.
    - Operative—flexor tenotomy or flexor to extensor tendon transfer
  - Fixed deformity
    - Nonoperative—accommodative shoes and protective padding can minimize callus formation. A corrective splint should *not* be used (Fig. 6.43).

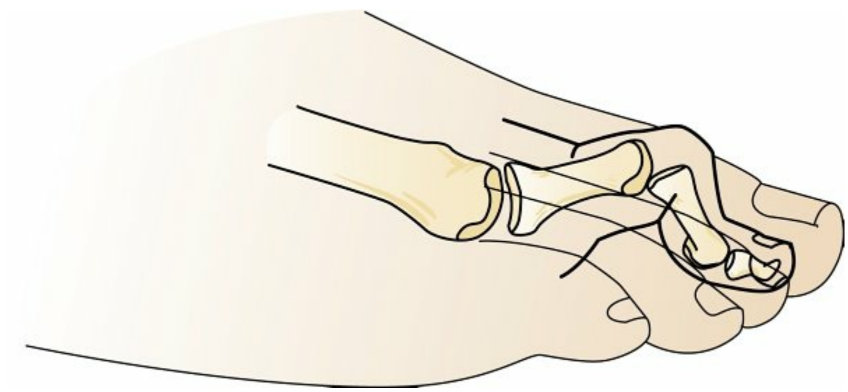


FIG. 6.42 Hammer-toe deformity.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle*, Philadelphia, 2007, Elsevier.

    - Operative—PIP arthroplasty (resection of distal neck and head of proximal phalanx) or PIP arthrodesis

- **Claw-toe deformity (intrinsic minus toe)**
  - Characterized by flexion of the PIP and DIP joints in the setting of fixed hyperextension of the MTP joint (Fig. 6.44)

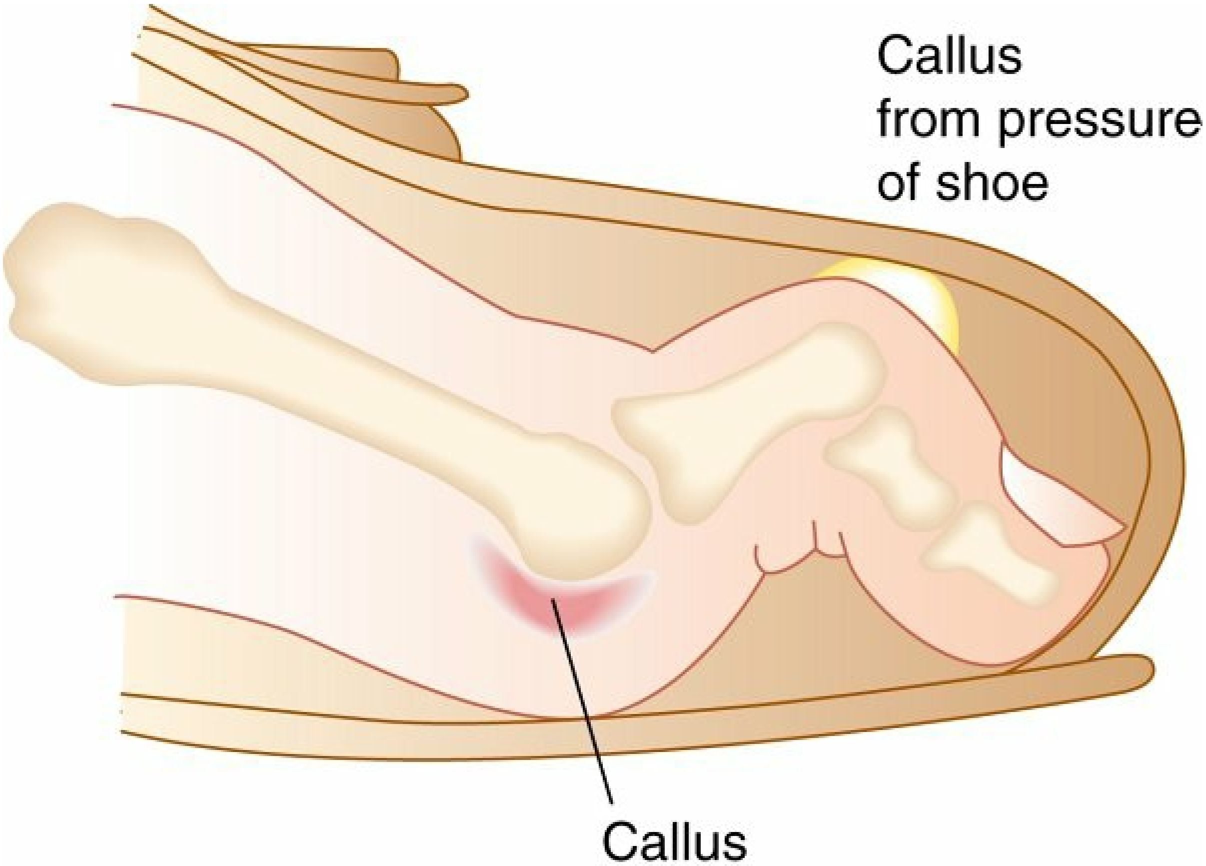


FIG. 6.43 Dorsal aspect of the proximal interphalangeal joint strikes the toe box, leading to callus formation. An intractable plantar keratosis may develop beneath the metatarsal head.
From DeLee J: *DeLee and Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2011, Saunders.

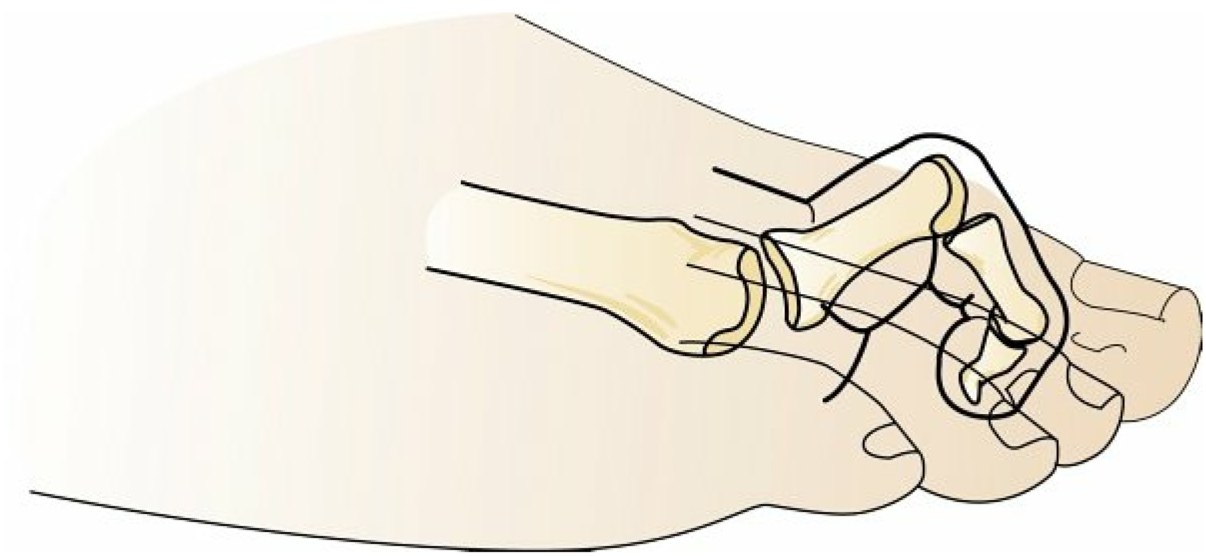


FIG. 6.44 Claw-toe deformity, characterized by fixed hyperextension of the MTP joint with flexion of the PIP and DIP joints.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.

- Clawing typically involves multiple toes and is often bilateral.
  - Results from dysfunction of the intrinsic musculature
  - Often a neurogenic etiology
- Cavus deformity, neuromuscular diseases that affect the balance of the

extrinsic and intrinsic musculature, inflammatory arthropathies that lead to attenuation of soft tissue structures and instability of the MTP joint, and trauma have all been implicated in the etiology of claw toes.

- Claw toes are a noted complication of compartment syndrome involving the deep compartments of the foot.
- Treatment depends on the flexibility of the deformity (see Table 6.3).
  - Flexible deformity
    - Nonoperative—shoe modification, padding over any prominent or painful callosities, and use of orthotics to offload and support a potentially painful, plantarly displaced metatarsal head
    - Operative
      - Flexor-to-extensor tendon transfer of the FDL alters the function of the FDL to function as an intrinsic and to maintain the correction (Fig. 6.45).
        - Often leads to stiffness of MTP joint
      - Lengthening of the EDL and EDB is typically required.
  - Fixed deformity
    - Nonoperative—shoe modification, padding over any prominent or painful callosities, and use of orthotics to offload and support a potentially painful, plantarly displaced metatarsal head
    - Operative
      - PIP arthroplasty or arthrodesis, along with MTP joint capsulotomy and extensor lengthening
      - Dislocated MTP joint requires use of a Weil or distal metatarsal shortening osteotomy to reduce the MTP joint (Fig. 6.46).

- **Mallet-toe deformity**
  - A mallet toe consists of an isolated flexion deformity at the DIP joint (Fig. 6.47).
  - Treatment (see Table 6.3)
    - Nonoperative—similar methods to those used in treating hammer-toe and claw-toe deformities

Table 6.3

Surgical Treatment of Lesser-Toe Deformities.

Deformity	Surgical Options	Comments
HAMMER TOE		
Flexible	Girdlestone-Taylor FDL flexor-to-extensor tendon transfer	Add EDL lengthening or tenotomy if active flexion <10–15 degrees
Fixed	PIP arthroplasty or arthrodesis	
MALLET TOE		
Flexible	FDL tenotomy	
Fixed	Excisional arthroplasty or arthrodesis of the DIP joint	
CLAW TOE		
Flexible	FDL flexor-to-extensor tendon transfer with EDB tenotomy and EDL lengthening	Look for underlying neuromuscular etiology when >2 toes are involved
Fixed	Weil osteotomy (oblique shortening osteotomy of the metatarsal) with MTP capsulotomy Extensor lengthening PIP arthroplasty or arthrodesis	
Crossover second toe	Extensor digitorum brevis tendon transfer with medial capsular release Flexor-to-extensor tendon transfer (for more severe MTP deformity)	Weil osteotomy should be performed if the MTP is dislocated

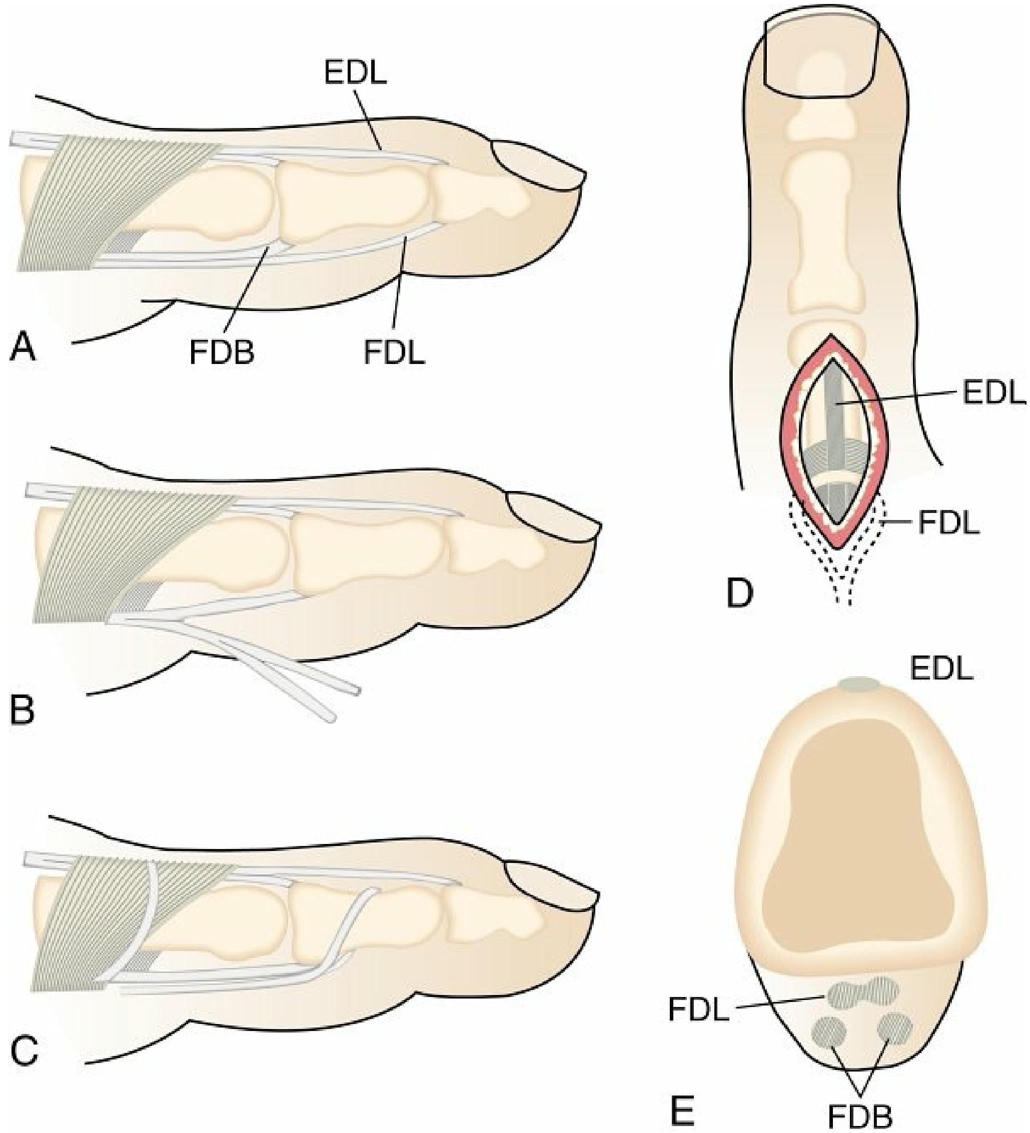


FIG. 6.45 Technique of flexor tendon transfer. (A) Lateral view shows flexor digitorum longus, flexor digitorum brevis, and extensor digitorum longus. (B) The flexor digitorum longus is detached through a distal puncture wound and is delivered through a transverse incision at the plantar metatarsophalangeal joint flexion crease. (C) The tendon is split longitudinally, and each half is delivered on either side of the proximal phalanx and then sutured into either the extensor expansion or the corresponding limb of the flexor tendon. (D) Dorsal view shows transferred flexor digitorum longus tendon. (E) Cross-sectional view shows the characteristic position of the flexor digitorum longus tendon. It is deep to the flexor digitorum brevis and is characterized by a midline raphe.
From DeLee J: *DeLee and Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2011, Saunders.

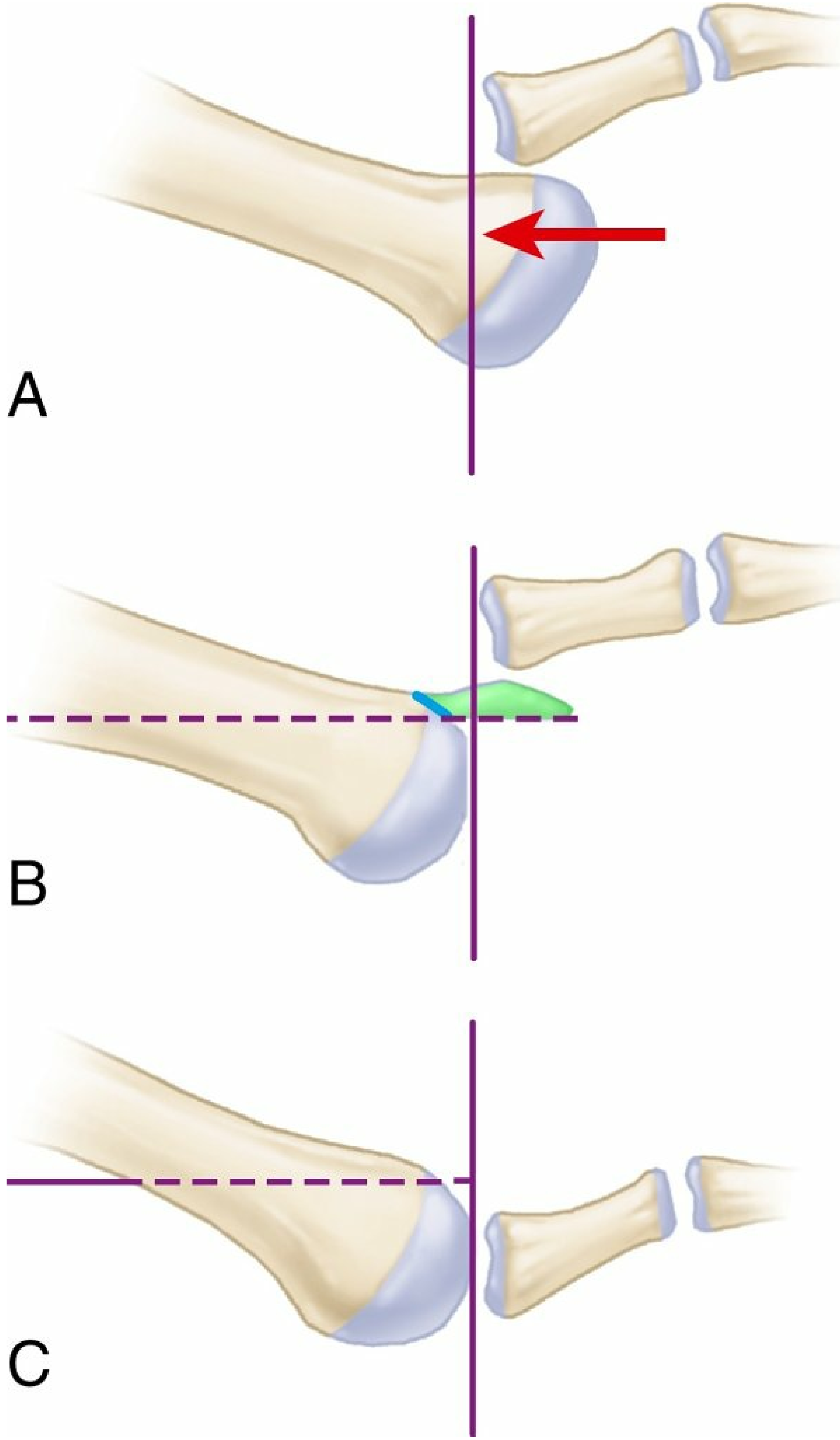


FIG. 6.46 Weil osteotomy. (A) Before surgery. Note the level of cut as denoted by the *red arrow*. (B) After proximal displacement of metatarsal head. (C) After resection of distal tip of dorsal fragment. From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier. Redrawn from Vandeputte G et al: The Weil osteotomy of the lesser metatarsals: a clinical and pedobarographic follow-up study, *Foot Ankle* 21:370, 2000.

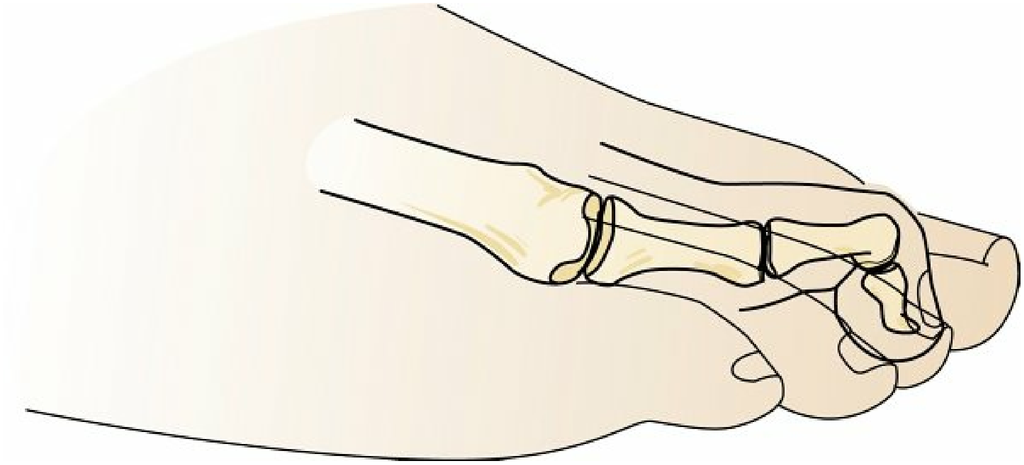
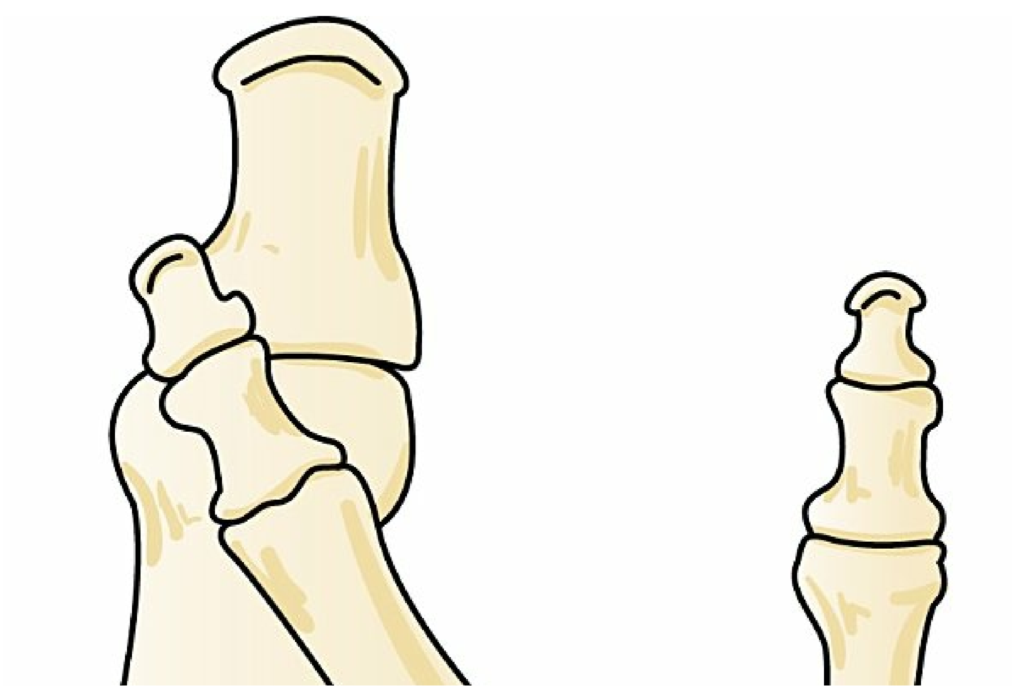


FIG. 6.47 Mallet-toe deformity.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.



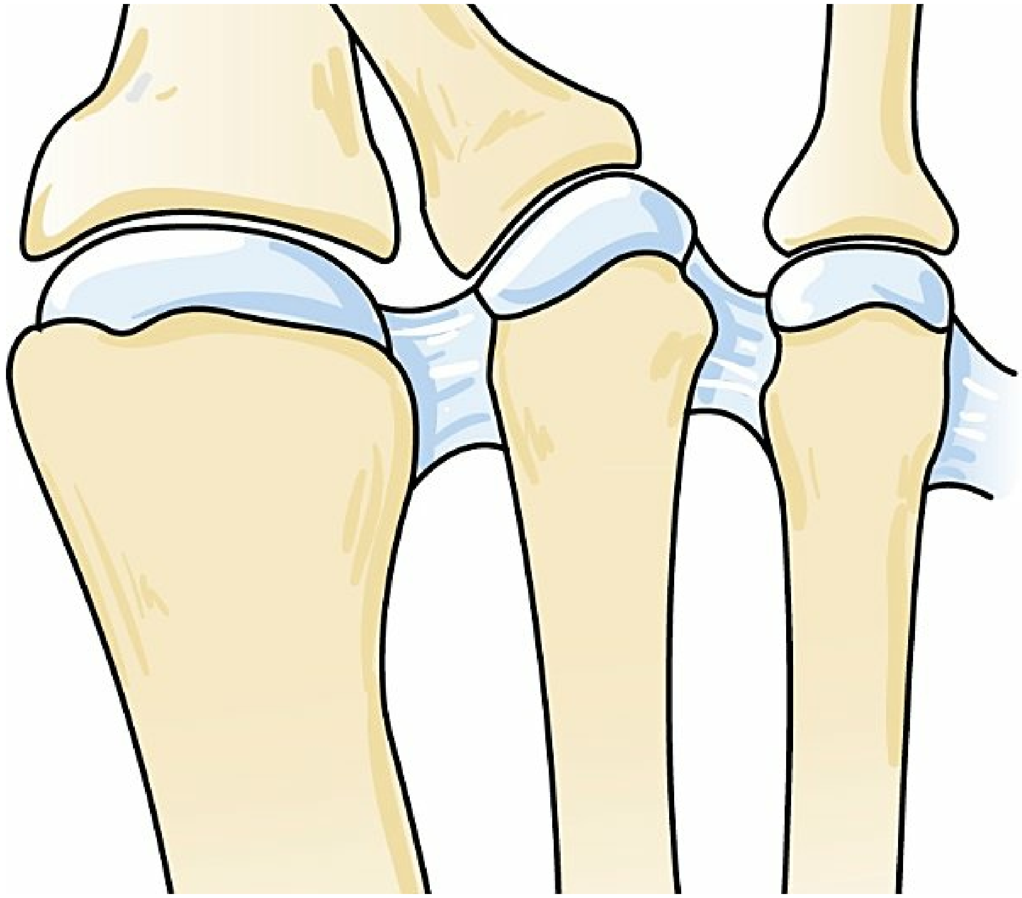


FIG. 6.48 A crossover-toe deformity resulting from a rupture of the lateral collateral ligament and plantar plate and contracture of the medial collateral ligament.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.

- Operative
    - Flexible deformity
        - Flexor tenotomy
    - Fixed deformity
        - DIP arthroplasty (excision of the distal neck and head of the middle phalanx) or DIP fusion
        - Extensor repair can be performed to minimize recurrence.

▪ **Crossover-toe deformity (see** Table 6.3)
- □ Multiplanar instability of the second toe may cause the toe to lie dorsomedially relative to the hallux (Fig. 6.48).
    - Commonly referred to as a *crossover second toe,* this deformity:
        - Requires disruption of the plantar plate—KEY component
        - Requires attenuation of the lateral collateral ligament
        - May be iatrogenic—caused by steroid injection within the MTP joint, which results in plantar plate attenuation

□ Treatment

- Nonoperative—toe taping and corrective splints can minimize the discomfort but will not permanently correct the deformity.
- Operative
    - For complete tears of the plantar plate, plantar plate repair has been advocated, with promising results. Plantar plate repair typically requires a shortening osteotomy of the distal metatarsal to aid in visualization and tissue repair.

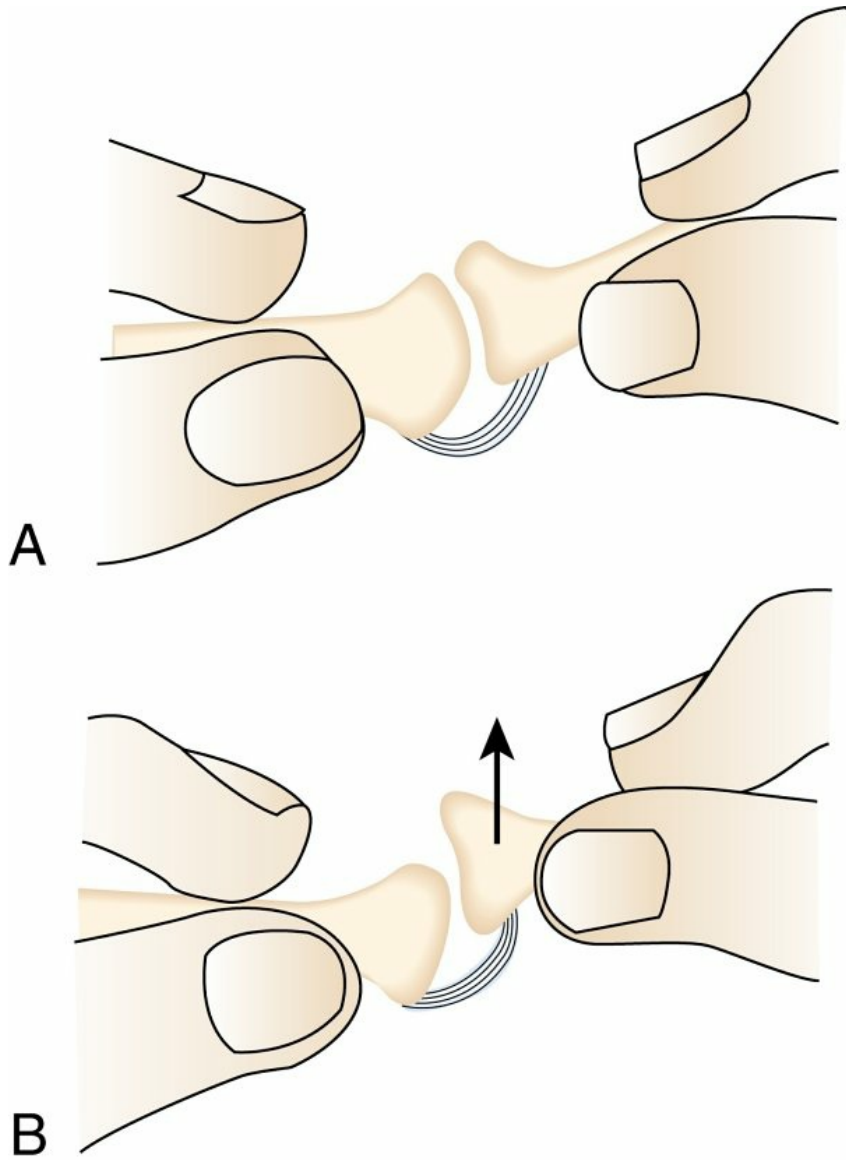


FIG. 6.49 A dorsal plantar drawer test is administered by thrusting the toe in a dorsal plantar direction. With capsulitis or MTP joint instability, pain is elicited. When a patient complains of presumable MTP pain but no deformity is present, eliciting pain with a drawer test assists in making the correct diagnosis.
From DeLee J: *DeLee and Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2011, Saunders.

- Flexor-to-extensor tendon transfer with release of the medial collateral ligament
- EDB tendon transfer with rerouting plantar to the intermetatarsal ligament
  - Reserved for less severe deformities; leads to more mobility of MTP joint than a flexor-to-extensor transfer
- Distal metatarsal osteotomy (Weil) required if severe subluxation or dislocation of the MTP joint
- If there is skin break down at the PIP dorsally, surgical débridement (with obtaining of specimen cultures) and delay of definitive treatment must be considered.

- **MTP joint instability**
  - Mild subluxation of the MTP joint that manifests as pain and swelling without any deformity
  - Drawer test results in pain within the joint (Fig. 6.49).
    - Most sensitive physical examination test to evaluate for plantar plate injury
  - More commonly seen in athletes (runners, tennis)
  - If the diagnosis is in question, an MR arthrogram of the involved joint will identify any injuries to the plantar plate or collateral ligaments.
  - Treatment
    - Nonoperative
      - Toe taping and stabilizing lesser-toe orthotics/metatarsal pads
      - Steroid injections are contraindicated and may result in iatrogenic creation of a crossover-toe deformity.
    - Operative
      - MTP synovectomy with reconstruction of the MTP joint capsule for isolated synovitis
      - With severe instability or deformity, a flexor-to-extensor tendon transfer is traditionally performed to stabilize MTP joint.

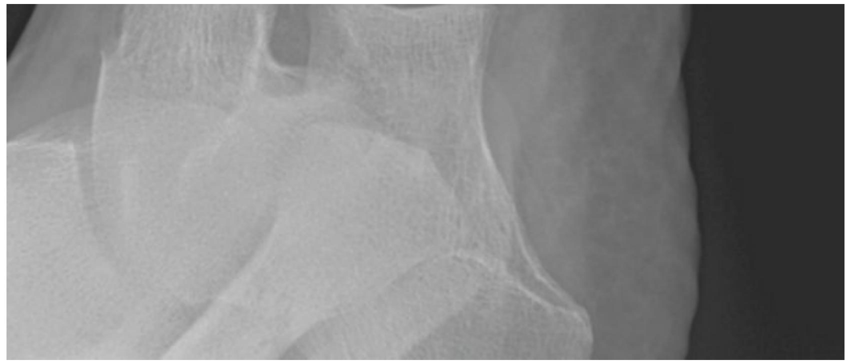


FIG. 6.50 Note the flattening of the metatarsal head that is commonly seen with Freiberg disease *(arrow).* After prior silicone arthroplasty of the great toe, Freiberg disease developed secondary to overload.
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

- For complete tears of the plantar plate, plantar plate repair has been advocated.
  - Especially in high-level athletes

- **Freiberg disease/infraction**
  - Osteochondrosis (avascular necrosis) of one of the lesser metatarsals, most commonly involving the second metatarsal
  - Patient has pain localized over the affected metatarsal head.
  - The second metatarsal is affected in over two-thirds of cases. The third metatarsal accounts for most of the remaining cases. The fourth is affected in less than 5% of cases. The first and fifth metatarsals are rarely affected.
  - Pain is worse with ambulation and activities, and relieved with rest.
  - Common radiographic findings in Freiberg disease include:
    - Resorption of the central metatarsal bone adjacent to the articular surface, with flattening of the metatarsal head (Fig. 6.50)
    - Osteochondral loose bodies
    - Joint space narrowing in late-stage disease, with associated osteophyte formation along with collapse of the articular surface (Fig. 6.51)
  - Nonoperative treatment
    - Common strategies consist of activity modification, shoewear modification (hard sole), orthotics (metatarsal bar), and a period of protected weight bearing.
  - Operative treatment
    - For early-stage disease, joint débridement should be considered.
      - All inflamed synovium, osteophytes, and loose bodies are débrided through a dorsal incision.

FIG. 6.51 Coned-down anteroposterior view of the forefoot demonstrating the natural history and long-term sequela of untreated Freiberg disease. Note the significant subchondral cysts *(arrowhead)* and osteophyte formation *(arrow)* indicating osteoarthritis. From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions*, Philadelphia, 2011, Elsevier.

- This procedure should be considered for patients with relatively good articular surface congruity and minimal metatarsal deformity.

- Many studies have reported good results with dorsal closed-wedge metaphyseal osteotomy of the affected metatarsal (Fig. 6.52).
    - Performed in conjunction with a thorough débridement of inflamed synovium, abnormal cartilage, osteophytes, and necrotic bone
    - Serves to rotate the plantar aspect of the articular surface, which is typically well preserved, to a more superior position, where it then articulates with the phalanx

- **Fifth-toe deformities**
  - Several types of deformity exist, including underlapping, overlapping, rotatory, and cock-up toes.
  - Subluxation at the fifth MTP results in weakened push-off during ambulation, a loss of coverage of the fifth metatarsal head, and subsequent callus formation under the dorsolateral aspect of the fifth toe.
  - Nonoperative treatment
    - For an overlapping fifth toe, stretching or taping may be helpful, as may wearing shoes with a wide toe box.
  - Operative treatment
    - Cock-up fifth toe
      - EDL transfer into the abductor digiti minimi, with rerouting inferior to the phalanx
      - Release of the dorsomedial capsule and Z-plasty of the skin may be required.
    - Congenital curly toe (underlapping)
      - Tenotomy of the FDL and FDB has been recommended in children with flexible deformities.
    - Syndactylization is reserved for salvage after failure of operative intervention.

Hyperkeratotic Pathologies

Intractable Plantar Keratosis (IPK)

- **Plantar callus secondary to excess pressure from metatarsal head**
- **Predisposing factors: fat pad atrophy, plantar-flexed first ray, equinus contracture, intrinsic minus toe contracture, and hypertrophy of the sesamoid**
- **Two main types (** Fig. 6.53):
  - Discrete form
    - Localized callus with a hyperkeratotic core, usually caused by prominence of fibular/lateral condyle of the lesser metatarsal head
    - Commonly associated with a prominent tibial sesamoid
    - Nonoperative treatment
      - Callus trimming and soft metatarsal pads
      - Total-contact orthosis or extended steel shank should be considered for patients with significant fat pad atrophy.
    - Operative treatment
      - Shaving of the plantar surface of the tibial sesamoid or fibular metatarsal condylectomy
      - In more advanced cases, complete excision of the tibial sesamoid should be considered.
      - In the patient with a plantar-flexed first ray, dorsiflexion osteotomy should be considered.
  - Diffuse form
    - Secondary to pressure phenomenon from the entire metatarsal head
    - Commonly associated with an elongated metatarsal, an excessively plantar-flexed metatarsal, or transfer lesion. If there is no first ray pathology, it is important to evaluate for the presence of a gastrocnemius contracture.
    - Nonoperative treatment—similar to the discrete form of IPK
    - Operative treatment
      - Correction of the underlying deformity is critical — revision of the first ray to restore weight bearing through the medial column is critical
      - Secondary shortening of the lesser metatarsals may be required if the first ray is excessively short; however, shortening should not be done without correction of first ray pathology.
      - Gastrocnemius recession as required by the

physical examination findings

Bunionette Deformity (Tailor's Bunion)

- **Diagnosis**
  - Prominence over distal aspect of fifth metatarsal head
  - Causes pain over lateral or plantar aspect of MTP joint, particularly with compressive shoewear
  - Bunionette deformity in conjunction with ipsilateral hallux valgus and metatarsus primus varus is termed *splayfoot*.
  - Three distinct types have been described, based on the anatomic location of the deformity along the fifth metatarsal:
    - Type I deformity—distinguished by presence of an enlarged fifth metatarsal head (Fig. 6.54)
    - Type II deformity—demonstrates lateral bowing of fifth metatarsal diaphysis (Fig. 6.55)
    - Type III deformity—demonstrates an abnormally widened fourth–fifth metatarsal angle (normal <8 degrees) (Fig. 6.56)
  - Conservative treatment
    - Shoewear modification, strategic padding, and shaving of the symptomatic callus are usually effective.
    - With plantar callus or associated pes planus, a metatarsal pad or custom orthotic device should be considered.
  - Surgical treatment
    - Lateral metatarsal head condylectomy (type I deformity)
    - Distal fifth metatarsal osteotomy (i.e., chevron; type II deformity)
    - Oblique diaphyseal osteotomy (type III deformity)
    - Metatarsal head resection should be considered for salvage.
    - Proximal osteotomy should be avoided owing to the tenuous blood supply at the proximal metadiaphyseal junction of the fifth metatarsal.

Sesamoids

Anatomy

- **Medial (tibial) and lateral (fibular) hallucal sesamoids are part of a strong sesamoid capsuloligamentous complex.**
- **Enveloped within the two heads of the flexor hallucis brevis (FHB) tendon, separated by an intersesamoid ridge called the** *crista*
- **Attached to proximal phalanx via the plantar plate**
- **Suspended by the collateral ligaments of MTP joint, metatarsosesamoid ligaments, intersesamoid ligament, abductor hallucis tendon, and adductor hallucis tendon**
- **Analogous to the patella, sesamoids provide a mechanism to increase the mechanical advantage of the pulley function of the intrinsics (FHB).**
- **Protect the FHL and disperse the forces beneath the first metatarsal head**

Deformities

- **Sesamoid disorders can include acute injury (fracture, dislocation, sprain/"turf toe"), sesamoiditis, stress fracture, arthrosis, AVN, and IPK.**
- **Diagnosis**
  - Chief complaint is pain under the first metatarsal head, especially with toe-off.
  - Physical examination—tenderness with direct palpation of the involved sesamoid, pain with first-MTP ROM
  - Radiographs—in addition to AP and lateral views, lateral oblique (fibular sesamoid) and medial oblique (tibial sesamoid) views isolate each bone, and axial view shows the articulation with the metatarsal head (Fig. 6.57).
    - **Radiographs of contralateral side should be obtained to compare position of sesamoids relative to the base of the proximal phalanx.**
      - Tibial sesamoid should be 10.4 mm from the base, and fibular sesamoid should be 13.4 mm from the base.
      - Should be within 3 mm of the spaces on the contralateral extremity
- **Mechanism of injury—forced dorsiflexion of the first MTP joint, repetitive loading**
  - Turf toe—**forced dorsiflexion with foot in equinus (and axial load)** can result in avulsion of the plantar plate off the base of the phalanx and

subsequent proximal migration of the sesamoids.

- Hyper–plantar flexion of MTP joint with valgus force is a less common mechanism; seen in beach volleyball players.
- Tibial sesamoid is more frequently involved in trauma but also more likely to be bipartite or multipartite.

- **Conservative treatment**
  - Turf toe
    - Grade 1—capsular strain
      - Signs—normal ROM, weight bearing without difficulty, normal radiographs
      - Treatment—stiff insole, taping, with immediate return to play
    - Grade 2—partial capsular tear
      - Signs—painful ROM, limited weight bearing, normal radiographs

FIG. 6.57 (A) An anteroposterior radiograph demonstrates a painful bipartite sesamoid. (B) An axial radiograph does not show evidence of a fracture or bipartite sesamoid. (C) Radiograph of a pathology specimen showing rounded edges pathognomonic of a bipartite sesamoid. (D) Axial view following excision of medial sesamoid. (E) Gross pathology of a specimen. (F and G) Radiographs obtained immediately following surgery. (H) Radiograph obtained at 19-year follow-up after medial sesamoid excision. Alignment of the first metatarsophalangeal joint is well maintained.
From Coughlin MJ et al: *Surgery of the foot and ankle*, ed 8, Philadelphia, 2006, Mosby.

- Treatment—no athletic activity for 2 weeks, stiff insole, return to play if painless 60-degree dorsiflexion present
- Grade 3—complete tear of the plantar plate
  - Signs—severe pain with palpation, limited and painful ROM, abnormal radiographs (fracture, proximal sesamoid migration)
  - **Treatment—superior results demonstrated with operative repair of the plantar plate over conservative care.**

□ Traumatic hallux valgus that involves the medial capsule and medial sesamoid with acute deformity of the hallux is best treated with immediate surgical repair as opposed to late reconstruction.

□ Sesamoid fracture
- Initial treatment with a fracture boot to limit the stress

across the sesamoid

- Transition to sesamoid relief pad (dancer's pad) with gradual resumption of activity

□ Sesamoiditis

- Treated with antiinflammatory medications, rest, ice, and activity, and then shoewear modification
- Operative treatment
  - Symptomatic nonunion or cases that prove refractory to conservative care can be treated surgically with bone grafting or with partial or complete sesamoidectomy.
  - Results of sesamoidectomy are the most predictable.
  - Excision of the proximal or distal pole achieves the best results and should be performed if the fracture pattern allows.

FIG. 6.58 Cock-up toe in a patient who had undergone tibial and fibular sesamoidectomies. To prevent this complication, resection of both sesamoids should never be performed. A first metatarsophalangeal joint fusion can be done concomitantly to prevent this complication.

  - Complications of medial and lateral sesamoidectomy are hallux valgus and varus, respectively.
    - Repairing the defect with capsule (or a slip of abductor hallucis for the tibial sesamoid) helps prevent this complication.

- Cock-up deformity (or claw toe) will occur if both sesamoids are excised (Fig. 6.58).
- Care should be taken to avoid injury to the FHL and loss of flexor function, especially in the high-performance athlete.

Accessory Bones (Fig. 6.59)

- **Accessory navicular (AN) is in 10%–14% of normal feet**
  - Type 1: small ossicle
  - Type 2: larger with synchondrosis
  - Type 3: fused to navicular body
- **50% of patients with AN have flexible flatfoot**

Neurologic Disorders

Interdigital Neuritis (Morton Neuroma)

- **Definition**
  - Compressive neuropathy of the interdigital nerve, most commonly in the third web space, followed by the second web space (Fig. 6.60)
  - The pathophysiology of this condition is still poorly understood.
    - Theories include compression/tension around the IM ligament, repetitive microtrauma, vascular changes, excessive bursal tissue, endoneural edema, and eventual perineural fibrosis.
- **Diagnosis**
  - Patients frequently report pain and burning on the plantar aspect of the web space, with more than 60% of patients noting pain radiating into the toe distally. Numbness is reported by only 40% of patients.
  - Exacerbated by footwear with narrow toe boxes and high heels
    - Higher predilection in the female population
    - Likely related to shoewear, with forced plantar flexion of the metatarsal heads
  - Physical examination
    - Palpation between and just distal to the metatarsal heads elicits plantar tenderness.
    - Compressing the medial and lateral aspects of the forefoot while palpating the web space structures can provoke symptoms and occasionally a bursal "click" with associated pain (Mulder sign).
    - Metatarsalgia and MTP synovitis often manifest similarly and should be ruled out.
  - Radiographs
    - Plain films should be obtained to rule out bony masses or deformity.
    - MRI or ultrasound can be used to identify other pathologies but are not required for diagnosis.
- **Nonoperative treatment**
  - Shoewear modification (avoiding high heels and narrow toe boxes) is the most important and effective intervention.
  - **Metatarsal pads placed proximal to the focus of pain can prevent direct pressure and widen the intermetatarsal space during weight bearing, thereby indirectly decompressing the nerve.**
  - Corticosteroid injections can have moderate effectiveness (≈50% of patients report positive response); **repetitive injections can lead to**

hammer-toe deformity.

- ▫ Alcohol sclerosing injections have not proved to be effective and are not recommended.

- ▪ **Operative treatment**
  - ▫ Excision of neuroma
    - • Dorsal approach most common
      - • Transverse intermetatarsal ligament is incised and resected.

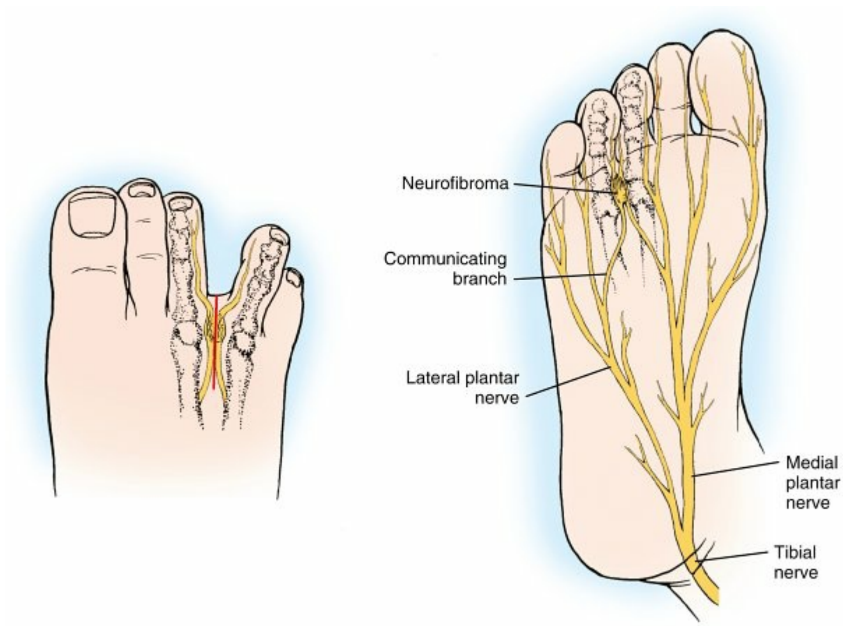


FIG. 6.60 Most common anatomic location of interdigital neuroma; plantar and dorsal views.
From Canale ST, Beaty J: *Campbell's operative orthopedics,* ed 11, Philadelphia, 2007, Elsevier. Modified from McElvenny RT: The etiology and surgical treatment of intractable pain about the fourth metatarsophalangeal joint (Morton's toe), *J Bone Joint Surg* 25:675, 1943.

- • The common digital nerve and its branches are identified and the nerve is resected 2 to 3 cm proximal to the intermetatarsal ligament (proximal to the small plantar branches), allowing the proximal stump to retract (Fig. 6.61).
  - • Minimizes formation of stump neuroma, the most common complication
    - • Difficult visualization results in a 4% rate of failure to excise the neuroma.
    - • Overall success rates approach 80%.
    - • **Neuroma often causes**

perineural fibrosis.

- Plantar approach
  - Decreases the rate of missed neuroma excision
  - Does not require incision of the transverse intermetatarsal ligament
  - Associated with increased risk (5%) of painful plantar scar
  - Typically used for revision neuroma resection

Recurrent Neuroma

- **Definition**
  - Bulbous enlargement of the neural stump (or secondary glioma)
  - Usually caused by inadequate proximal resection or failure of the nerve to retract after excision
  - Neural stump adheres to adjacent bone and soft tissue, causing a traction neuritis.
- **Diagnosis**
  - Localized pain and tenderness to palpation (Tinel sign) in web space of previous neuroma resection, at or proximal to metatarsal heads
  - Recurrent neuroma is likely if symptoms are localized and reproducible.

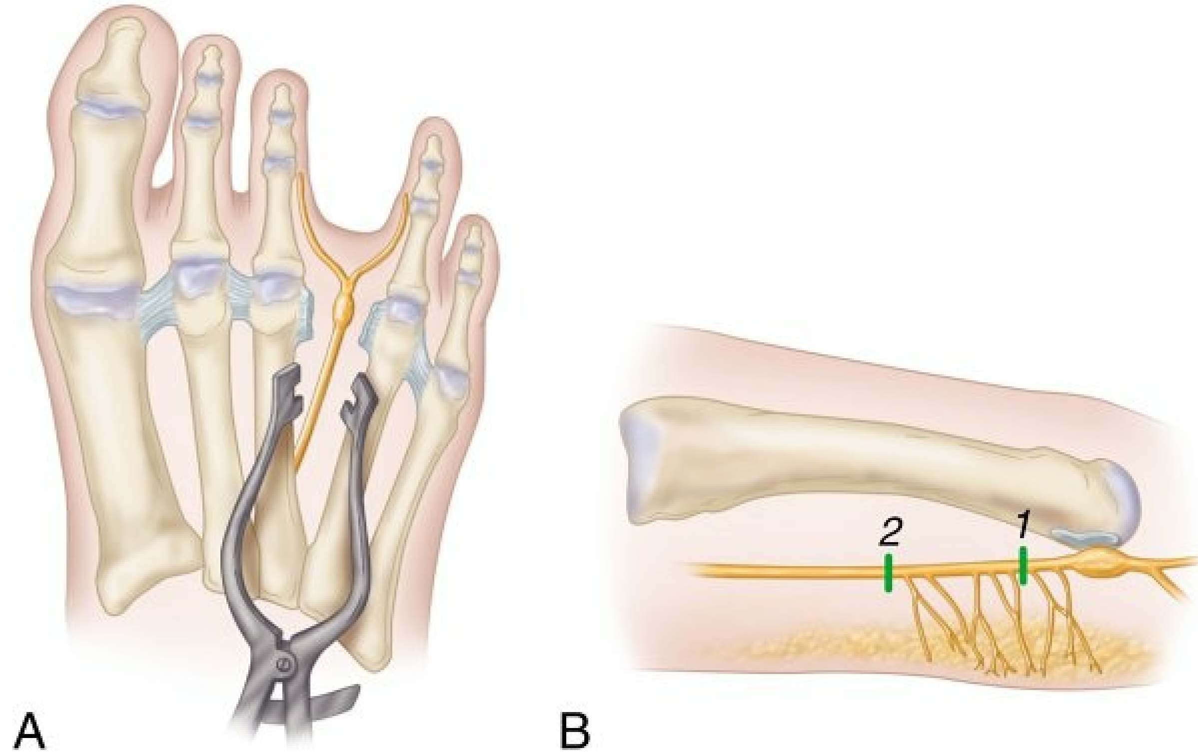


FIG. 6.61 (A) Lamina spreader used to expose neuroma. (B) Lateral view of plantar branches of digital nerve. *1,* Previously recommended level of neurectomy; *2,* currently recommended level of neurectomy (3 cm proximal to ligament) to avoid plantarly directed nerve branches. From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier. Modified from Weinfeld SB, Myerson MS: Interdigital neuritis: diagnosis and treatment, *J Am Acad Orthop Surg* 4:328, 1996.

- **Nonoperative treatment—similar to that for primary neuroma (see earlier)**
- **Operative treatment**
  - □ Excision of the stump neuroma can be performed through another dorsal incision or through a plantar incision.
  - □ Plantar incision allows access to a very proximal location in which to place the resected neuroma stump.
    - • Preferred approach for revision neuroma excision
  - □ The new stump should be transposed into muscle tissue if possible.
  - □ Success rate after excision of a recurrent or stump neuroma is 65%–75%.

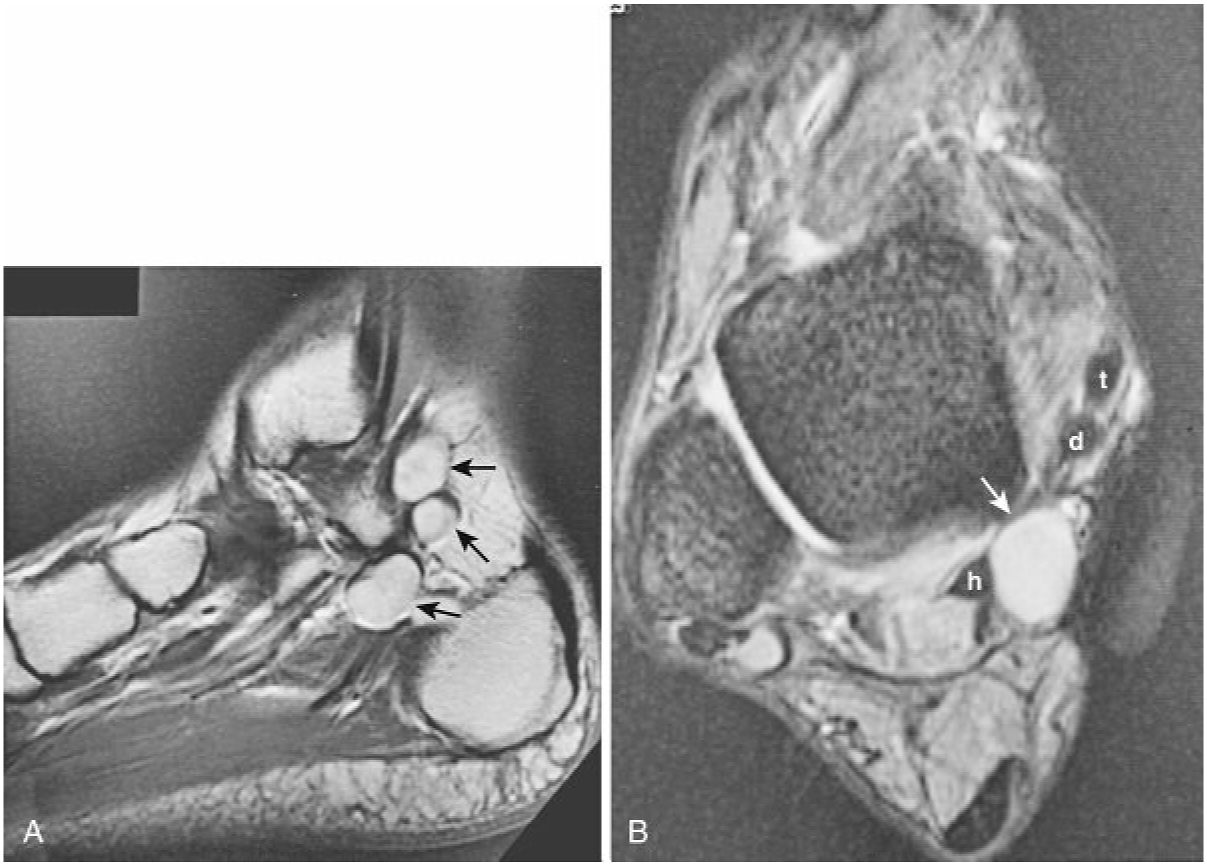


FIG. 6.62 Tarsal tunnel syndrome from schwannomas. (A) T1-weighted, contrast-enhanced sagittal MR image of the hindfoot. Three round masses *(arrows)* that show enhancement are running through the tarsal tunnel. (B) T2-weighted axial MR image of the hindfoot. One of the schwannomas is shown as a high-signal mass *(arrow)* in the space normally occupied by the posterior tibial nerve, artery, and vein. *d,* Flexor digitorum tendon; *h,* flexor hallucis tendon; *t,* tibialis posterior tendon.
From Helms C et al: *Musculoskeletal MRI,* ed 2, Philadelphia, 2009, Saunders.

Tarsal Tunnel Syndrome

- **Definition**
  - □ Compressive neuropathy of the tibial nerve within the fibroosseous tunnel posterior and inferior to the medial malleolus
  - □ Tarsal tunnel is bounded by the flexor retinaculum (laciniate ligament) superficially; the medial talus, medial calcaneus, and sustentaculum tali deeply; and the abductor hallucis inferiorly.
  - □ The tarsal tunnel also contains the tibialis posterior, the FHL and FDL tendons, the posterior tibial artery, the venae comitantes, and the numerous septa that subdivide the tunnel.
  - □ Reported causes of tarsal tunnel syndrome include tenosynovitis, engorged or varicose vessels, synovial or ganglion cysts, pigmented villonodular synovitis, nerve sheath tumors, lipomas, fracture of the sustentaculum tali or medial tubercle of the posterior process of the talus, middle facet tarsal coalition, and accessory muscles.
  - □ Systemic diseases such as diabetes mellitus, RA, and ankylosing spondylitis may have an indirect effect by causing inflammatory

edema.

- **Diagnosis**
  - Symptoms of tarsal tunnel syndrome may be vague and misleading.
    - Include a burning sensation on the plantar surface of the foot and medial ankle and occasional sharp pains or paresthesias
      - "Irritable" tibial nerve must be ruled out.
      - Palpation should be performed along tibial nerve and branches distal to flexor retinaculum.
    - Prolonged standing, walking, or running can exacerbate the symptoms.
  - Physical examination
    - Percussion of the entire course of the distal tibial nerve and its branches should be performed.
    - Tinel sign, radiating pain or discomfort with continuous deep compression over the nerve, or diminished two-point discrimination may be elicited.
    - Sensory examination is usually unpredictable.
    - Hindfoot alignment should be assessed—pes planus may cause increased tension on the nerve.
    - Prior lateral closed-wedge osteotomy of the calcaneus can increase tension on nerve as well.
    - Wasting of the abductor hallucis or abductor digiti quinti may be seen if the medial or lateral plantar nerve is involved, respectively.
  - Diagnostic tests
    - Electrodiagnostic studies should be performed to help make the diagnosis or determine a different level of compression.
      - Sensory nerve conduction study findings are more commonly abnormal than those of motor nerve conduction studies.
      - Electromyography (EMG) abnormalities are less sensitive.
    - MRI may identify the presence of a mass-occupying lesion or middle facet subtalar coalition, which if present must be excised (Fig. 6.62).
      - Surgical decompression with mass excision results in more predictable symptomatic improvement compared with patients with tarsal tunnel syndrome and no associated mass.
    - Correlation with history and physical examination findings is essential.
  - Nonoperative treatment
    - Management should begin with conservative measures

unless there is a suspicious mass or suspected malignancy.

- Medications such as NSAIDs, vitamin B_6, and tricyclic antidepressants are most commonly prescribed.
- SSRIs and antiseizure medications (gabapentin, pregabalin) are also used.
- Physical therapy may include stretching, massage, desensitization, and iontophoresis.
- Orthoses to correct hindfoot valgus (medial heel wedge) play an important role as well.
- In cases of acute inflammation or severe limitation because of pain, a brief course of a controlled ankle motion (CAM) walker boot or short-leg cast may be helpful.

□ Operative treatment

- Space-occupying lesion should be excised, with concomitant nerve release.
  - If appropriate conservative management for 3 to 6 months is unsuccessful, surgical intervention is warranted.
  - Longitudinal incision is made over the course of the tibial nerve; it curves distally behind medial malleolus to the abductor musculature (Fig. 6.63)
  - The nerve is identified proximally, and the proximal investing fascia and flexor retinaculum are released.
  - Care must be taken to release the superficial and deep fascia of the abductor hallucis muscle.
  - Endoscopic tarsal tunnel release is not recommended.
  - Recurrence of tarsal tunnel syndrome is a challenging problem.
    - Incomplete release is the most common etiology; however, intrinsic nerve damage may play a role in recurrent symptoms.
    - Revision release may be of benefit if incomplete release is suspected, although results are often poor.

Plantar Nerve Problems

▪ **Lateral plantar nerve entrapment**

□ Nerve provides sensation to the plantar lateral aspect of the foot.

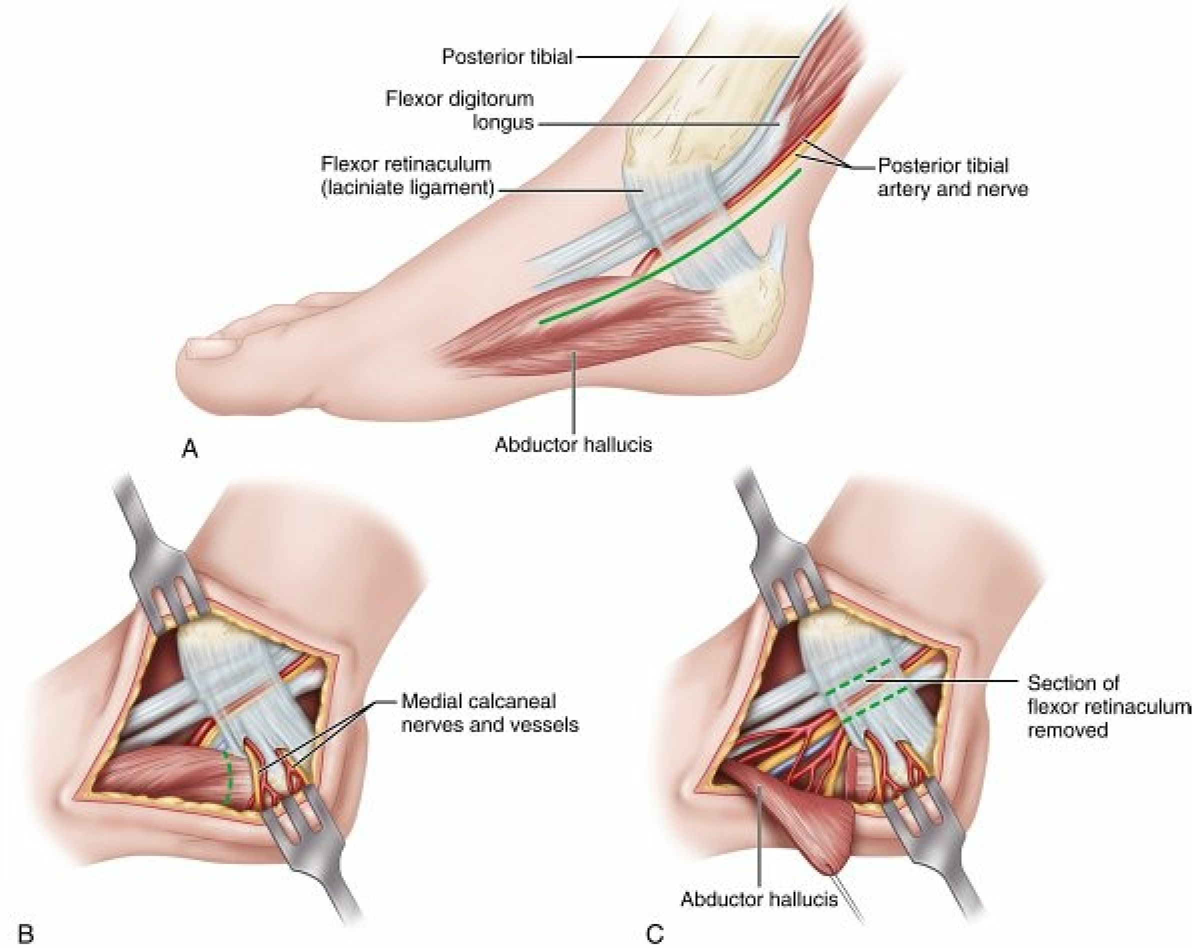


FIG. 6.63 Tarsal tunnel release. (A) Skin incision. (B) Note branches of medial calcaneal nerve and artery penetrating retinaculum. Broken line indicates incision for reflecting abductor hallucis muscle. (C) Abductor hallucis is reflected plantarward, and section of flexor retinaculum to be removed is outlined.
From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier.

- It may be injured during surgical approaches that require a plantar incision, such as a tibiotalocalcaneal (TTC) arthrodesis with an intramedullary nail.
    - If no evidence of paresthesias and persistent hindfoot pain, evaluation for nonunion of the ankle or subtalar joints needed
- First branch of the lateral plantar nerve (Baxter nerve) may be a source of chronic plantar medial heel pain.
    - Associated with long-distance/marathon running

- **Medial plantar nerve entrapment**
    - Nerve provides sensation to the plantar medial aspect of the foot.
    - Entrapment occurs at the knot of Henry (junction of FDL and FHL tendons).
        - FDL is plantar to FHL at knot of Henry.
        - Most common etiology is external compression from orthotic devices.
        - Also called *jogger's foot*
        - Conservative treatment is often successful and includes

avoidance of orthotics and of pressure along the plantar medial hindfoot.

Anterior Tarsal Tunnel Syndrome

- **Definition**
  - ▫ Compressive neuropathy of the deep peroneal nerve in the fibroosseous tunnel formed by the Y-shaped inferior extensor retinaculum (Fig. 6.64)
  - ▫ The nerve divides into the lateral motor and the medial sensory branches within the tunnel and is accompanied by the dorsalis pedis artery.
  - ▫ Common causes of compression include tightly laced shoes, anterior osteophytes at the tibiotalar and TN articulations, a bony prominence associated with pes cavus deformity or fracture, ganglion cysts, and tendinitis of the EDL, EHL, or tibialis anterior (Fig. 6.65).

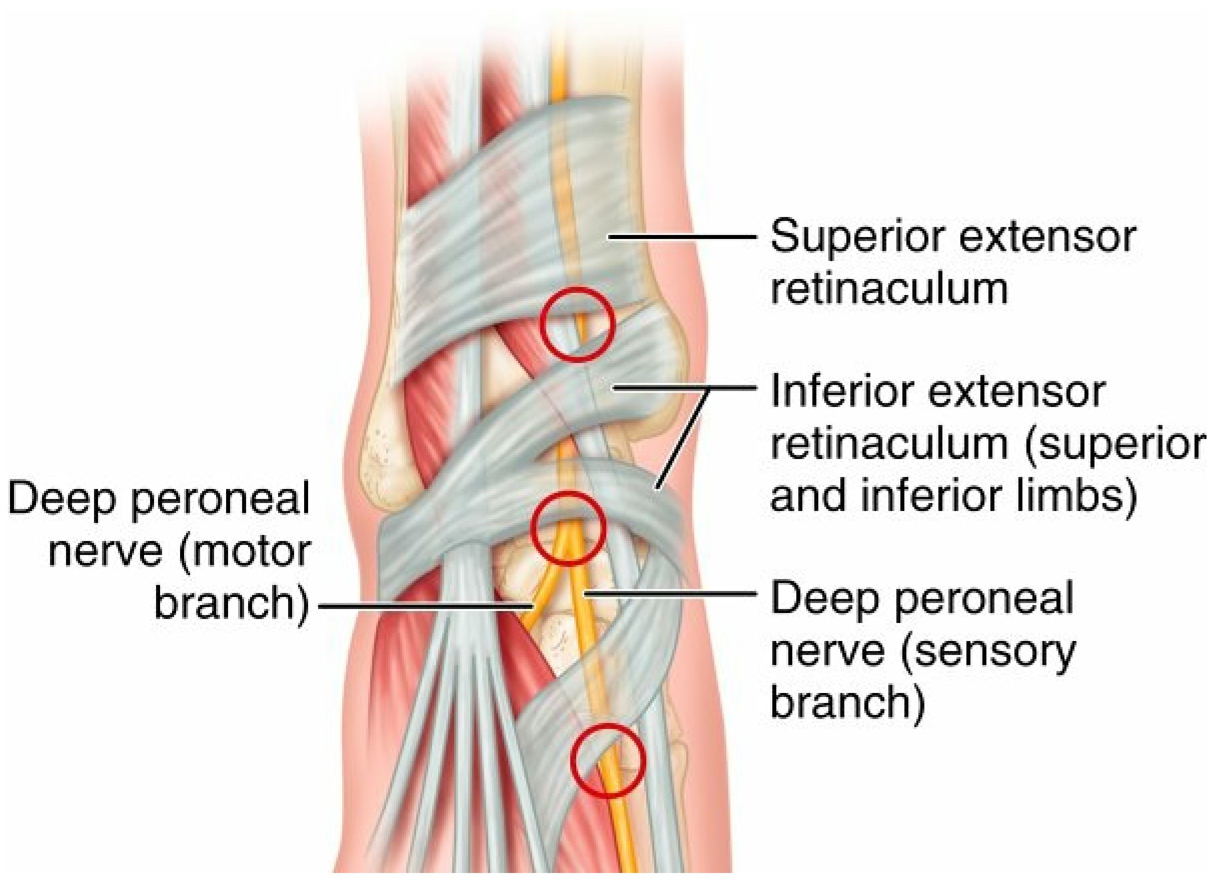


FIG. 6.64 Deep peroneal nerve entrapment. *Circles* denote areas of impingement.
From Mann RA, Baxter DE: Diseases of the nerves. In Mann RA, Coughlin MJ, editors: *Surgery of the foot and ankle,* ed 6, St. Louis, 1993, Mosby.

- **Diagnosis**
  - Patients present with burning pain and paresthesias along the medial second toe, lateral hallux, and first web space, or even vague dorsal foot pain.
  - Symptoms are often worse at night when the ankle assumes a plantar-flexed posture for sleep, and with wearing of shallow, laced shoes.
  - Physical examination
    - Decreased two-point discrimination, presence of Tinel sign along course of the deep peroneal nerve
    - Pain may be worse with plantar flexion of ankle as the nerve is stretched.
- **Nonoperative treatment**
  - Night splints, NSAIDs, diagnostic/therapeutic injections, shoe tongue padding, and footwear with loose lacing or alternative lacing techniques are the conservative approaches.
- **Operative treatment**
  - Surgical release involves incising the distal half of the inferior extensor retinaculum, releasing both branches of the nerve, excising bone spurs, and carefully repairing the bony capsule to avoid exposing the nerve to bleeding bone while protecting the dorsalis pedis artery.
  - Patients should understand that relief of the paresthesias and dysesthesias may take weeks or months.

Superficial Peroneal Nerve Entrapment

- **Definition**
  - Compressive neuropathy of the superficial peroneal nerve as it exits from the lateral compartment into the anterior ankle

- The opening in the fascia is approximately 12 cm proximal to the tip of the lateral malleolus.
- Neuritis may occur after an inversion injury or with fascial defects.
- **The nerve can also be damaged or entrapped in scar tissue at the anterolateral portal following an ankle arthroscopic procedure.**

▪ **Diagnosis**

- Symptoms include burning pain and tingling over the dorsum of the foot.
- Symptoms exacerbate with plantar flexion and inversion.
- Tinel sign is frequently present over the nerve as it exits the lateral compartment.

▪ **Treatment**

- Nonoperative treatment includes NSAIDs, diagnostic/therapeutic injections, and other nerve modalities with physical therapy.
- Surgical release of the nerve with fasciotomy is indicated if nonoperative treatment fails.

Sural or Saphenous Nerve Entrapment

- **Entrapment of the sural or saphenous nerves is rare, typically occurring only after surgical procedures as the nerves become entrapped in scar tissue.**
- **Conservative treatments may be successful, but neurolysis or resection of neuroma with burial of the nerve end is indicated for refractory cases.**
- **The sural nerve is prone to injury with lateral hindfoot procedures that use a sinus tarsi approach. The traditional extensile lateral calcaneus approach places the sural nerve at risk at both the proximal and distal ends of the incision.**

FIG. 6.65 Arthritis of the talonavicular joint (A) or nonunion of a navicular fracture (B) can compress the deep peroneal nerve.
From Myerson MS: *Foot and ankle disorders,* Philadelphia, 2000, Elsevier.

- **Popliteal nerve blocks do not typically include the saphenous nerve.**

Sequelae of Upper Motor Neuron Disorders

- **Definition**
  - Most commonly secondary to traumatic brain injury, stroke, and spinal cord injury
  - Disruption of the upper motor neuron pathways can lead to paralysis, muscular imbalance, and acquired spasticity, which ultimately may cause deformity of the foot and ankle.
  - Secondary problems include fixed contractures, calluses, pressure sores, hygiene issues, joint subluxation, shoewear difficulties, and dissatisfaction with physical appearance.
  - The most common deformity of the foot and ankle is equinovarus.
    - The equinus component is caused by overactivity of the gastrocnemius-soleus complex.
    - The varus is due to relative overactivity of the tibialis anterior and the tibialis posterior tendons with lesser contributions from the FHL and FDL.
      - The posterior tibial tendon is balanced by the peroneus brevis.
      - The anterior tibial tendon is balanced by the peroneus longus.
      - The anterior tibial tendon is balanced by the Achilles tendon complex in the sagittal plane.
- **Nonoperative treatment**
  - Early intervention with physical therapy, stretching and strengthening, and maintenance of joint ROM.
  - Other modalities include splinting, serial casting, oral muscle relaxants, phenol and lidocaine nerve blocks, and botulinum type A toxin injections.
    - Phenol blocks have a proven history, often have longer-lasting effects, and are less expensive than botulinum toxin injections.
    - Advantage of botulinum is ease of delivery—requires only an injection into the muscle belly rather than a precise injection around the motor nerve.
- **Operative treatment**
  - Surgery for acquired spasticity should be delayed at least 6 months after onset to allow for maximum recovery.
  - Equinus deformity is addressed with either an open Z-lengthening of the Achilles tendon or a percutaneous triple hemisection technique (Fig. 6.66).

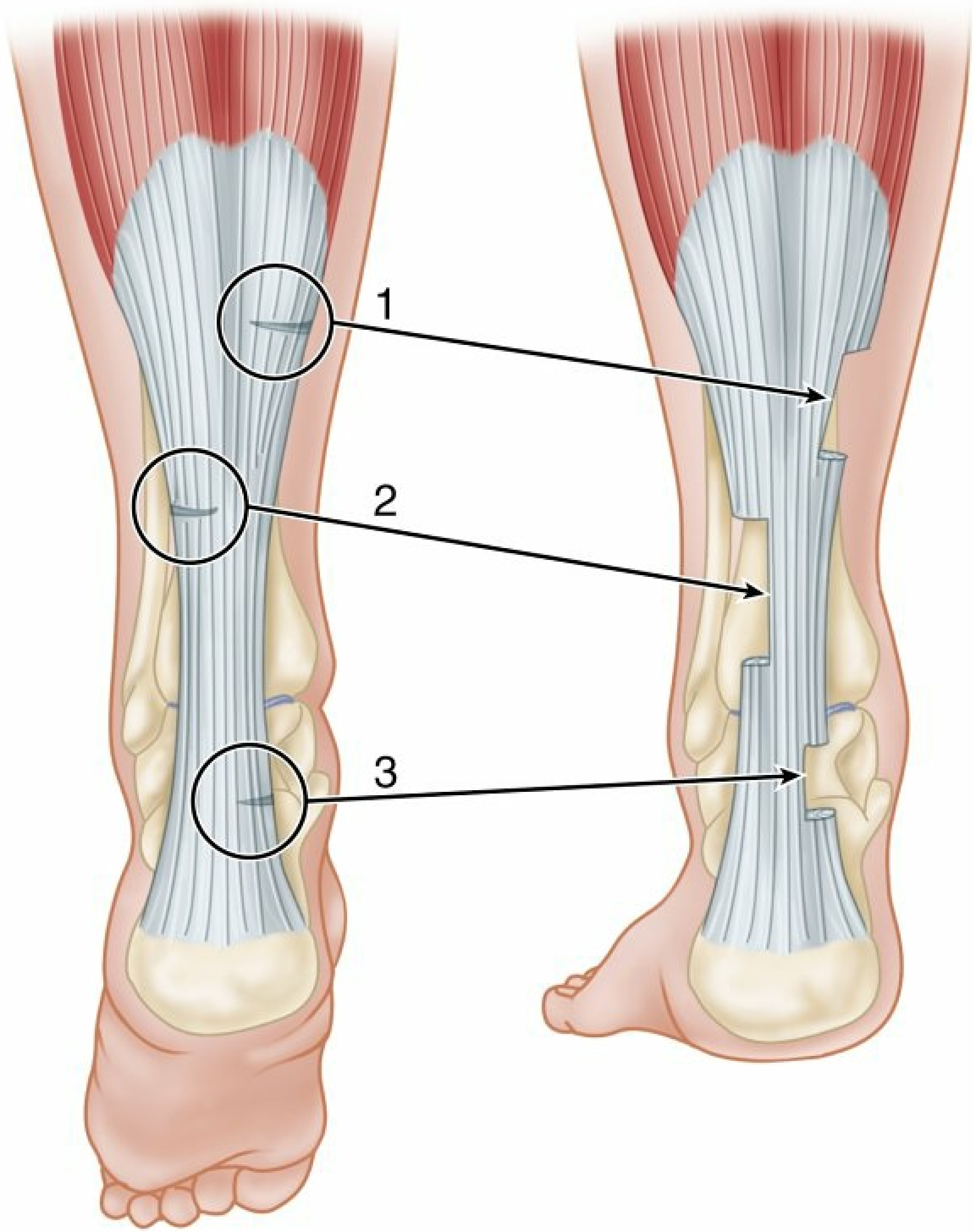


FIG. 6.66 *Left,* The three incisions for percutaneous Achilles tendon lengthening. *Right*, Cut ends slide on themselves with forceful dorsiflexion of foot.
From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier. Modified from Hsu JD, Hsu CL: Motor unit disease. In Jahss MH, editor: *Disorders of the foot,* Philadelphia, 1982, WB Saunders.

- Varus deformity is addressed with one of two procedures.
  - Tendon transfer to lateral cuneiform
    - Lateral cuneiform is center of rotation of the foot
  - Split anterior tibial tendon transfer (SPLATT) or total anterior tibial tendon
  - Posterior tibial tendon transfer is not the preferred surgical

procedure in the setting of spasticity. If the varus deformity is fixed, lateral closed-wedge calcaneal osteotomy or subtalar fusion may be necessary.

- Release of the toe flexors is often required secondary to a tenodesis effect as the ankle is brought into a plantigrade position.

Charcot-Marie-Tooth (CMT) Disease

- **Definition**
  - CMT disease is the most common inherited progressive peripheral neuropathy, affecting approximately 1 in every 2500 people.

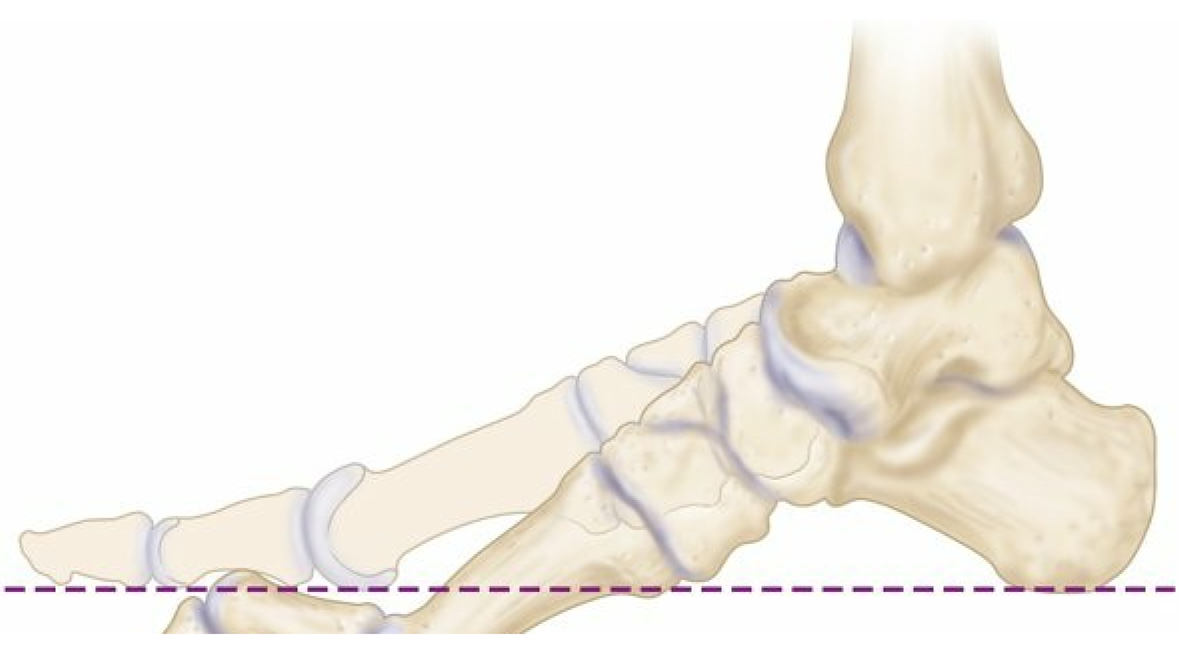


FIG. 6.67 Lateral and frontal views of plantar-flexed first ray as seen in Charcot-Marie-Tooth disease.
From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier.

- As a group, the many genetic variants of CMT disease are referred to as *hereditary motor-sensory neuropathies* (HMSNs).
  - Type I HMSN is the most common presentation of CMT.
    - Usually autosomal dominant with a duplication of chromosome 17
- An abnormal myelin sheath protein (PMP 22) is the basis of CMT degenerative neuropathy.
- The earlier the onset, the more severe the neurologic findings.

- **Diagnosis**
  - Deformity and awkward gait are common initial complaints, with weakness, lateral ankle instability, and lateral foot pain presenting later.
- **Physical examination**
  - Bilateral symmetric pes cavovarus deformity is caused by motor imbalance.
    - Tibialis anterior (TA) and peroneus brevis (PB) weakness seen early
    - First ray is plantar flexed because of relatively unopposed pull of peroneus longus (PL > TA) (Fig. 6.67).

            - This creates forefoot cavus and compensatory hindfoot varus (tripod effect).
        - Hindfoot is pulled farther into varus because of relatively unopposed pull of posterior tibial (PT) muscle (PT > PB).
                - Plantar-flexed first ray and hindfoot varus lead to external rotation of distal tibia and fibula.
        - Intrinsic (EDB, EHB, interossei) wasting leads to overpull of extrinsics (EHL, EDL, FHL, FDL), which causes claw-toe deformity;
        - Intrinsics are affected first as they have the longest axons.
            - Weak TA leads to recruitment of EHL and EDL during swing phase of gait, worsening claw-toe deformity.
            - Prominent and tender calluses may be present beneath the metatarsal heads.
    - Coleman block test (Fig. 6.68) should be used to determine whether a hindfoot varus deformity is secondary to plantar flexion of the first ray or is an independent component.
        - Deformity corrects with Coleman block—forefoot-driven hindfoot varus.
            - Surgical correction involves dorsiflexion osteotomy of the first metatarsal.
        - Deformity does not correct with Coleman block—hindfoot varus independent of the forefoot.
            - Surgical correction involves both
                - Dorsiflexion osteotomy of the first metatarsal (forefoot)
                - Lateral closed-wedge calcaneal osteotomy (hindfoot)
    - Sensory deficit is variable.
        - Proprioception, vibration, and two-point discrimination affected first
        - Severe sensory loss may lead to recurrent ulceration, deep infection, and even neuropathic arthropathy.
- **Treatment**
    - Flexible deformity (hindfoot can be passively manipulated)
        - In an adolescent with closed physes and a supple deformity, surgical treatment rather than brace management is currently recommended because of the progressive pattern of this disease.
        - Operative treatment
            - Release of the plantar fascia

- Closed-wedge dorsiflexion osteotomy of first metatarsal
  - Always required; if deformity corrects with Coleman block test, no other bony correction is required.
- Lateral calcaneal slide and/or closed-wedge osteotomy if deformity does *not* correct with the Coleman block (Fig. 6.69)
- Transfer of peroneus longus into peroneus brevis at the level of the distal fibula
- Frequently a tendon Achilles lengthening (TAL) procedure is required.
- Forefoot correction is performed according to the guidelines outlined previously.
- A flexible clawed hallux can be surgically treated with a Jones procedure (arthrodesis of interphalangeal joint and transfer of EHL to first metatarsal).

□ Fixed deformity (hindfoot cannot be passively manipulated)

- Nonoperative management can be attempted with a brace.
  - Locked-ankle, short-leg ankle-foot orthosis (AFO) with an outside (varus-correcting or lateral) T-strap is recommended.

FIG. 6.68 (A) Unilateral cavus foot on left (patient's right foot). Note the appearance of the medial heel on the left; on the other side the medial heel is not visible. (B) Right varus heel alignment on the same patient viewed from behind. Note the normal heel alignment of the left foot. (C) Correction of heel alignment with Coleman block testing on the same patient. Note both feet have the same alignment while right foot is on the block, implying forefoot-driven cavus.

From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.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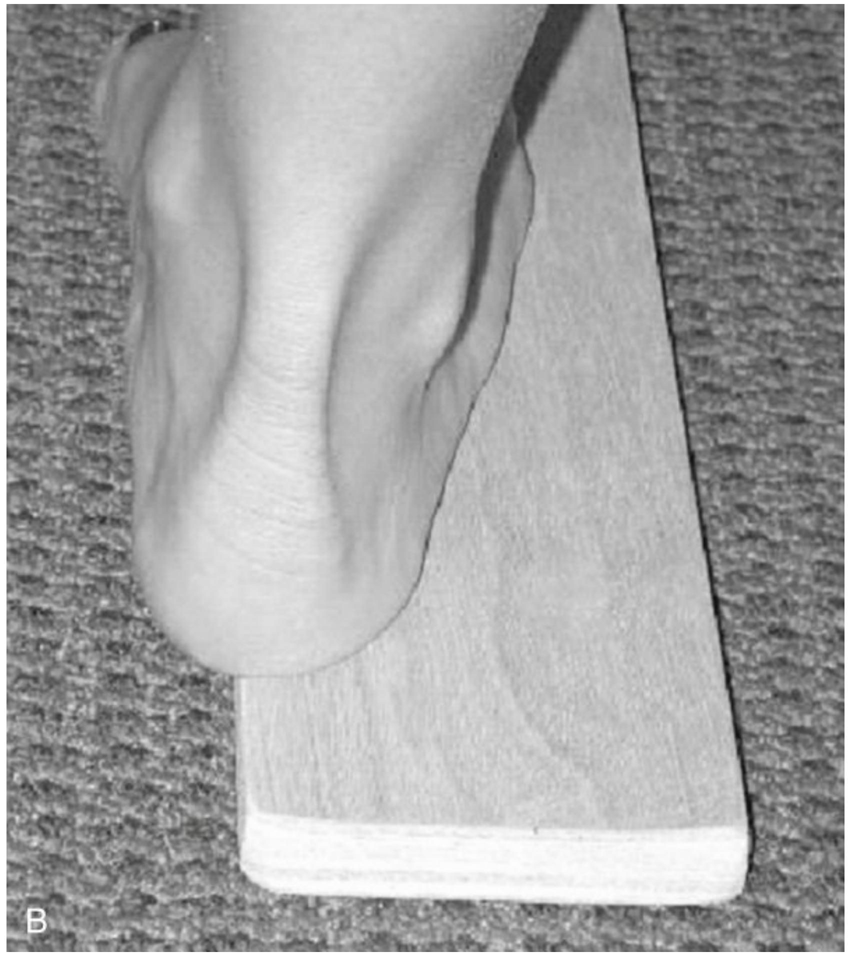


FIG. 6.69 (A) Unilateral right heel varus. (B) Same right foot on a Coleman block with no change in heel position, indicating hindfoot-driven cavus.

  - Rocker sole can improve gait and decrease energy expenditure.
- Operative treatment
  - Dorsal closing midfoot arthrodesis or triple arthrodesis is usually required for deformity correction.
  - PTT transfer through the interosseous membrane and TAL procedure can correct equinus contracture and dorsiflexion weakness.
  - Plantar fascia release and dorsiflexion osteotomy of the first metatarsal
  - Forefoot correction is performed according to the guidelines outlined previously.

Peripheral Nerve Injury and Tendon Transfers

- **Traumatic injuries to the lower extremity can result in injury to the nerves and/or musculature, resulting in a paralytic deformity.**
- **Use of AFO can be a successful nonoperative treatment; however, many patients desire to become brace free.**

- **Principles of tendon transfers**
  - Deformity must be flexible (passive ROM must be present). A rigid deformity requires an arthrodesis.
  - Preoperative physical examination is critical to determine which tendons should be transferred.
    - Assessment for which muscles are still active—must have at least four-fifths strength for transfer.
    - A deforming force is redirected to create a restoring force.
- **Peroneal nerve palsy**
  - Loss of the anterior and lateral compartments—loss of active dorsiflexion and eversion
  - Deformity—equinovarus
  - Treatment—transfer of PTT (deforming force) through the interosseous membrane anteriorly to the dorsal midfoot (restores dorsiflexion) with a TAL procedure.
- **Compartment syndrome—loss of the anterior and deep posterior compartments**
  - Deformity—cavovarus (PL) with equinus (Achilles)
    - Treatment—TAL with transfer of the PL (deforming force) to the dorsolateral midfoot (restores dorsiflexion).
- **Unique cases such as compartment syndrome and traumatic injury can demonstrate variable patterns of motor loss. Correction of the deformity is unique to each case, depending on the remnant motor function.**

Arthritic Disease

Crystalline Disease

- **Gout**
  - Pathology
    - Abnormal purine metabolism results in precipitation and deposition of monosodium urate crystals into synovium-lined joints.
      - Induces a severe inflammatory response
      - Induced by certain medications that increase serum uric acid, localized trauma, alcohol, or purine-rich foods, as well as by the postsurgical state
    - Men are more commonly affected than women.
  - Diagnosis
    - Patients complain of sudden joint pain, with a characteristic history ("not even a sheet could touch it").
    - Physical examination—intense signs of inflammation (redness, swelling, warmth, tenderness) and pain with ROM
    - The great-toe MTP joint is most often involved (50%–75% of initial attacks).
    - 90% of patients with chronic gouty attacks have one or more episodes involving the hallux MTP joint (podagra).
    - Characteristic radiographic signs
      - Inordinate soft tissue enlargement about the MTP joint
      - Bony erosions both at a distance from and within the joint articular surface
        - Extensive articular and periarticular destruction can occur in chronic conditions (Figs. 6.70 and 6.71).
        - Secondary to large soft tissue deposits of gouty residue (tophi)
    - Definitive diagnosis—needle aspiration of the joint
      - Indicated in the presence of an acute swollen painful joint; fluid sent for crystal analysis and Gram stain with culture.

FIG. 6.70 Gouty arthritis. Multiple punched-out lesions are present.
From Mercier L: *Practical orthopaedics,* ed 6, Philadelphia, 2008, Elsevier.

- **Pathognomonic signs: needle-shaped monosodium urate crystals, which under polarized light are strongly negatively birefringent**
- Ruling out an acute septic joint—which would be determined from the aspirate Gram stain and culture—is critical.
- Serum uric acid may or may not be elevated and should not be used to confirm or refute the diagnosis.

□ Treatment
- Acute attacks treated with indomethacin or colchicine
  - Colchicine inhibits microtubule formation, preventing inflammatory cell migration into the area.
- Chronic attacks treated with allopurinol
  - Allopurinol is a xanthine oxidase inhibitor.
- Joint destruction or deposition of large quantities of tophi

may require arthrodesis and/or débridement of tophaceous debris.

- **Pseudogout (chondrocalcinosis)**
  - Pathology
    - Deposition of calcium pyrophosphate dihydrate (CPPD) crystals in or about a joint may lead to severe initial inflammatory response.
    - Usually articular, with less periarticular soft tissue involvement than gout
    - Commonly affects the knee but may manifest in articulations of the foot or ankle
  - Diagnosis
    - Analysis of joint aspirate reveals weakly positive birefringent crystals with varied shapes under polarized light microscopy.
    - Lesser MTP, TN, and subtalar joints can be affected.
    - Characteristic radiographic signs
      - Intraarticular calcifications commonly seen (unlike in gout)
      - Joint destruction can occur with recurrent attacks over a long period but is rare.
  - Treatment—rest, oral NSAIDs for acute synovitis, protected weight bearing, and corticosteroid injections

Seronegative Spondyloarthropathy (SNSA)

- **Definition**
  - Inflammatory arthritides in which rheumatoid factor is absent
  - Distinguished from RA clinically by a higher incidence of involvement of entheses (i.e., the interface between collagen and bone where ligament, tendon, and capsular tissue insert into bone)
    - Involvement of this transitional tissue is found in psoriatic arthritis, ankylosing spondylitis, Reiter syndrome, and inflammatory bowel disease.
  - May destroy articular cartilage but characteristically are more destructive of collagen and fibrocartilage
- **Diagnosis**
  - Often manifest in the foot as plantar fasciitis, Achilles tendinitis, or posterior tibial tendinopathy
  - Psoriatic arthritis can manifest as swollen and inflamed distal joints or, more classically, as dactylitis (“sausage digit”).
  - Periarticular bony erosion may occur, causing a classic pencil-in-cup sign typical of psoriatic arthritis (Fig. 6.72).

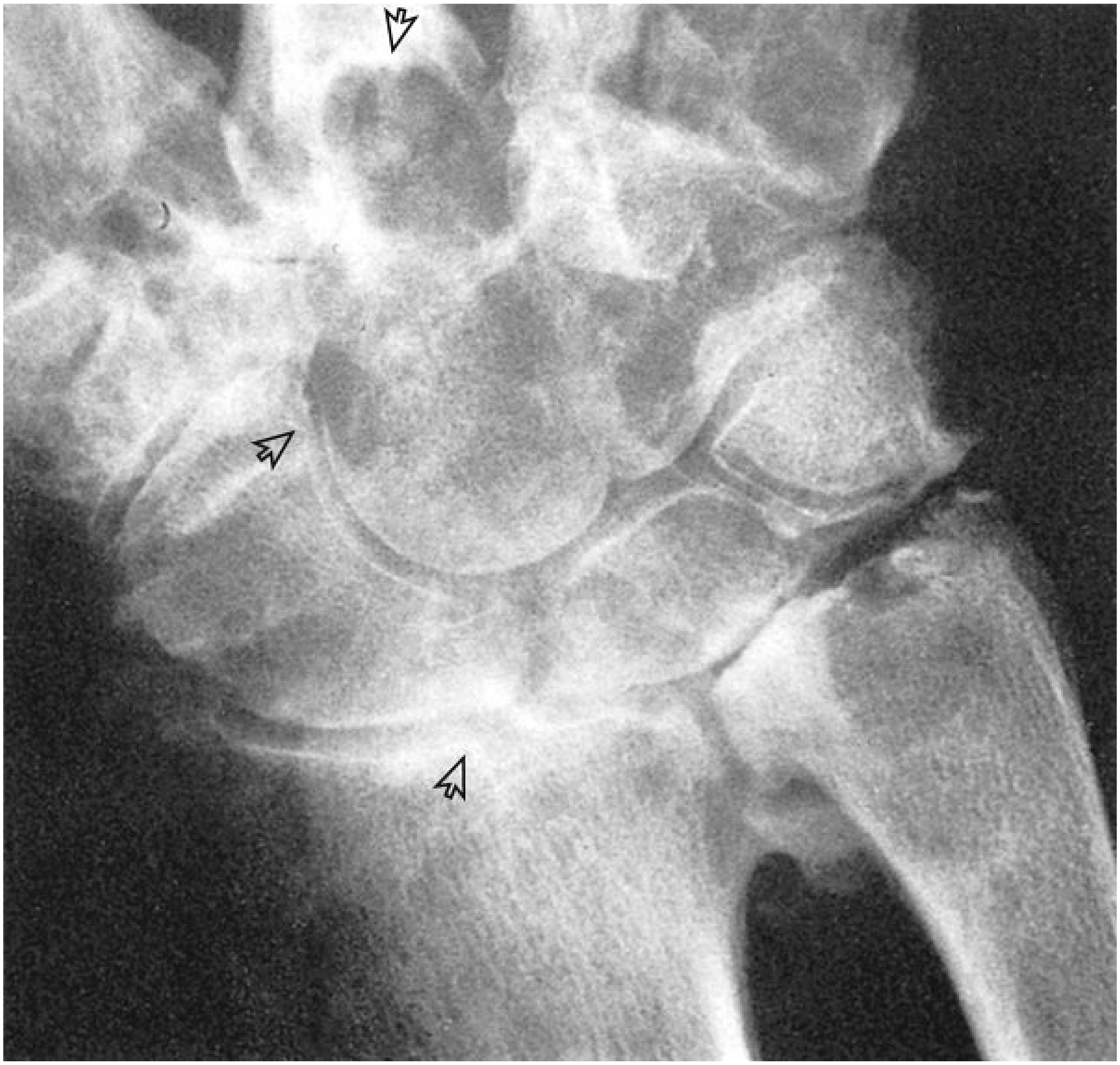


FIG. 6.71 Wrist abnormalities in gout. Diffuse disease of all compartments of the wrist is evident. Erosions *(arrows)* are most prominent at the common carpometacarpal compartment *(upper arrow).*
From Resnick D: The radiographic manifestations of gouty arthritis. *CRC Crit Rev Diagn Imaging* 9:265, 1977.

- □ Additional findings may include nail pitting, onycholysis, and keratosis.

- **Treatment**
  - □ Pharmacologic agents such as NSAIDs, or occasionally salicylates or cytotoxic drugs under the direction and observation of a rheumatologist, are the mainstays of treatment.
  - □ Intraarticular corticosteroid injections may improve symptoms, especially for acute flares.
  - □ Surgical intervention is sometimes required for small joint erosions, recalcitrant Achilles tendinopathy, and plantar fasciitis.

Rheumatoid Arthritis

- **Definition**

- ☐ Chronic symmetric polyarthropathy that most commonly manifests in the third and fourth decades and is more prevalent in women.
- ☐ Synovitis causes ligament and capsular laxity and cartilage and bony erosion.
- ☐ Vasculitis and soft tissue fragility are common, requiring diligent care of the soft tissues during nonoperative and operative management.
  - Use of immune-mediating pharmacologic therapies in the perioperative period should be discussed with a rheumatologist because of possible complications.
    - Most can be continued (prednisone, methotrexate, hydroxychloroquine), but the newer biologic agents (e.g., TNF antagonists) should be discontinued.
  - Most significant risk factor for development of a postoperative wound infection: history of previous wound infection

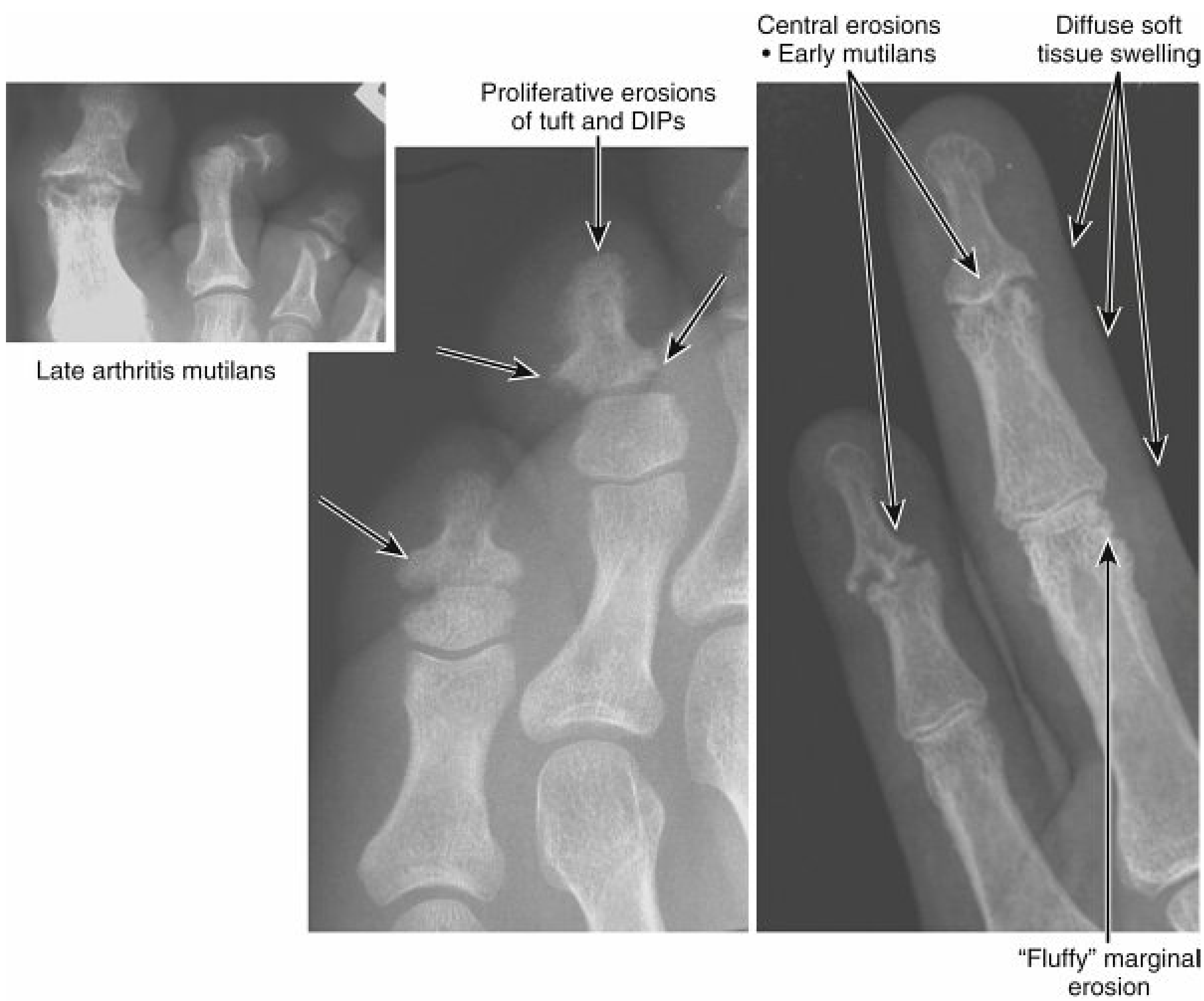


FIG. 6.72 Psoriatic arthritis. Erosions classically have a proliferative appearance, with a fluffy or whiskered quality. Central erosions can lead to joint destruction with a pencil-in-cup pattern. From Morrison W, Sanders T: *Problem solving in musculoskeletal imaging*, Philadelphia, 2008, Elsevier.

▪ **Diagnosis**

- □ Foot involvement very common in RA
  - • Forefoot more commonly involved than midfoot or hindfoot
- □ Patients complain of forefoot swelling, poorly defined pain, and eventually deformity.
- □ MTP joint pathophysiology
  - • Chronic synovitis leads to incompetence of the joint capsules and collateral ligaments.
  - • Toes subluxate or dislocate dorsally, deviate laterally into valgus, and develop hammering (Fig. 6.73).

FIG. 6.73 Rheumatoid foot. Note multiple deformities of rheumatoid arthritis of forefoot with hallux valgus, subluxed and dislocated metatarsophalangeal joints, claw toes, hammer toes, and bursal formation.
From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier.

  - • Intrinsic muscles worsen the claw-toe deformity.
  - • Plantar fat pad migrates distally and atrophies, causing metatarsalgia and painful keratoses.
  - • As lesser toes deviate laterally, hallux valgus occurs and

transfer metatarsalgia worsens.

- Midfoot and hindfoot are less commonly and less severely involved in RA.
  - Significant midfoot/hindfoot arthrosis (TN joint characteristic)
  - Often results in a pes planovalgus deformity
  - Underlying cause of flatfoot deformity must be carefully assessed to determine whether it is midfoot driven or hindfoot driven.
    - Midfoot etiology—TMT joints subluxated, with a congruent hindfoot (Fig. 6.74)
      - Treatment—realignment midfoot arthrodesis
    - Hindfoot etiology—transverse tarsal and subtalar joints are subluxated, with a normal midfoot.
      - Treatment—triple arthrodesis
- Tibiotalar joint also commonly involved—easily differentiated from osteoarthritis by lack of osteophyte formation, osteopenia, and symmetric joint space narrowing (Fig. 6.75)
  - Ankle arthrodesis is currently the treatment of choice, with ankle replacement emerging as a more reliable technique.
  - A tibiotalar and subtalar (tibiotalocalcaneal [TTC]) arthrodesis performed with an intramedullary nail risks a tibial stress fracture in patients with RA.
    - This complication is best treated conservatively with a cast.
  - Risks of wound complications after total ankle arthroplasty have been shown to be higher in patients with RA.

- **Treatment**
  - Nonoperative treatment
    - Rest, NSAIDs, immune-modulating drugs under the direction of a rheumatologist, toe taping, orthoses, and careful use of corticosteroid injections may help symptoms related to synovitis.

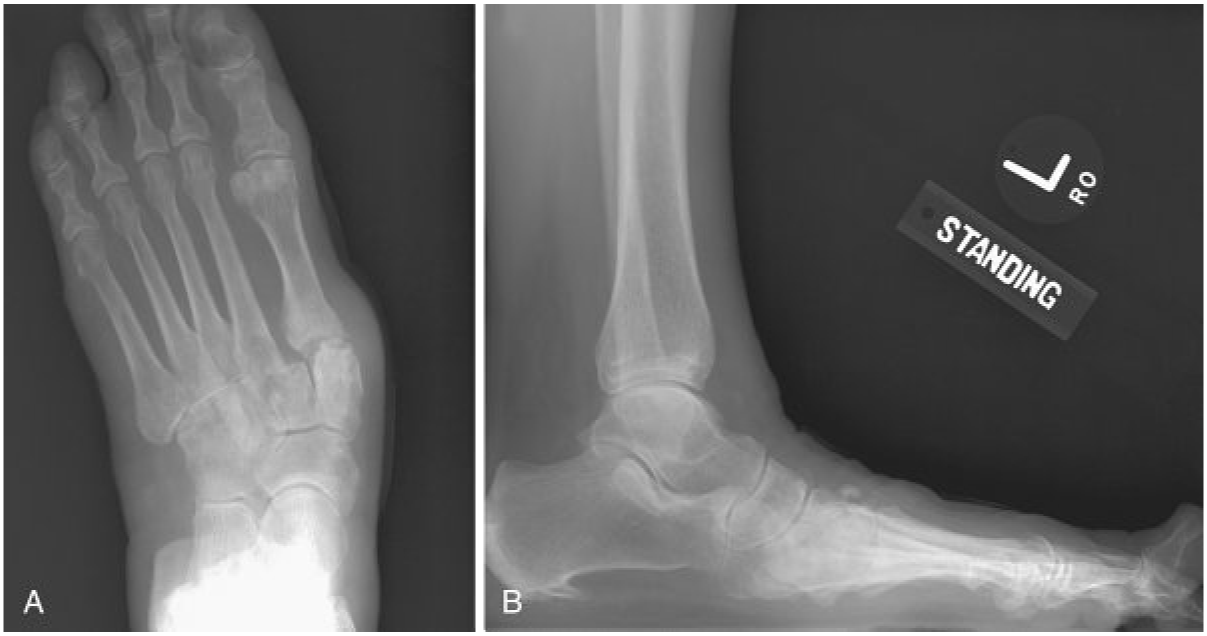
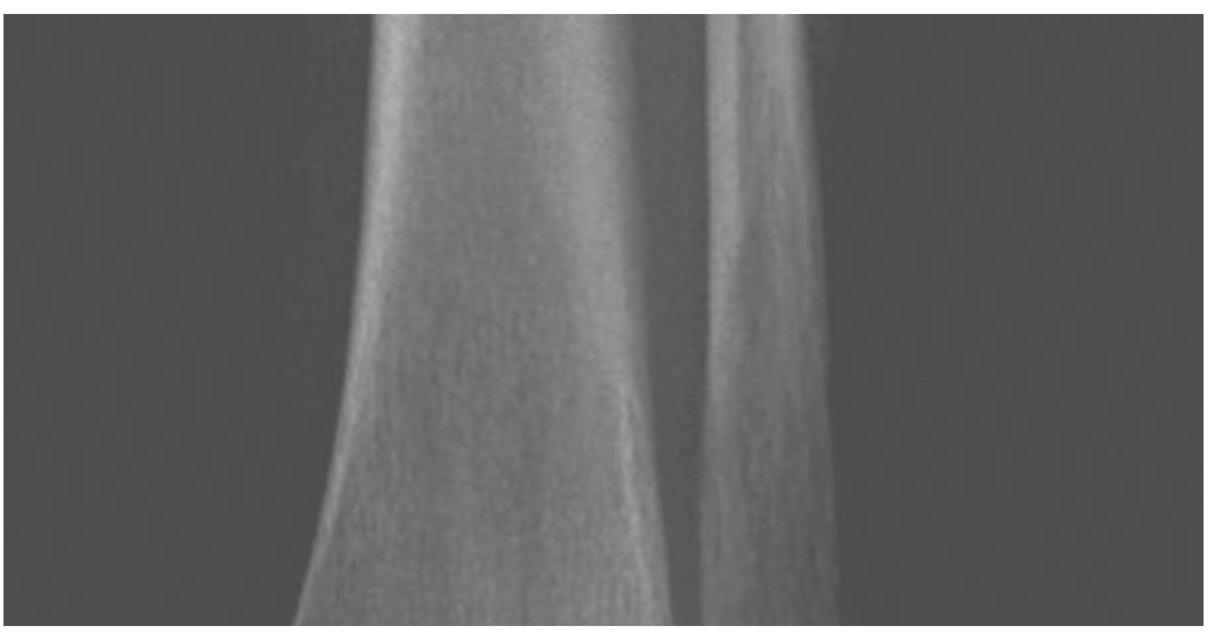


FIG. 6.74 (A) Anteroposterior radiograph of a patient with rheumatoid arthritis with a flatfoot deformity that is secondary to midfoot arthritis. Note how the first and second metatarsals are subluxated laterally relative to the cuneiforms. (B) The lateral radiograph demonstrates loss of the longitudinal arch centered at the tarsometatarsal joints, with obvious degenerative changes. Surgical treatment is a realignment midfoot arthrodesis. Care must be taken in differentiating this condition from a hindfoot-driven flatfoot, in which the deformity is centered at the talonavicular joint.

- Operative treatment
    - Early (mild hallux valgus, mild claw toe without dislocation)
        - The new disease-modifying medication has resulted in a significant decrease in end-stage rheumatologic deformity. In patients with mild deformity without joint pain and with radiographic evidence of sparing of the joint space, joint preservation surgery as would be performed for nonautoimmune cases should be considered. Patients must be informed that the rate of recurrence may be higher and that late arthrodesis may be necessary secondary to the underlying disease process.
    - Late (in presence of severe deformity)—“rheumatoid forefoot reconstruction” (Hoffman procedure) (Fig. 6.76)
        - First MTP arthrodesis, lesser metatarsal head resection with pinning of the lesser MTP joints, and closed osteoclasis of the interphalangeal joints versus PIP arthroplasty
            - Silicone arthroplasty not recommended; complications are cock-up deformity, silicone synovitis, and osteolysis.

- Accomplished through three well-placed longitudinal dorsal incisions (Fig. 6.77)
- Extensor brevis tenotomy and Z-lengthening of the extensor longus tendons may be necessary.
- Most common complication of forefoot arthroplasty is intractable plantar keratoses.

- Midfoot, hindfoot, or ankle arthrodesis indicated as previously described



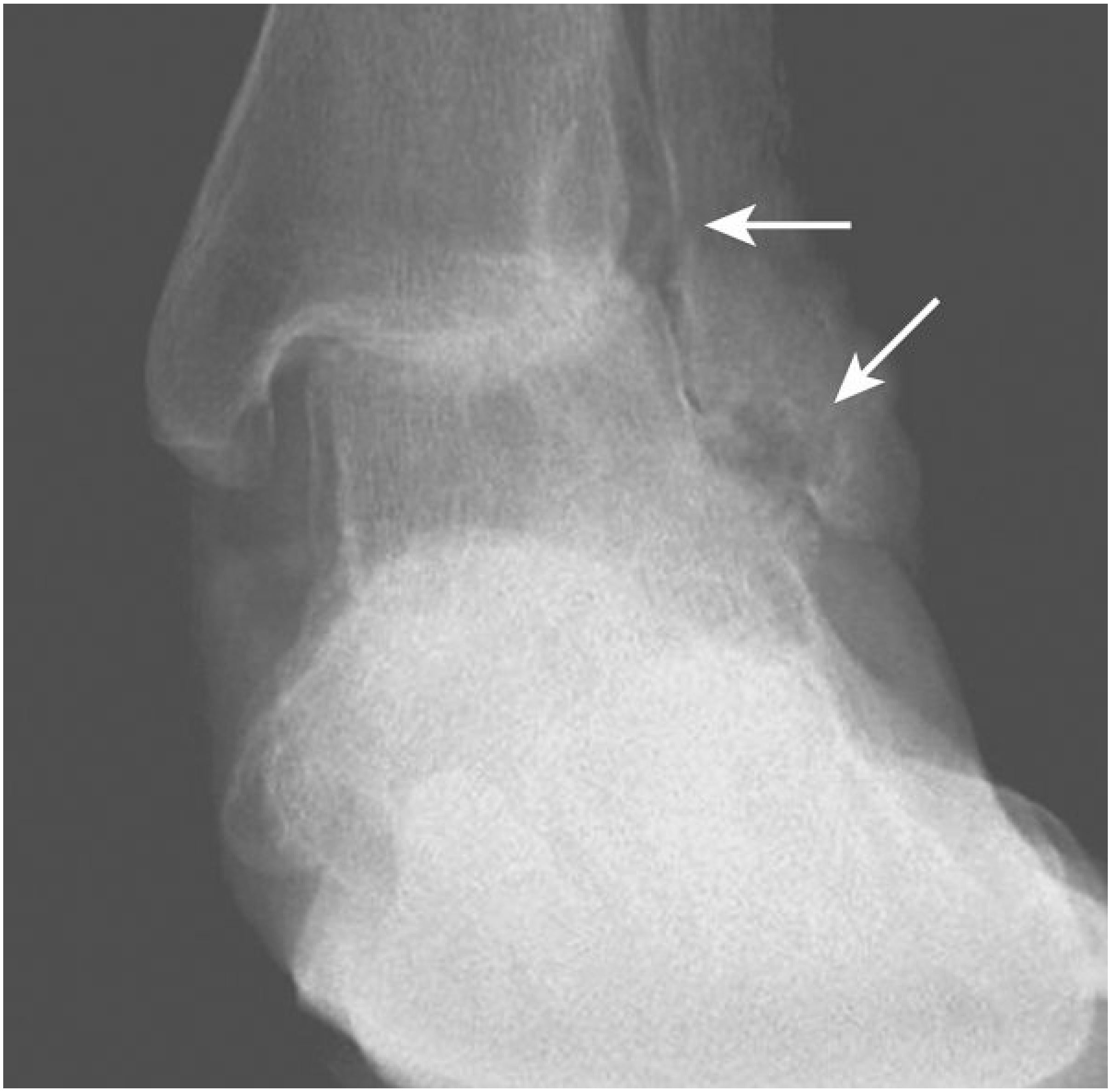


FIG. 6.75 Rheumatoid arthritis of the ankle. There is diffuse loss of cartilage space with erosions of the fibula *(arrows).* The scalloping along the medial border of the distal fibula, designated the *fibular notch sign,* is a characteristic finding in rheumatoid arthritis. The hindfoot is in valgus alignment. From Firestein G et al: *Kelley's textbook of rheumatology,* ed 8, Philadelphia, 2008, Elsevier.

Osteoarthritis

- **Definition**
  - Osteoarthritis and posttraumatic arthritis have similarities in the mechanical nature of the problem, clinical presentation, and treatment algorithm.
  - Posttraumatic arthritis is most common in the hindfoot, tibiotalar, and TMT articulations.
  - Osteoarthritis commonly affects the first MTP joint and the midfoot joints (TMT, intercuneiform, naviculocuneiform [NC], and TN joints).
  - Lateral ankle instability, PTT insufficiency, and neuromuscular deformities also commonly contribute to degenerative arthritis.


STAND
A
B

FIG. 6.76 Preoperative (A) and postoperative (B) radiographs for rheumatoid forefoot reconstruction.

- **Diagnosis**
  - Patients complain of dull, achy pain at the involved joint, usually worse with activity.
  - Physical examination—tenderness to palpation at the joint surface, with loss of ROM and pain with passive ROM
  - Radiographs—loss of joint space, subchondral sclerosis and cysts, osteophyte formation (Fig. 6.78)
  - First MTP joint
    - Tenderness over the dorsum of the joint, limited dorsiflexion secondary to large dorsal osteophyte, and pain with grind test
    - Graded clinically and radiographically:
      - Grade 0—normal radiograph features, stiff on examination
      - Grade I—mild dorsal osteophyte, joint space preserved, mild pain at extremes of ROM, less than 50% loss of ROM

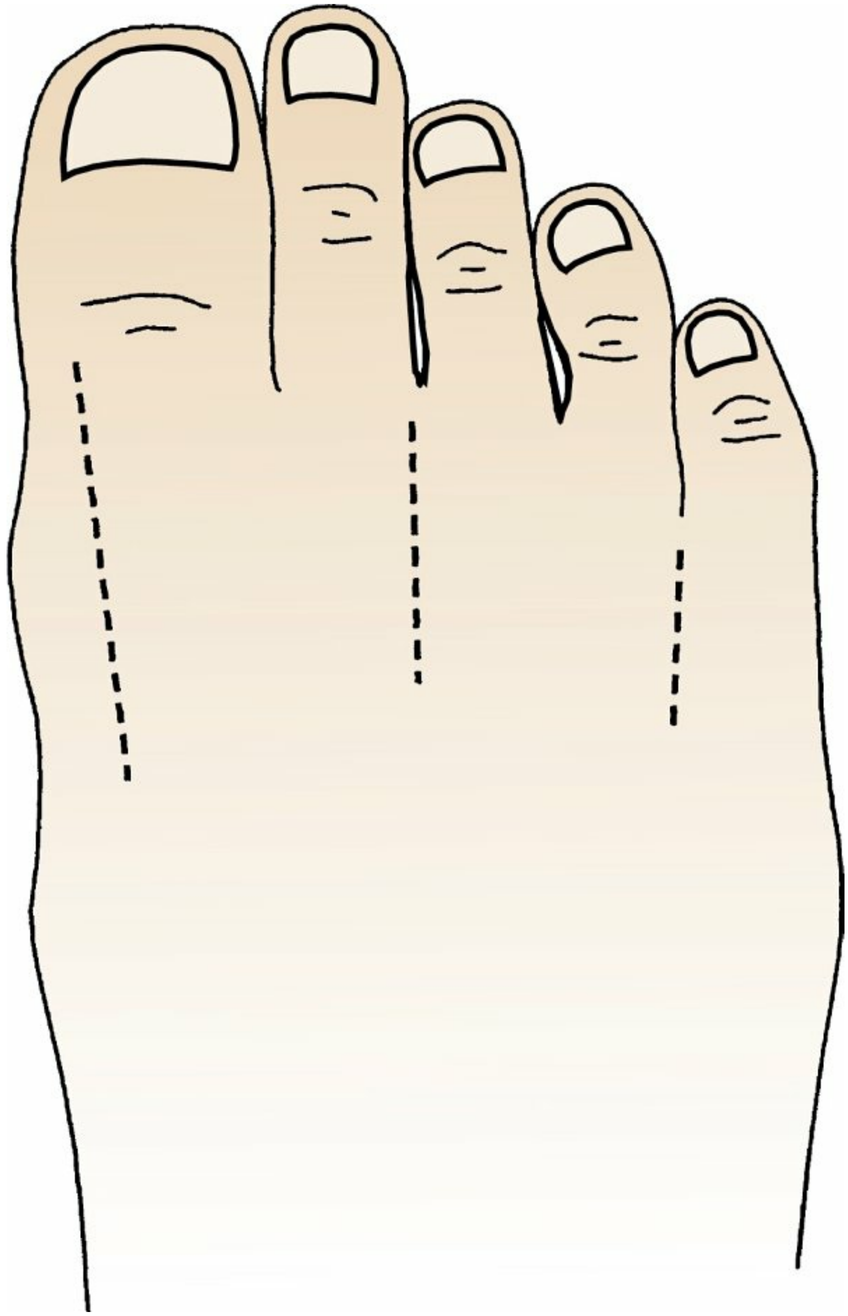


FIG. 6.77 Incisions for first MTP joint arthrodesis and lesser MTP joint resection arthroplasty for rheumatoid arthritis.

  - Grade II—moderate osteophyte formation, joint space narrowing (<50%), moderate pain with ROM that may be more constant
  - Grade III—severe osteophyte formation, substantial joint space narrowing (>50%), significant stiffness with pain at extreme ROM but not at midrange
  - Grade IV—same as grade III but with pain at midrange of passive motion
- Subtalar, TN, CC joints
  - Tenderness at the sinus tarsi (subtalar joint), dorsal TN joint, and/or lateral column

        - Pain with passive hindfoot inversion/eversion (subtalar), midfoot ROM (TN, CC)
        - Radiographs show varying severity of joint space narrowing and osteophyte formation.
        - Rigid flatfoot without arthritis is also common presentation but is not amenable to joint preservation surgery and should be treated with a triple arthrodesis.
    - Tibiotalar joint
        - Tenderness in anterior ankle joint line
        - Limited ROM with pain, especially in extreme dorsiflexion
        - May be associated varus or valgus deformity, either at ankle or more proximally, especially with history of prior fracture or injury.
        - Radiographs show joint space narrowing, sclerosis and cysts, osteophytes, and possibly varus or valgus deformity.
            - Standing radiographs essential; long-leg alignment view may be needed for history of leg trauma
        - May be associated with cavovarus deformity, rigid flatfoot (valgus), or chronic lateral ankle instability (varus)

- **Nonoperative treatment**
    - Initial treatment should include antiinflammatory medications, activity modification, orthotic support or bracing, and corticosteroid injections.
    - Hallux rigidus—stiff footplate with an extension under the great toe (Morton extension)

FIG. 6.78 Hallux rigidus (arthritis of the hallux metatarsophalangeal joint). (A) Posteroanterior radiograph of the great toe shows cartilage space narrowing and hypertrophic lipping. (B) The lateral radiograph shows a prominent dorsal osteophyte *(arrow)*.
From Weissman B: *Imaging of arthritis and metabolic bone disease*, Philadelphia, 2009, Elsevier.

- Midfoot (TMT) arthritis—stiff-soled or steel shank–modified shoe with a rocker bottom in addition to a cushioned heel. Use of a full-length rigid foot orthotic can also be beneficial.
- Hindfoot (ST, TN, CC) arthritis—AFO or rigid lace-up leather brace (Arizona type)
- Tibiotalar arthritis—**NSAIDs, AFO, or rigid lace-up leather brace (Arizona type). Shoe modification consists of a single hindfoot rocker sole.**

▪ **Operative treatment**
- Hallux rigidus
  - Grades I and II (pain at extreme ROM only)—usually treated with dorsal cheilectomy (removal of all osteophytes including portion of dorsal metatarsal head with loss of cartilage; Fig. 6.79)
  - Grades III and IV (pain throughout ROM with positive grind)—best treated with arthrodesis (Fig. 6.80)
    - Position—neutral rotation, 10–15 degrees dorsiflexion, and 5 degrees valgus
  - The use of “synthetic cartilage” implants and interposition arthroplasty are options reserved for younger patients who require preserved hallux ROM. The results have not shown superiority to those of arthrodesis.
  - Metallic or silicone implant arthroplasty not recommended owing to poor results
    - Silicone arthroplasty can result in a heavy synovitis with destruction of the joint.
      - Postoperative isolated pain within the

great toe

    - Removal of implant with synovectomy is only successful in providing pain relief.

- Postoperative great toe pain with lesser metatarsalgia
    - Implant removal with bone grafting and arthrodesis needed to restore function of the great toe
- Failure of partial or total joint replacement of the hallux (osteolysis/implant loosening) may necessitate implant removal and arthrodesis with structural grafting.
    - The same is true if osteotomies are completed, leading to implant failure, AN, and subsequent fragmentation of the metatarsal head.

FIG. 6.79 Hallux rigidus of left foot treated with cheilectomy. (A–C) Before surgery. Radiographic hallmarks of hallux rigidus denoted by *white arrows* (dorsal osteophyte [A] and joint space narrowing [B and C]). (D and E) One year after surgery. Postoperative radiographs after cheilectomy (*white arrow*; D) with diminished but preserved joint space (*white arrow*; E).
From Canale ST, Beaty J: *Campbell's operative orthopaedics*, ed 11, Philadelphia, 2007, Elsevier.

- Midfoot joints
    - Midfoot arthrodesis is the treatment of choice.
    - In the setting of deformity (flatfoot) the joints must be reduced into anatomic position to achieve a satisfactory result (realignment arthrodesis) (Fig. 6.81).
    - *Medial column arthrodesis* refers to fusion of both the NC and first TMT joints; it is occasionally required for a flatfoot deformity to stabilize the collapsed midfoot and restore the lateral–first TMT angle.
    - In situ fusion in the setting of a deformity will predictably lead to a poor result.
- Hindfoot (ST, TN, CC) joints
    - Arthrodesis of single joints leads to significant limitation in hindfoot inversion/eversion (affects TN > ST > CC).

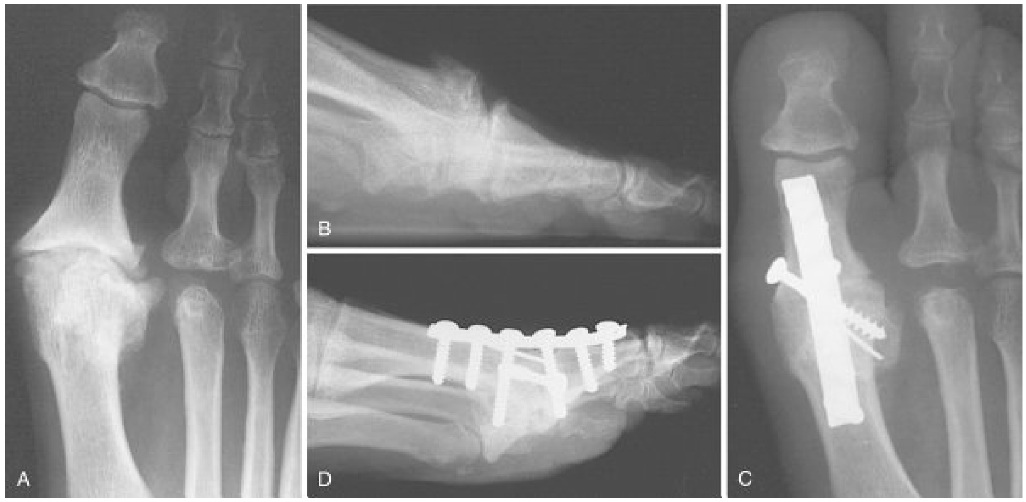


FIG. 6.80 Fusion for severe hallux rigidus. (A and B) Preoperative radiographs. (C and D) Postoperative radiographs.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

FIG. 6.81 (A) This posttraumatic deformity involved the entire midfoot, with all three columns seemingly affected. Despite the severity of the deformity, only the medial and middle columns were clinically symptomatic. (B and C) Arthrodesis was performed with realignment and screw fixation.
From Myerson MS: *Reconstructive foot and ankle surgery: management of complications,* ed 2, Philadelphia, 2010, Elsevier.

- Isolated TN fusion has a high rate of nonunion, and given the significant restriction of hindfoot motion from a TN fusion, an ST fusion is commonly performed in addition to ensure union without causing any incremental functional deficit.
- Triple arthrodesis is also an appropriate option. If the CC joint is unaffected, it is more common to *not* include the CC joint in the arthrodesis ("medial double") for a pes planovalgus deformity.
    - Triple arthrodesis is usually performed to correct

arthritis of the triple joint complex or rigid deformity that is not pes planovalgus (Fig. 6.82).

- Position—0 to 5 degrees of hindfoot valgus, neutral abduction/adduction, plantigrade (both the first and fifth metatarsal heads evenly strike the ground)
- Revision of a malunited triple arthrodesis requires
    - Calcaneal osteotomy (corrects varus or valgus)
    - Transverse tarsal osteotomy (allows rotation of the foot into a plantigrade position)
    - Wedge resection can correct abduction (medial wedge) or adduction (lateral wedge).

- Subtalar arthrodesis
    - Indications
        - Subtalar DJD
        - Calcaneus fracture (Sanders IV) or late sequelae
        - Posttraumatic DJD secondary talus fracture (no deformity) (Fig. 6.83)
        - Talocalcaneal coalition

FIG. 6.82 Triple arthrodesis, methods of internal fixation. (A) Diagram of triple arthrodesis. (B1 and B2) Postoperative radiographs demonstrating triple arthrodesis with anatomic restoration of foot posture. (C1 and C2) Triple arthrodesis using 7.0-mm cannulated screws for the subtalar and talonavicular joints and multiple power staples for the calcaneocuboid joint. (D1–D4) Correction of severe hindfoot deformity secondary to long-standing posterior tibial tendon dysfunction with restoration of the longitudinal arch using a 7.0-mm cannulated screw for the subtalar joint and power staples for the talonavicular and calcaneocuboid joints. Note that the height of the longitudinal arch has been restored and severe abduction of the foot corrected.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

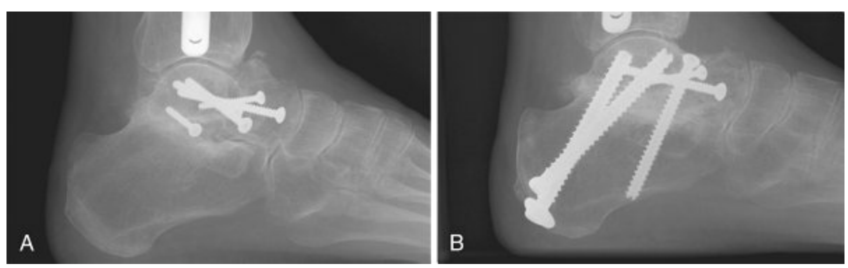


FIG. 6.83 (A) Preoperative radiograph of a patient with subtalar arthritis, the most common complication following a talus fracture. Importantly, the patient did not have a varus deformity with shortening of the medial column. Note that screws are from previous talus fracture repair. (B) Postoperative radiograph demonstrates a subtalar fusion that eliminated the patient's pain. If the patient had had a varus deformity, a triple arthrodesis would have been required.

- Complications
    - Increased nonunion rate with history of ankle arthrodesis or smoking; nonunion rate higher with prior ankle arthrodesis than with nicotine use

- Subtalar bone-block arthrodesis (Fig. 6.84)
    - Indicated for prior calcaneal fracture with loss of height
        - Normal calcaneal declination is ≈26 degrees
        - Results in anterior impingement, complaints of anterior ankle pain with ambulation in addition to hindfoot pain
    - Autograft or allograft bone block arthrodesis restores the height of the calcaneus.
        - Less successful at correcting residual hindfoot varus

□ Tibiotalar joint

- Arthrodesis provides excellent pain relief but also results in some restricted function (Fig. 6.85).
    - Position—neutral dorsiflexion (90 degrees), 0–5 degrees hindfoot valgus, 5–10 degrees external rotation
        - Valgus and external rotation keep the hindfoot unlocked to allow for accommodative hindfoot motion.
    - Leads to radiographic arthritis in surrounding foot joints
        - Subtalar joint is the most common location of adjacent joint arthritis.
        - No evidence to show causation or progress of knee or hip arthritis.
    - Malunion may lead to anterior talar translation of the talus. This can elongate the lever arm of the foot and needs a revision arthrodesis of the ankle.
        - If fibula was taken as part of ankle fusion, total ankle replacement is not possible.
- Total ankle arthroplasty outcomes are improving and are no longer considered experimental.
    - Can be considered in patients who have low demand in the ankle, are more than 50 years old, and have minimal deformity (<10 degrees)
    - Pain relief equivalent to that for arthrodesis, function and gait are slightly better, risk of revision surgery is higher
    - Total ankle replacement (TAR) has shown the best

outcome in patients with osteoarthritis.

- Superior to that shown in patients with rheumatoid or posttraumatic etiology
- **Syndesmotic fusion is associated with decreased rate of failure when the Agility ankle replacement system was previously used.**

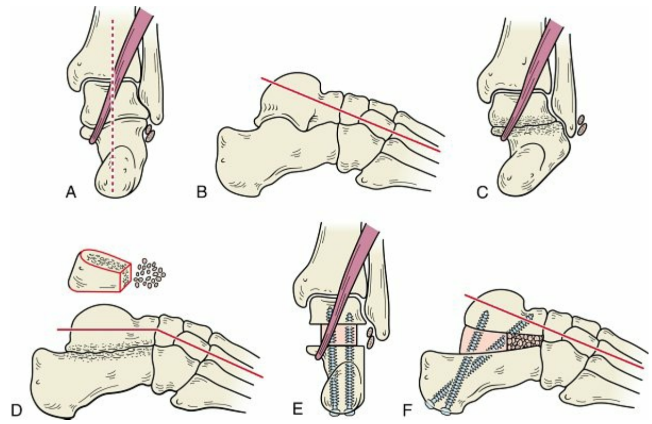


FIG. 6.84 Subtalar fusion with distraction. (A) The dashed line shows the alignment of the tibia through the tuber, the area where the flexor hallucis longus crosses at the back of the joint, and the location of the peroneal tendons under the fibular tip. (B) Normal alignment of the subtalar joint and inclination of the talus are depicted. Notice that the all-important midaxial line of the talus continues directly through the midfoot and the apex of the first metatarsal in the medial column. (C) After a typical high-energy calcaneal crush injury, the tuber is angled into varus while the lateral wall is angled and has exploded laterally toward valgus and impinges on the distal fibula, pushing the peroneal tendons out of their normal position. The subtalar joint is crushed and the hindfoot has lost height. (D) The inclination of the talus is out of line with the medial column and markedly limits the range of dorsiflexion in the anterior dome of the talus. A wedge of posterior iliac crest tricortical bone will be used to open the talocalcaneal joint and restore height. (E) Two large 6.5-mm bolts or fully threaded screws are positioned much as they would be for subtalar arthrodesis in situ. In this case, however, they serve as positioning

screws rather than lag screws and maintain distraction of the talus from the calcaneus instead of compressing the graft. The exploded lateral wall is excised and the tuber repositioned with less varus tilt and in slight valgus alignment in relation to the weight-bearing line of the tibia. (F) Reconstruction restores ideal talar inclination and talar–naviculocuneiform–first metatarsal axial alignment. An anteroposterior radiographic view of the foot should be taken intraoperatively to ensure that the talocalcaneal alignment is correct in the transverse plane and that the foot is not significantly pronated or supinated.

From Browner B et al: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier. Adapted and redrawn from Hansen ST Jr: *Functional reconstruction of the foot and ankle,* Philadelphia, 2000, Lippincott Williams & Wilkins.

FIG. 6.85 (A) Preoperative anteroposterior and lateral radiographs of a patient with end-stage ankle arthritis. (B) An ankle fusion was performed with an anterior plate and cross screws. The method of fixation is not as critical as ensuring a neutral clinical position of the ankle.

- Current generation of implants preserves the syndesmosis and distal fibula.
- Newer-generation implants retain ligamentous and bony stabilizers and require careful anatomic balancing.
- Medialization of extramedullary tibial cutting guides can lead to fracture of the medial malleolus.
- **Salvage of implant failure is difficult given the amount of bone loss and current lack of available revision components. The most reliable current technique is a bone-block ankle arthrodesis (femoral head) with or without additional subtalar**

fusion.

- Wound breakdown in the acute period (3 weeks) after TAR requires débridement and polyethylene exchange; if 6 weeks or longer after TAR, removal of implant and placement of antibiotic spacer should be considered.
- Contraindications include severe coronal plane deformity, AVN (talus or tibia), Charcot arthropathy, young age, and history of infection.

- Distraction arthroplasty using thin-wire external fixation—limited role; may be option in younger patients with preserved ankle ROM
- Bipolar osteochondral allograft transplantation—data are few and most series report high failure rates

Postural Disorders

Pes Planus (Flatfoot Deformity)

- **May be congenital (see** Chapter 3, Pediatric Orthopaedics) or acquired (also called *adult-acquired flatfoot deformity* [AAFD])
- **Determining whether the deformity is flexible or fixed is important**
  - Fixed or rigid deformity requires a triple arthrodesis.
- **Tarsal coalitions tend to cause rigid flatfoot deformities.**
- **Present in adolescence or later**
- **50% bilateral**
- **1 in 100 people affected**
- **Diagnostics: radiographs and CT scans**
- **Treatment**
  - Nonoperative: rests, walking boot, casts, injections
  - Operative: resection and interposition with muscle/fatty tissue if less than 50% of middle facet is involved; arthrodesis if more than 50%
- **Pathology**
  - Most common cause of AAFD is PTTD.
    - PTT is the primary dynamic support for the arch.
    - PTT fires after the foot is flat to generate heel rise and lock the transverse tarsal joint for a rigid, stable foot during push-off (toe-off).
    - The tibia rotates externally and the transverse tarsal locks as the PTT fires during push-off.
    - Etiology of PTTD is multifactorial and includes:
      - Zone of hypovascularity 2–6 cm proximal to the PTT insertion on the navicular
      - Overload of the arch due to activity or obesity
      - Inflammatory disorders such as RA
  - **The spring (calcaneonavicular) ligament is the primary static stabilizer of the TN joint.**
    - Incompetence of the spring ligament is associated with increased flatfoot deformity.
      - Most commonly the superomedial band (70%)
    - Isolated acute rupture of the spring ligament has been reported to cause an acute deformity without PTTD.
    - Reconstruction of the spring ligament with allograft or autograft as an adjunct to standard flatfoot reconstruction has shown success in early series.
- **Diagnosis**
  - Patients complain of medial ankle/foot pain early, progressive loss of

arch, and lateral ankle pain late (subfibular impingement).

- Physical examination
  - Standing examination demonstrates asymmetric hindfoot valgus, depressed arch, and an abducted forefoot.
    - Too-many-toes sign: when the foot is viewed posteriorly, it appears to have more than five toes (Fig. 6.86)
  - Pain or inability to perform single-limb heel rise indicates insufficient PTT.
  - Whether deformity is flexible (passively correctable to a plantigrade foot) or fixed (rigid deformity that is not passively correctable) must be determined
  - Lateral impaction syndrome or subfibular impingement with significant valgus of the heel, such that it abuts the fibula, may be present; abutment of the lateral process of the talus and the calcaneus can occur as well.
- Radiographs (Fig. 6.87)
  - Pes planus indicated by negative lateral talar–first metatarsal angle (Meary angle)
  - Forefoot abduction indicated by TN uncoverage

- **Treatment—based on stage of the deformity**
  - Stage I—tenosynovitis without deformity
    - Nonoperative
      - Immobilization (cast or boot)
      - Orthotic after acute swelling and pain subside
        - Arch support with medial heel wedge
    - Operative
      - Synovectomy of PTT
  - Stage II—flexible deformity is the critical feature; PTT is degenerated and functionally incompetent.
    - Nonoperative
      - AFO in conjunction with physical therapy has demonstrated the highest success rate.
      - Use of a full-length orthotic with an arch support, medial heel wedge, and medial forefoot support (if supination/forefoot varus present) is used after acute pain has resolved.

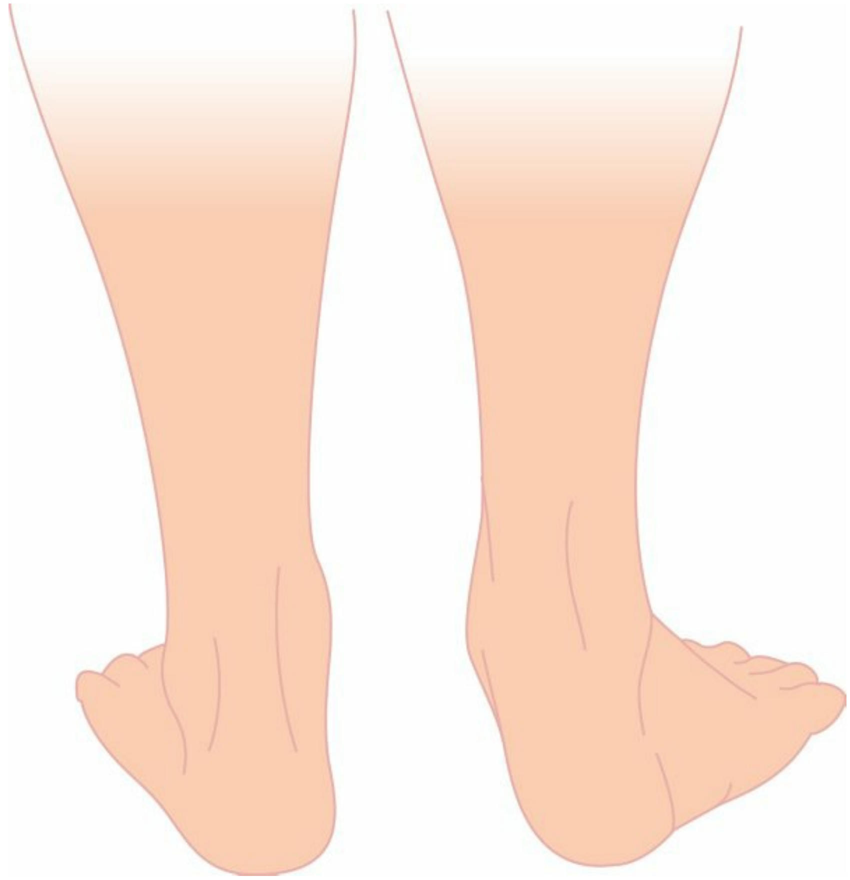


FIG. 6.86 Patients with tendon ruptures have either a unilateral flatfoot or, in those who had previous flatfoot, a relatively flatter foot on the involved side. Excessive forefoot abduction also can be suspected from posterior observation when more toes are visible lateral to the patient's heel on the involved side. This finding is called the *too-many-toes sign.*
From DeLee J: *DeLee and Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2011, Saunders.

- A lace-up ankle brace may also be used.
- Operative (if conservative measures fail after 6 months or more)
  - Correction of all stage II deformities includes a tendon transfer (FDL or FHL) into the navicular to reconstruct the PTT.
  - Presence of a gastrocnemius contracture should be assessed for and if present corrected with a gastrocnemius recession.
  - Although reconstruction of the spring ligament has been advocated, there are limited data to demonstrate its efficacy at this time.
- Stage IIA—defined by hindfoot valgus without significant forefoot abduction (<40% uncovering of the talus)
  - Medial slide calcaneal osteotomy (Fig. 6.88)
    - To address signs of subfibular impingement

- Stage IIB—defined by forefoot abduction (>40% uncovering of the talus) in addition to hindfoot valgus
    - Lateral column lengthening (Fig. 6.89)
        - To address hindfoot valgus and improve the longitudinal arch of the foot/medial column of the foot
    - Additional medial slide calcaneal osteotomy may be required.
- Stage IIC—defined by fixed forefoot supination/varus (first ray is elevated after correction of the hindfoot to neutral) in addition to hindfoot valgus (Fig. 6.90). Forefoot abduction may also be present.
    - Stable medial column—navicular is colinear with first metatarsal.
        - Cotton osteotomy (dorsal open-wedge osteotomy of the cuneiform) to plantar flex the first ray, to correct forefoot varus
    - Unstable medial column—plantar sag at NC or first TMT joint
        - Medial column fusion (based on point of collapse)
        - Isolated first TMT fusion
        - Isolated NC fusion
        - Combined NC and TMT fusion (both joints are involved radiographically)

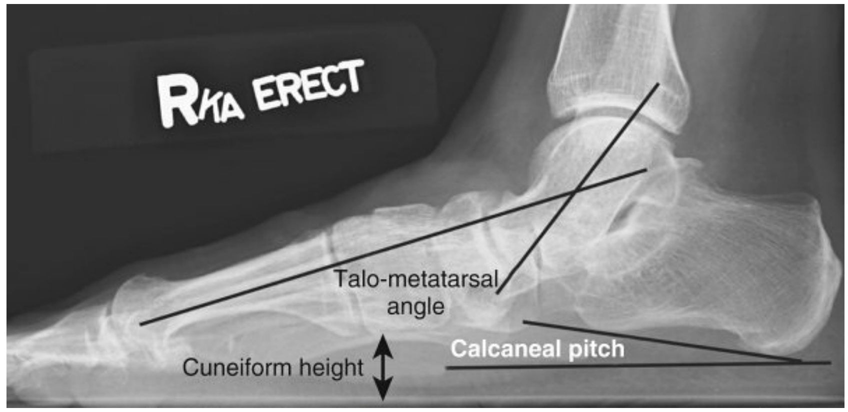


FIG. 6.87 The lateral foot radiograph images the loss of alignment between the first metatarsal and midfoot. A talar–first metatarsal angle greater than 4 degrees signifies pes planus (as shown, 32 degrees). The calcaneal pitch angle is also determined on the lateral radiograph; a normal angle is between 17 and 32 degrees (12 degrees in this patient). Arch height loss is documented by a decrease in this angle. A loss of medial cuneiform–floor height is also indicative of loss of arch height. This height is indicated by the black arrow.

From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.

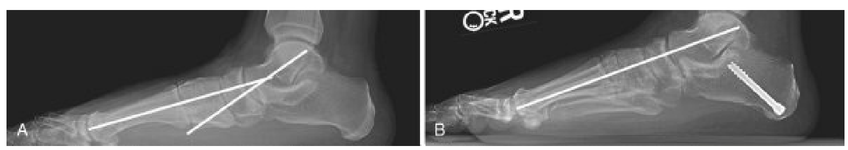


FIG. 6.88 (A) Preoperative radiograph of a patient with stage II posterior tibial tendon dysfunction. Note the break in the lateral talar–first metatarsal angle centered at the talonavicular joint. (B) Excellent correction is shown on the postoperative radiograph, with restoration of the lateral talar–first metatarsal angle with colinearity of the first metatarsal and the talus.

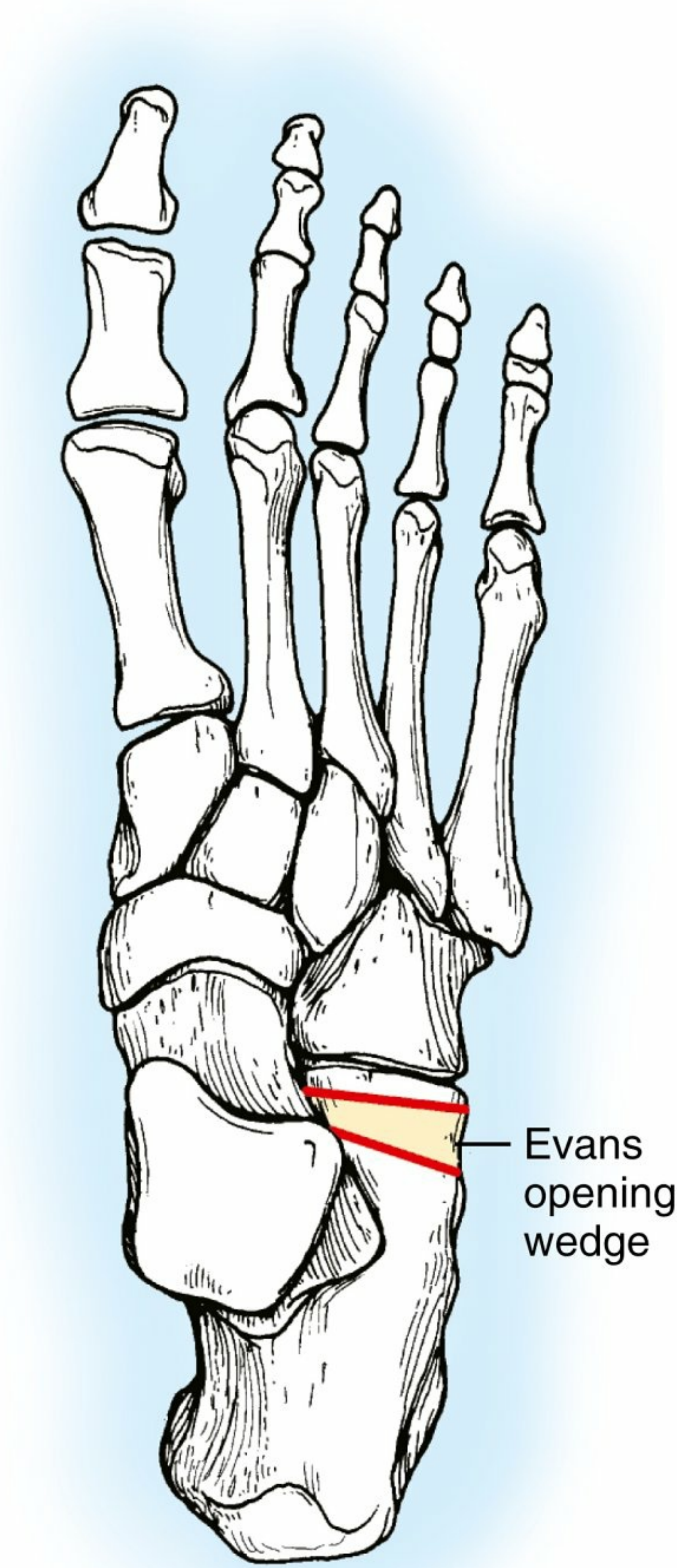


FIG. 6.89 Evans anterior calcaneal osteotomy helps restore and stabilize longitudinal arch by elongating

lateral column of foot.

From Coughlin M et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Elsevier. Modified from Pedowitz WJ, Kovatis P: Flatfoot in the adult, *J Am Acad Orthop Surg* 3:293, 1995.

        - Hindfoot treatment based on talar uncovering
            - Less than 40%—medial slide calcaneal osteotomy
            - More than 40%—lateral column lengthening and possible medial slide calcaneal osteotomy if residual hindfoot valgus
    - Stage II surgical summary
        - FDL or FHL tendon transfer for *all* patients
        - Gastrocnemius recession if contracture present
        - Hindfoot valgus—medial slide calcaneal osteotomy
        - Forefoot abduction—lateral column lengthening
        - Forefoot supination
            - Stable medial column—Cotton osteotomy
            - Unstable medial column—first TMT arthrodesis
- Stage III—defined by a fixed/rigid pes planovalgus deformity
    - Nonoperative
        - Accommodative rigid AFO or Arizona brace. *No* attempt should be made to correct the deformity—correction carries increased risk of pain and pressure points, leading to ulceration.

FIG. 6.90 Demonstration of forefoot varus. The degree of forefoot varus is determined by placing the heel in neutral position, covering the head of the talus with the navicular, and then observing the relationship of the metatarsal heads to the neutral hindfoot. In fixed forefoot varus, the lateral border of the foot is more plantar flexed than the medial border.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

- Operative
  - Triple arthrodesis
    - If subtalar arthrodesis (alone or as part of triple) has been malunited in valgus, with tenderness in the lateral subfibular region, arthrodesis takedown and revision arthrodesis may be required.
    - Severely abducted deformities may require an all-medial approach, to limit risk of wound healing issues with the sinus tarsi approach.
    - Some authors argue that the calcaneocuboid joint is challenging to see, but cadaveric studies have demonstrated the ability to see >90% of each joint from the medial

approach alone.

- Additional medial column stabilization is occasionally needed for severe deformities (Fig. 6.91).
- TAL if equinus contracture present

- Stage IV—defined by incompetence of the deltoid ligament; standing AP ankle radiograph demonstrates lateral talar tilt (valgus) or ankle arthritis.
    - If the ankle valgus is passively correctable with minimal degenerative changes, an attempt can be made at deltoid ligament reconstruction with hindfoot reconstruction.

FIG. 6.91 (A to C) Rigid flatfoot deformity before treatment with a triple arthrodesis.
From Myerson MS: *Reconstructive foot and ankle surgery: management of complications,* ed 2, Philadelphia, 2010, Elsevier. [Photos courtesy John Campbell, MD, Baltimore, MD.]

FIG. 6.92 Radiograph showing tibiotalocalcaneal arthrodesis for involvement of the ankle and subtalar joints performed with an intramedullary device and augmented with screw fixation.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle*, Philadelphia, 2007, Elsevier.

- Rigid deformity or progressive arthritis requires TTC arthrodesis (Fig. 6.92).
- The most reliable operation for a stage IV deformity is a TTC fusion.
    - Especially when the talar tilt is greater than 10 degrees

Pes Cavus Deformity

- **Defined by a high-arched foot, often with associated heel varus (cavovarus)**
- **Pathology**
    - Neuromuscular
        - Unilateral—tethering of the spinal cord or spinal cord tumors must be ruled out.
        - Bilateral—most commonly Charcot-Marie-Tooth (see Section 11, Neurologic Disorders)
        - Idiopathic—usually subtle, bilateral
        - Traumatic—secondary to talus fracture malunion,

compartment syndrome, crush injury

- **Diagnosis**
  - **Patients complain of painful calluses under the first metatarsal, fifth metatarsal, and medial heel.**
    - There may be pain along the peroneal tendons as well.
      - These may need to be addressed as part of surgical intervention.
    - Secondary to the plantar-flexed first ray and varus hindfoot
      - Plantar flexion of the first ray is secondary to overpowering of the tibialis anterior by the peroneus longus.
      - Varus of the hindfoot is secondary to the overpull of the PTT.
      - On an adequate weight-bearing, lateral foot radiograph, visibility of the middle facet of the subtalar joint indicates varus hindfoot.
  - Often associated with lateral ankle ligament instability, peroneal tendon pathology
  - Coleman block test used to assess flexibility of the hindfoot (out of varus) when the first metatarsal plantar flexion (forefoot valgus) is eliminated.
    - Wooden block placed just lateral to the first ray; first metatarsal head then lies off the block, with remainder of block on the weight-bearing foot.
      - If the hindfoot passively corrects into valgus, the deformity is forefoot driven (due to plantar-flexed first ray).
- **Treatment**
  - **Nonoperative—orthotics with lateral heel wedge, accommodative arch, and depressed first ray may be effective (Fig. 6.93).**
  - Operative
    - Forefoot-driven deformity—first metatarsal dorsiflexion osteotomy is indicated.
    - With no or incomplete correction of the hindfoot on the Coleman block test, a lateral calcaneal closed-wedge osteotomy (Fig. 6.94) is indicated in addition to a dorsiflexion osteotomy of the first metatarsal (Fig. 6.95).
    - A subtalar fusion or triple arthrodesis may be needed if arthritic symptoms are present.

Tendon Disorders

Achilles Tendon

- **The Achilles tendon is addressed in Section 15.**

Peroneal Tendons

- **Most common disorders include tendinitis/tenosynovitis and tendon subluxation/dislocation, which often causes peroneus brevis degenerative tears.**
- **Diagnosis**
    - Acute or chronic localized swelling and tenderness over peroneal tendons
    - **Common cause of chronic pain following an ankle sprain or with chronic instability**
    - Associated with cavovarus foot deformity
    - Peroneal subluxation or dislocation
        - Caused by forced eversion and dorsiflexion leading to disruption of superior peroneal retinaculum (SPR)
        - Pain and/or sensation of snapping in the retrofibular groove
        - Often causes peroneus brevis degenerative tears
        - Sudden dorsiflexion during downhill skiing is a common report.
        - Plain radiographs may demonstrate a rim fracture of the lateral aspect of the distal fibula.
    - Acute rupture of the peroneus longus tendon at or through a fracture of the os peroneum can occur.
        - Radiographs show a retraction or fracture of the os peroneum.
        - **MRI may demonstrate displacement of peroneal tendons anterolateral to the retrofibular region.**
- **Treatment**
    - Nonoperative treatment
        - Chronic peroneal tendinosis or tenosynovitis is initially treated with activity modification, NSAIDs, lace-up ankle brace, and physical therapy.
        - Ultrasound or MRI can be used to aid diagnosis (Fig. 6.96).
            - Ultrasound useful as dynamic tool to evaluate subluxation/dislocation.
            - False-positive results showing longitudinal tears common with MRI.

- Operative treatment—based on the pathology
  - Tenosynovectomy, débridement, and repair of degenerative tears (usually peroneus brevis)
    - If conservative management (immobilization/physical therapy) fails
    - Early treatment of longitudinal splits, reduces risk of progression to full tear
    - Synovitis or less than 50% diseased tendon
    - Groove deepening if shallow fibular groove and peroneal retinacular repair if evidence of tendon subluxation
    - Patients may have evidence of apprehension with resistant eversion, which may be relieved with manual stabilization of the peroneal tendons
    - Assessment for intratendinous subluxation also needed
  - Excision and tenodesis
    - Required when there is a complete rupture or severely degenerative tendon (>50%) that prohibits repair
  - For hindfoot varus
    - Dwyer osteotomy (lateral closed-wedge osteotomy of the calcaneus)
      - Limits risk of recurrent tears and continued pain
  - For peroneal subluxation or dislocation
    - Chronic
      - Requires repair/reconstruction of the SPR and fibular groove deepening
    - Acute
      - SPR repair/reconstruction
  - Tendon transfer to fifth metatarsal
    - More than 50% degeneration of both peroneus longus and brevis requires excision of both tendons.
    - Good results reported with both lateral transfer of the FHL or FDL and allograft.
      - Allograft may be used if peroneal muscles demonstrate adequate excursion at the time of surgery with minimal atrophic change to the muscle.

Posterior Tibial Tendon

- **The posterior tibial tendon is addressed in Section 13, Pes Planus (Flatfoot Deformity).**

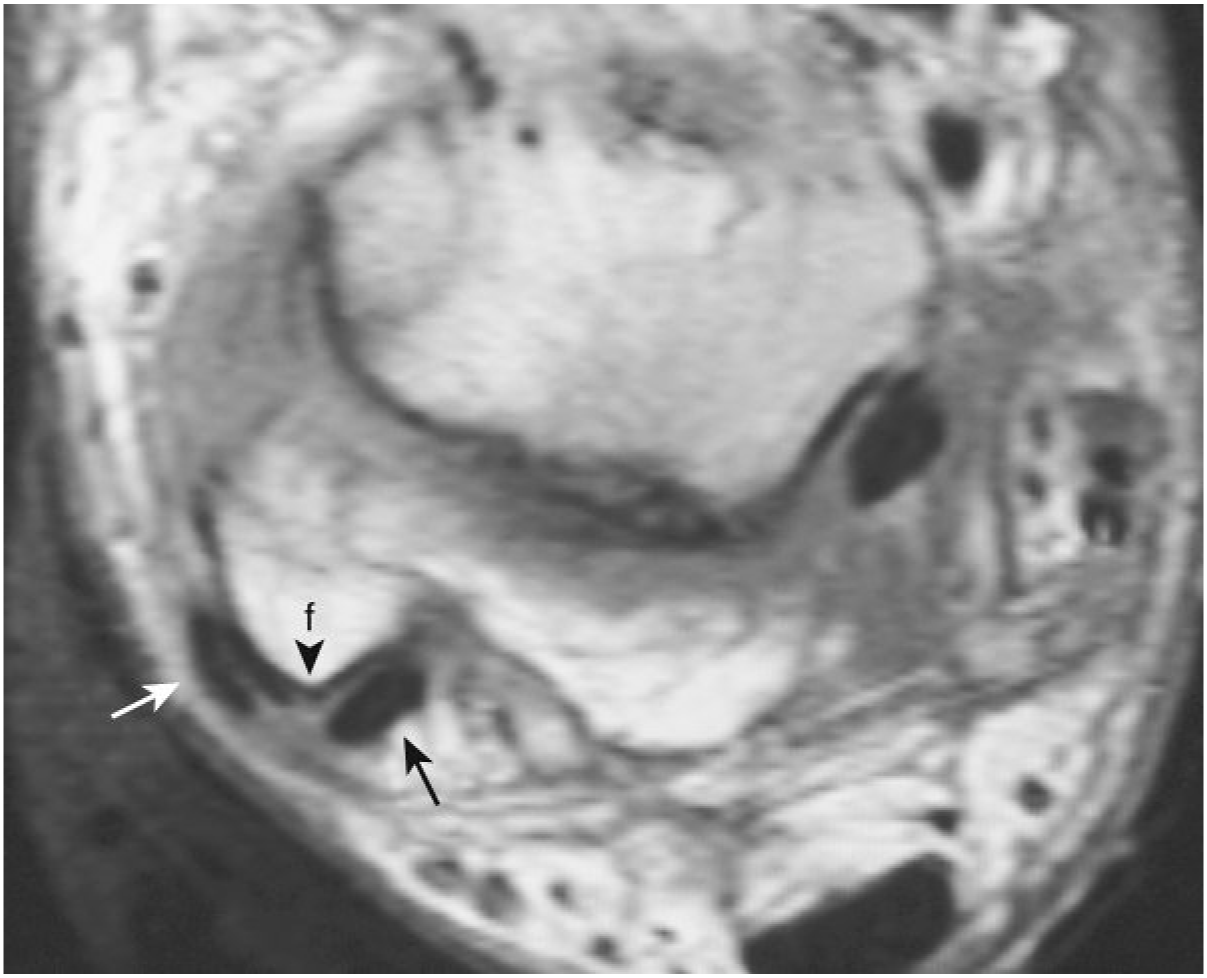


FIG. 6.96 Peroneal tendon subluxation. Axial proton density MR image shows longitudinally torn peroneus brevis *(white arrow)* subluxed laterally and anteriorly from its normal position adjacent to the peroneus longus *(black arrow).* Note that the distal fibula has a rounded contour *(small black arrowhead),* a finding that can be associated with peroneal subluxation. *f,* Fibula.
From Manaster BJ et al: *Musculoskeletal imaging—the requisites,* ed 3, Philadelphia, 2006, Elsevier.

Anterior Tibial Tendon

- **Tenosynovitis uncommon but can be observed in patients with inflammatory arthritis**
  - NSAIDs and walking cast or boot recommended
  - Corticosteroid injections may provide relief but increase the risk of tendon rupture.
- **Complete ruptures rare—occur mainly in older patients**
  - Commonly missed diagnosis

- Manifests as painless anterior ankle mass
- Footdrop may be subtle because of recruitment of toe extensors.
- **Primary repair generally improves functional results regardless of age.**
- **Tendon grafting augmentation may be warranted if there is adequate excursion of the myotendinous unit and the muscle is healthy**.
- **Interpositional graft may be required in delayed cases**.

Flexor Hallucis Longus

- **Stenosing FHL tenosynovitis**
  - Usually seen in dancers on pointe and gymnasts
  - Posterior ankle pain, triggering of the hallux interphalangeal joint, and pain with resisted hallux plantar flexion
  - Stenosis occurs along course of FHL between the posterolateral and posteromedial tubercles of the talus.
  - MRI is the diagnostic modality of choice.
    - Fluid (high signal intensity) is noted surrounding the FHL at the level of the ankle joint (Fig. 6.97).
  - Nonoperative treatment—activity modification, consideration of boot immobilization for short period of rest, NSAIDs
  - Operative treatment—open (posteromedial approach) or arthroscopic FHL tenosynovectomy and release of the fascia

Heel Pain

Plantar Heel Pain

- **Plantar fasciitis**
  - Definition
    - Painful heel condition that can affect both sedentary and active individuals and is most often seen in the adult population
    - Associated with a contracture of the gastrocnemius-soleus complex
    - Biggest risk factor for plantar fasciitis is BMI over 30 kg/m^2
  - Pathology
    - Likely involves microtears at the origin of the plantar fascia, which initiates inflammation and an injury-repair process that leads to a traction osteophyte
    - 90%–95% of cases improve within a year regardless of the specific treatment offered.
    - Associated with a gastrocnemius contracture
  - Diagnosis
    - Exquisite pain and tenderness over the plantar medial tuberosity of the calcaneus at the proximal insertion of the plantar fascia
    - Classic symptoms include pain with the first step in the morning and after prolonged sitting.
    - Bilateral symptoms are common; may be seen in conjunction with posterior tibial tendon dysfunction.
    - Small subset of patients may experience pain and tenderness at the origin of the abductor hallucis, which may indicate entrapment or inflammation of the first branch of the lateral plantar nerve.
    - **Weight-bearing x-rays are an important first diagnostic step to evaluate for stress injuries, subtalar arthritis, tumor, and insertional enthesophytes.**
    - **Advanced imaging (MRI) may demonstrate thickening of the plantar fascia and surrounding inflammation.**
  - Nonoperative treatment
    - Plantar fascia–specific stretching protocols and Achilles tendon (heel cord) stretching are the key to effective nonoperative management.
    - Also includes cushioned heel inserts, night splints, physical therapy, walking casts, and antiinflammatory medications

- Cortisone injections may relieve pain but are associated with attenuation or rupture of the plantar fascia, fat atrophy.
  - Number of injections that can lead to rupture has been found to be 2.67.
- Platelet-rich plasma injections and low-intensity extracorporeal shock wave therapy (ESWT) have demonstrated success in limited studies.

□ Operative treatment
- Indicated for fewer than 5%
- Limited release of the plantar fascia (medial half) may be necessary in refractory cases.
- Complete release can place the longitudinal arch of the foot at risk, overload the lateral column, and lead to dorsolateral foot pain and metatarsal stress fractures.
- Concomitant release of the deep fascia of the abductor hallucis may relieve entrapment of the lateral plantar nerve and improve the surgical result (Fig. 6.98).
- **Gastrocnemius recession has been advocated and should be considered in isolation in patients with clear evidence of a gastrocnemius contracture without evidence of jogger's foot/Baxter neuritis.**

▪ **Baxter neuritis (compression of first branch of lateral plantar nerve)**

□ Definition
- Baxter neuritis manifests as plantar medial heel pain that can be difficult to differentiate from plantar fasciitis.
- Seen in athletes involved in running sports

□ Diagnosis
- Pain more medial over abductor hallucis (as compared to the more plantar pain seen with plantar fasciitis)
- Compression over Baxter nerve reproduces the pain and may cause radiation into the plantar lateral foot.
- Diagnostic tests
  - EMG/nerve conduction velocity (NCV) measurement may demonstrate increased motor latency within the abductor digiti quinti.
  - MRI may show fatty infiltration of the abductor digiti quinti, best seen on coronal views.

□ Nonoperative treatment
- Heel cord stretching and cushioned heel inserts

□ Operative treatment
- Open release of Baxter nerve must include release of the deep fascia of the abductor hallucis.

▪ **Bony causes of plantar heel pain**

- Calcaneal stress fractures
  - Most common in the active individual or military recruit
  - MRI typically used to aid diagnosis.
  - Treated with rest, protected weight bearing (cast, CAM walker).
- Periostitis
  - Pain and tenderness in the central portion of the heel pad
  - Represents traumatic periosteal or bursal inflammation secondary to a known injury or atrophic heel pad
  - Treated with cushioned shoe inserts or a short course in a well-padded cast.
  - The examiner should be vigilant for other signs or symptoms suggesting inflammatory arthritis.
- Sever disease
  - Also referred to as *calcaneal apophysitis*
  - More common in boys; typically appears between age 10 and 14 years, prior to closure of calcaneal apophysis and just before or during a growth spurt
  - Treatment includes activity modification, gastrocnemius stretching, and cushioned heel orthotics.
  - No correlation between symptoms and fragmentation of apophysis.

Achilles Disorders

- **Definition**
  - The Achilles tendon (comprising the gastrocnemius and soleus tendons) rotates 90 degrees laterally to insert on the posterior aspect of the calcaneal tuberosity.
    - Inserts more medially on the calcaneus, making it a secondary invertor

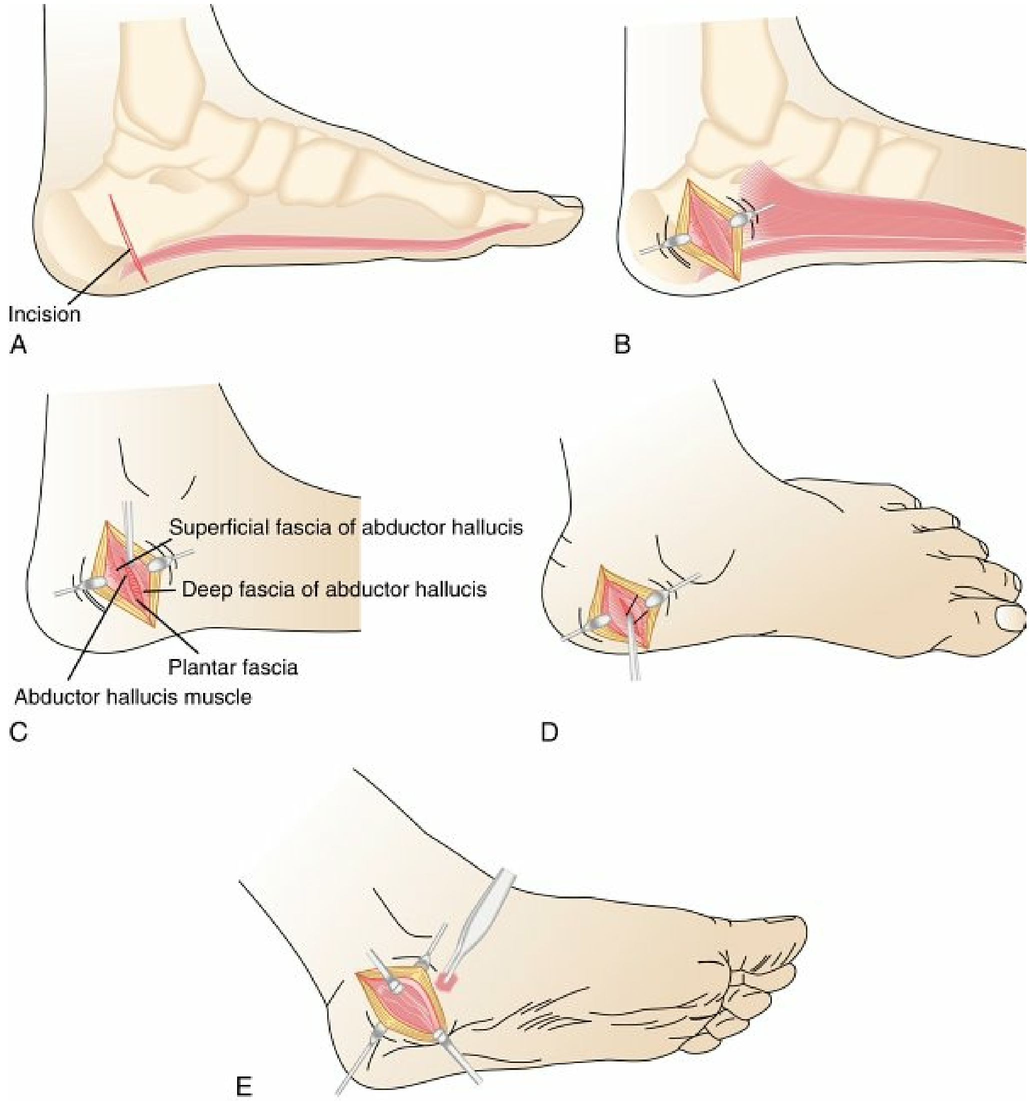


FIG. 6.98 Plantar fascia and nerve release. (A) Incision. (B) Release of the abductor hallucis muscle. (C) Abductor hallucis muscle is reflected proximally. (D) Abductor hallucis is retracted distally. (E) Resection of small medial portion of the plantar fascia.
From DeLee J: *DeLee and Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2011, Saunders.

- □ The retrocalcaneal bursa lies between the anterior surface of the Achilles tendon and the posterosuperior aspect of the calcaneus.
- □ *Haglund deformity* refers to an enlarged prominence of the posterosuperior calcaneal tuberosity.
- □ The Achilles accepts 2000 to 7000 N of stress, depending on the applied load, and transfers forces of 6 to 10 times body weight during a running stride.

▪ **Physical examination**
- □ Bony prominence, tendon thickening, and area of tenderness should be evaluated.
- □ The Silfverskiöld test evaluates for contracture.
  - Ankle dorsiflexion is tested with the knee extended and flexed and the hindfoot in neutral position.
  - Tightness in both knee flexion and extension indicates Achilles contracture.

- Improvement in ankle dorsiflexion with knee flexion (relaxing the gastrocnemius origin proximal to the knee) indicates isolated gastrocnemius contracture.

- **Retrocalcaneal bursitis/Haglund deformity**
  - Inflammation of the retrocalcaneal bursa often occurs along with insertional tendinopathy and Haglund deformity
  - Diagnosis
    - Patient presents with deep posterior heel pain, fullness and tenderness with palpation medial and lateral to the tendon, and increased pain with ankle dorsiflexion.
    - Symptoms often seen in conjunction with insertional Achilles tendinopathy.
    - Lateral foot radiographs demonstrate Haglund deformity.
    - MRI is rarely necessary to make the diagnosis.
  - Nonoperative treatment
    - NSAIDs, external padding, ice, heel-lift orthotics, and shoewear modification
    - Steroid injection should be avoided owing to inherent risk of Achilles rupture.
  - Operative treatment—includes débridement of inflamed retrocalcaneal bursa along with excision of Haglund deformity when present (Fig. 6.99)
- **Insertional Achilles tendinopathy**
  - Degenerative process showing disorganized collagen and mucoid degeneration with minimal inflammatory cells

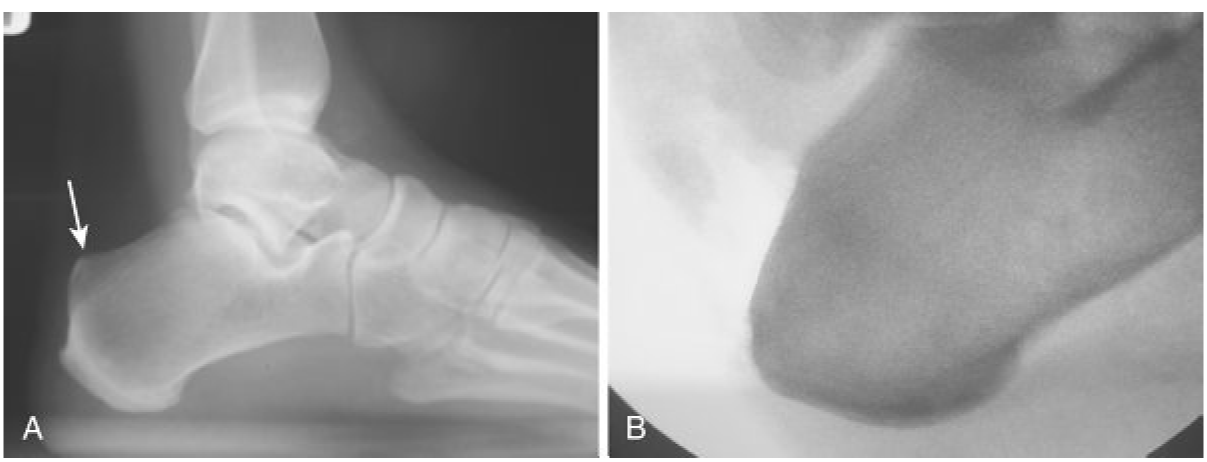


FIG. 6.99 Preoperative (A) and intraoperative (B) radiographs of Haglund deformity *(arrow).*
From Porter D, Schon L: *Baxter's the foot and ankle in sport,* ed 2, Philadelphia, 2007, Elsevier.

  - *Tendinopathy* is preferred description.
  - Accounts for approximately one-fourth of Achilles tendinopathy cases
  - Diagnosis
    - Patient complains of pain, swelling, burning, and stiffness in

the posterior heel.
    - Progressive enlargement of the bony prominence of the heel, along with pain caused by direct pressure from shoewear is common.
    - Tenderness localized to the Achilles tendon insertion on the posterior calcaneus, most often midline
  - Radiographic evaluation
    - Bone spur and intratendinous calcification seen on lateral foot radiograph (Fig. 6.100)
    - MRI and ultrasound can be helpful to determine extent of Achilles tendon degeneration.
  - Nonoperative treatment
    - Activity and shoewear modification, heel lifts, stretching, physical therapy with heavy load eccentric training, and silicone heel sleeves/pads to decrease pain from direct pressure are mainstays of conservative treatment.
    - Although it has been used, ESWT lacks definitive supporting data.
    - Steroid injections should be avoided.
    - Nonoperative treatment beneficial in approximately 50% to 70% of cases
  - Operative treatment
    - Includes excision of retrocalcaneal bursa, resection of prominent superior calcaneal tuberosity, and débridement of degenerative tendon including calcification
    - If tendon detachment (>50%) is required for thorough débridement, reattachment with suture anchors is indicated.
    - Lateral, midline, and medial J-shaped incisions have all been described.
    - FHL tendon transfer is indicated if more than 50% of the Achilles tendon requires excision (Fig. 6.101).
- **Noninsertional Achilles tendinopathy**
  - May consist of inflammation of the paratenon alone, peritendinitis with a component of tendon thickening (commonly referred to as *tendinosis*), or tendinosis alone
  - Multifactorial etiology includes overuse, mechanical imbalance, poor tissue vascularity, genetic predisposition, and use of fluoroquinolone antibiotics.
  - Thought to involve the response to microscopic tearing of the tendon

FIG. 6.100 Radiography of the Achilles tendon. Insertional tendinosis. The distal tendon is thickened at its site of insertion onto the calcaneus, and an insertional enthesophyte has formed *(arrow)*.
From Weissman B: *Imaging of arthritis and metabolic bone disease*, Philadelphia, 2009, Elsevier.

□ Abnormal vascularization of the ventral mesotenal vessels 2 to 6 cm proximal to the insertion limits blood flow to diseased tissue and decreases capacity for healing.

□ Accounts for nearly half of all Achilles tendinopathy cases

□ Diagnosis

- Patients often present with pain, swelling, and impaired performance, especially with running.
- Tender area of fusiform thickening localized approximately 2 to 6 cm proximal to the insertion of the tendon
- MRI demonstrates thickening of the tendon, with intrasubstance intermediate signal intensity consistent with the disorganized tissue. In the setting of a chronic rupture, a large gap is present between the hypoechoic (dark) tendon ends (Fig. 6.102).

□ Nonoperative treatment

- Heavy load eccentric strengthening has demonstrated the highest success rate.

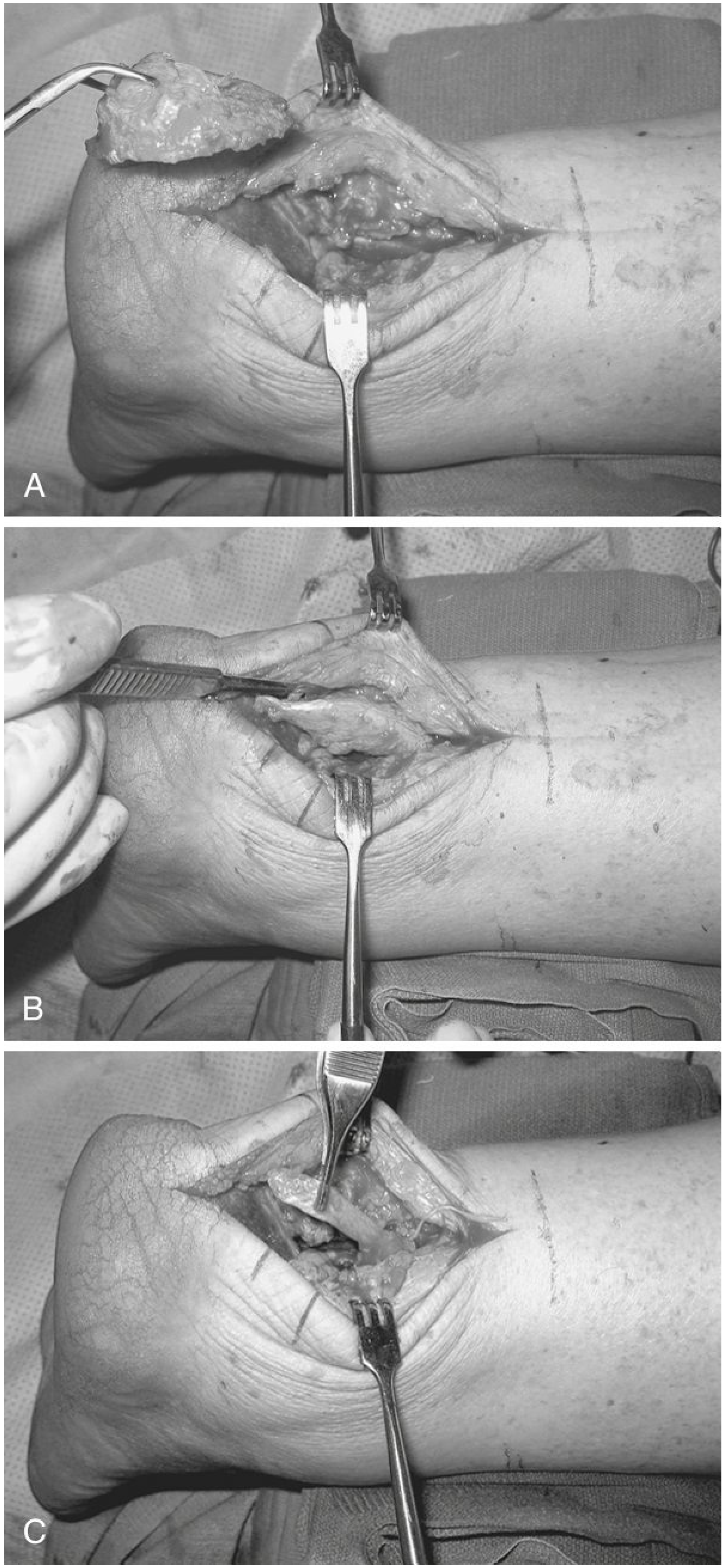

A
B
C

FIG. 6.101 (A) When the Achilles is degenerative at the insertion and proximally or when more than 50% of the tendon is involved, an FHL graft should be considered. (B) The central approach is used to detach the Achilles posteriorly and then to resect the prominent bone. (C) The degenerative tendon is débrided (C). The FHL tendon is harvested from behind the ankle and will be reattached through a tunnel or into a trough before the Achilles tendon is repaired.
From Porter D, Schon L: *Baxter's the foot and ankle in sport,* ed 2, Philadelphia, 2007, Elsevier.

- Includes rest, activity modification, heel lifts, physical therapy with emphasis on modalities (massage, ultrasound treatment, ionotophoresis) and eccentric strengthening exercises, and ESWT.
- Other treatments with evolving evidence of effectiveness include glyceryl trinitrate patches, prolotherapy, and aprotinin injections.
- Nonoperative treatment effective in approximately 50%–70% of cases

□ Operative treatment

- Less invasive options include percutaneous longitudinal tenotomies in the area of degeneration, as well as stripping of the anterior aspect of the tendon with a large suture to free adhesions. Additionally, in the patient with a gastrocnemius contracture, isolated gastrocnemius recession has shown good results for noninsertional disease, prior to consideration of a tendon débridement.

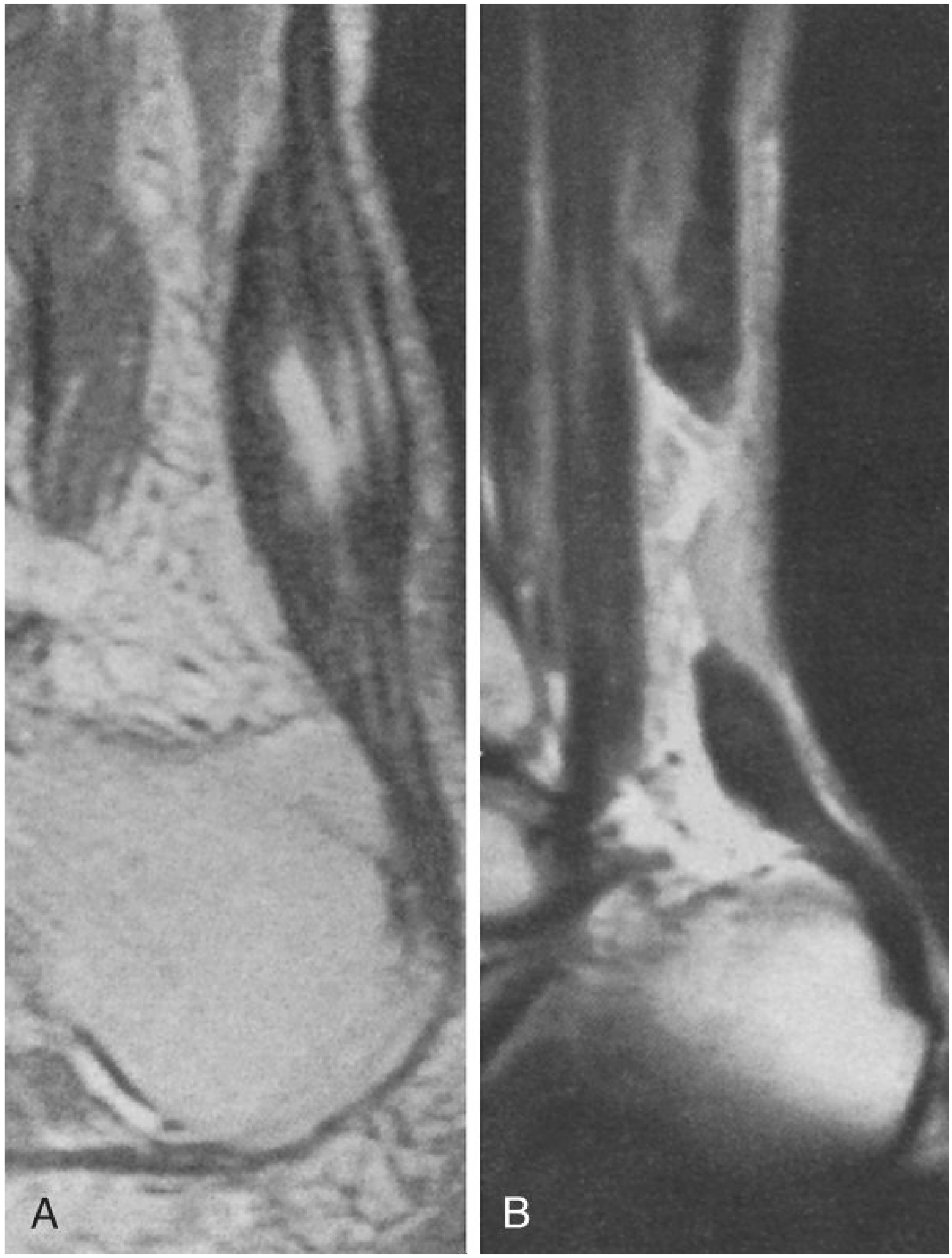


FIG. 6.102 Chronic Achilles tendinosis with a partial or complete tear. (A) Partial tear. Sagittal T2-weighted (TR/TE, 2000/70) spin-echo MR image shows an enlarged Achilles tendon containing irregular regions of high signal intensity. (B) Complete tear. Sagittal intermediate-weighted (TR/TE, 3000/30) spin-echo image shows complete disruption of the Achilles tendon and a proximal segment that is inhomogeneous in signal intensity. Note the edema and hemorrhage of high signal intensity around the acutely torn tendon.
From Resnick D, Kransdorf M: *Bone and joint imaging,* ed 3, Philadelphia, 2004, Saunders.

- For moderate to severe disease, open excision of the degenerated tendon tissue with tubularization has had good results.
- For more than 50% degenerative involvement of the Achilles, débridement with an FHL tendon transfer is recommended.
    - MRI evidence of significant involvement (diffuse thickening of the tendon without a focal area of

disease) indicates the need for FHL transfer.

- **Acute Achilles tendon rupture**
  - Most common tendon rupture in the lower extremity
  - Complete rupture associated with a sudden or violent dorsiflexion of ankle or a lunge.
  - Increased risk with prior intratendinous degeneration, use of fluoroquinolones, steroid injections, inflammatory arthritis
  - Frequently misdiagnosed (up to 20%) as ankle sprain or deep vein thrombosis (DVT), because active plantar flexion may be intact with activation of toe flexors and plantaris.
  - Prodromal symptoms present in only 10% of patients
  - Peak incidence in third to fifth decades of life
  - Palpable gap in the tendon not always appreciated
  - Thompson test
    - Squeezing the calf with the ankle and foot at rest should result in passive plantar flexion of the foot.
    - A positive (abnormal) result is strongly associated with Achilles rupture.
  - The affected ankle demonstrates decreased plantar flexion tone with the patient in a prone position and the knees flexed.
  - Imaging studies are often unnecessary; MRI or ultrasound may be helpful if the diagnosis is in question.
  - Treatment
    - Controversial because both nonoperative and operative treatments have had good functional results and good rates of patient satisfaction in multiple studies.
    - Nonoperative treatment has been historically associated with higher risk of rerupture (approaching 20%).
      - However, current data have definitively demonstrated that the rate of rerupture with functional rehabilitation is equivalent to that with surgical repair.
      - Cast immobilization longer than the initial 2 weeks after injury is *not* appropriate nonoperative management.
        - Prolonged cast treatment is associated with a higher rerupture rate than surgical treatment and nonoperative functional rehabilitation.
    - Surgical treatment has demonstrated better results than nonoperative treatment.
    - Neither course of treatment results in normal function like

that of the unaffected extremity.

- Operative treatment
  - Associated with increased risk of wound complications and infection
    - Treated with aggressive débridement and culture-specific antibiotics
  - Percutaneous techniques have demonstrated good clinical outcomes, but have increased risk of sural nerve injury
  - Minimally invasive techniques have demonstrated outcomes similar to those of traditional open approaches but with significantly lower wound complication rates.
  - Therefore, given these data, the best approach for surgical repair of an Achilles rupture is a minimally invasive approach that places the suture deep to the crural fascia with commercially available devices.
  - Early protected mobilization in a CAM boot after 2 weeks of non–weight-bearing status with splint immobilization; generally this approach has better functional results than prolonged non–weight-bearing status with delayed rehabilitation.
  - Operative intervention is cautioned in patients with diabetes mellitus, neuropathy, immunocompromised states, age older than 65 years, tobacco use, sedentary lifestyle, BMI above 30 kg/m^2, peripheral vascular disease, or local/systemic dermatologic disorders.

▪ **Chronic Achilles tendon rupture**

□ Nonoperative treatment—AFO

- **Operative treatment—in the setting of a chronic rupture, FHL transfer is the treatment of choice, with a possible turndown procedure.**
  - This is particularly applicable if there is a 5–6-cm gap between tendon ends.
  - If the gap is between 2 and 5 cm, a V-Y reconstruction should be performed.
  - If the gap is less than 2 cm after débridement, end-to-end repair is possible.
  - Allograft remains an option if excursion of the gastrocnemius-soleus muscle complex is retained.

Ankle Pain and Sports Injuries

Ankle Sprains

- **Common in athletes; most frequently involves ATFL (weakest lateral ankle ligament)**
- **CFL is less commonly involved.**
- **The strong PTFL is rarely implicated.**
- **Diagnosis**
  - Patients often recall twisting mechanism, typically inversion.
    - This can lead to injury to branches of the superficial peroneal nerve and cause numbness over the dorsal midfoot.
  - If persistent nerve symptoms, neurotomy and burial may be needed
  - Swelling, ecchymosis, pain with weight bearing all common.
  - Assessment for recurrent instability and questioning patient about symptoms of a loose body or osteochondral injury (mechanical symptom such as locking or catching) are required.
- **Radiographic evaluation**
  - AP, mortise, and lateral x-rays of the ankle obtained; weight-bearing x-ray preferable if patient can tolerate it
  - Foot x-rays should be obtained for any pain on examination—especially at base of fifth metatarsal or anterior process of calcaneus—to rule out fracture.
    - Radiographs should be evaluated for lateral process of the talus fracture, anterior process fracture, osteochondral defects, and mortise or syndesmosis instability.
  - CT scanning is considered for evaluation of a suspected or identified lateral process fracture.
  - MRI typically reserved for patients with continued pain despite weeks of conservative treatment (immobilization, elevation, ice, NSAIDs) or concern about a loose body or osteochondral defect
    - MRI may demonstrate attenuation or tear of the lateral ligamentous structures.
    - Bone bruising common in severe sprains and may result in longer time to pain-free activity and return to sports
- **Nonoperative treatment**
  - All patients started on RICE (rest, ice, compression, elevation) protocol with limited weight bearing if there is marked ankle joint-line tenderness or pain with weight-bearing activity
  - Progressive and protected weight bearing initiated as symptoms allow
  - Physical therapy important for balance, proprioception, and peroneal strengthening; is associated with a decreased rate of reinjury

- ▫ Neuromuscular (i.e., proprioceptive) training paired with functional bracing reduces risk of recurrence of low ankle sprains more than neuromuscular training alone.
- ▫ Consider additional physical therapy if there is no evidence of peroneal tendon injury on examination or if patient has not completed an adequate amount of rehabilitation.

▫ Operative treatment

- Reserved for patients with recurrent and symptomatic instability with excessive and asymmetric talar tilt and positive anterior drawer test, symptomatic osteochondral defects
- Instability can occur without ligamentous issues (peroneal tendinopathy, osteochondral defects, fracture nonunion, anterior ankle impingement).
- Multiple procedures described; anatomic procedures typically first-line treatment and successful in 85%–90% of cases
  - Modified Broström procedure—anatomic reconstruction of ATFL supplemented with extensor retinaculum
  - Nonanatomic—peroneal tendon procedures (Evans procedure, Chrisman-Snook) or allograft procedures reserved for recurrent instability after initial operative treatment

High Ankle Sprains

- **Sprains involving the syndesmosis ligaments**
  - ▫ Require nearly twice as long to return to activity as “low” ankle sprains.
  - ▫ Pain in the anterior syndesmosis with syndesmosis squeeze or external rotation stress tests suggestive of injury
  - ▫ Stable injuries may be treated with RICE protocol (see earlier).
  - ▫ Clear diastasis or unstable injuries are treated with operative intervention, if there is any doubt MRI should be ordered to determine the extent of the injury.
    - Evidence of a posterior malleolus fracture or tear of the deltoid ligament is consistent with an unstable pattern, and operative stabilization should be considered.
  - ▫ Tibiofibular synostosis a common complication. May be addressed with excision of synostosis or syndesmosis fusion if conservative treatment fails.

Ankle Impingement

- **Anterior**
  - ▫ Soft tissue or bony condition leading to increased pain, decreased ROM, and occasionally a sense of instability

- Common in athletic population, especially with history of ankle sprains
- Pain with dorsiflexion and pivoting activities common
- Reproducible tenderness over anterior ankle joint line is key to diagnosis.
- Lateral radiographs may demonstrate osteophyte formation at anterior tibial plafond (lateral) or dorsal talar neck (medially); best visualized with anteromedial oblique view.
- Ice, NSAIDs, brace immobilization, and corticosteroid injections may provide relief.
- Operative intervention reserved for failure of conservative management; typically includes arthroscopic débridement of synovitis and bone spurs

- **Posterior**
    - Common in ballet dancers, gymnasts, soccer players, and downhill runners
    - May be associated with os trigonum (present in 7% of adults), prominent posterolateral process of talus (Stieda process), or loose bodies
    - **Pain exacerbated and reproducible with maximum plantar flexion of ankle and push-off maneuvers**
        - An anomalous soleus muscle can cause similar symptoms.
    - May lead to synovitis of FHL tendon
        - FHL travels between the posterior tubercles of the talus.
    - Nonoperative treatment as in anterior impingement
    - **Operative intervention includes arthroscopic or open débridement of posterior inflamed synovium and excision of symptomatic os trigonum/impinging bone.**

Osteochondral Lesions

- **Most commonly due to trauma or repetitive microtrauma**
- **Seen in up to 70% of ankle sprains, 75% of ankle fractures**
- **Location**
    - Medial talar dome
        - Most common
        - Historically, posterior location was considered to be more common; however, modern data have proved that most common location is central.
        - Unreliable history of trauma; if provided, inversion sprain with plantar flexion
        - Larger and deeper than lateral lesions

- Lateral talar dome
  - Less common
  - Central location is most common as well, although historically, it was believed to be more anterior.
  - Usually history of acute trauma, inversion sprain with dorsiflexion
  - More often unstable, displaced, or symptomatic
  - Often refractory to conservative measures
- Patients often present with history of ankle injury, continued pain, and mechanical symptoms such as locking and catching with activity.
- Physical examination demonstrates deep pain over ankle joint line; palpation often does not reproduce described symptoms; ankle effusion common.
- Radiographic evaluation
  - AP, mortise, and lateral weight-bearing ankle x-rays obtained; may not demonstrate subtle lesions.
  - CT scan helpful for bony lesions, determining integrity of subchondral bone, identifying cysts, preoperative planning
  - MRI sensitive for all lesions, but edema pattern frequently overestimates severity of injury
    - Linear fluid signal deep to subchondral bone indicates unstable injury.
    - Sensitivity 92% for predicting stable versus unstable lesions

- **Treatment**
  - Acute stable defects may heal with rest, protected weight bearing.
  - Nonoperative treatment: 45% excellent to good results
  - Operative intervention reserved for unstable defects or patients with mechanical symptoms, symptoms not responding to conservative measures
  - Arthroscopic intervention most common
  - 80%–85% success rate reported for nearly all interventions for defects smaller than 1.5 cm^2
    - Débridement of defect to stable border with microfracture is first-line treatment.
    - Large (>1.5 cm^2), cystic, or shoulder lesions, recurrent pain, or refractory cases may be more effectively addressed with graft procedures, osteochondral autograft transplantation surgery, autologous chondrocyte implantation, and bulk allograft.
      - Autologous osteochondral grafting produces hyaline cartilage with minimal degradation over time.

- Chondroplasty/microfracture generates type 1 collagen–based fibrocartilage.
- Osteochondral allograft contains high volume of viable chondrocytes if transplanted less than 2 weeks from time of harvest.
  - High rates of collapse/resportion noted.
  - 60% of patients have joint space narrowing at 44 months after treatment.
- Autologous chondrocyte implantation (ACI) can lead to hyaline cartilage or fibrocartilage.

□ Lesions smaller than 1 cm in diameter with stable cartilage cap are amenable to retrograde drilling techniques.

□ Open intervention with medial malleolar osteotomy required for posterior defects

- If cystic defect larger than 1.5 cm^2 consider a medial malleolar osteotomy and grafting

□ Treatment of tibial defects has lower success rate than that of talar lesions.

Chronic Exertional Compartment Syndrome

□ Condition that may manifests in athletes (especially runners and cyclists) with pain that increases gradually with activity and eventually restricts performance. In severe cases, paresthesias may be noted secondary to compression of the superficial peroneal nerve.

- Relief of pain and swelling soon after rest is consistent with the disease process.
  - In contrast to stress fracture

□ Compartment pressures should be measured before, during, and after exercise.

- Pressures higher than 30 mm Hg 1 minute after exercise or 20 mm Hg 5 minutes after exercise, or absolute values higher than 15 mm Hg during rest can help establish the diagnosis.

□ The anterior compartment is the more commonly involved and has the best prognosis for recovery.

□ Fasciotomy is indicated for refractory cases.

□ Popliteal artery entrapment syndrome is often confused with chronic posterior compartment syndrome.

- Patients with popliteal artery entrapment syndrome present with intermittent claudication, including calf pain, cramping, coolness, and at times paresthesias into the foot.

- Provocative tests include obliteration of pedal pulses with active plantar flexion or passive dorsiflexion of the ankle with Doppler recordings.
- Treatment is release and recession of the medial head of the gastrocnemius.

Technical Pearls for Ankle Arthroscopy (Fig. 6.103)

□ Patient positioned supine with a bump under the ipsilateral thigh to allow for traction on the ankle.

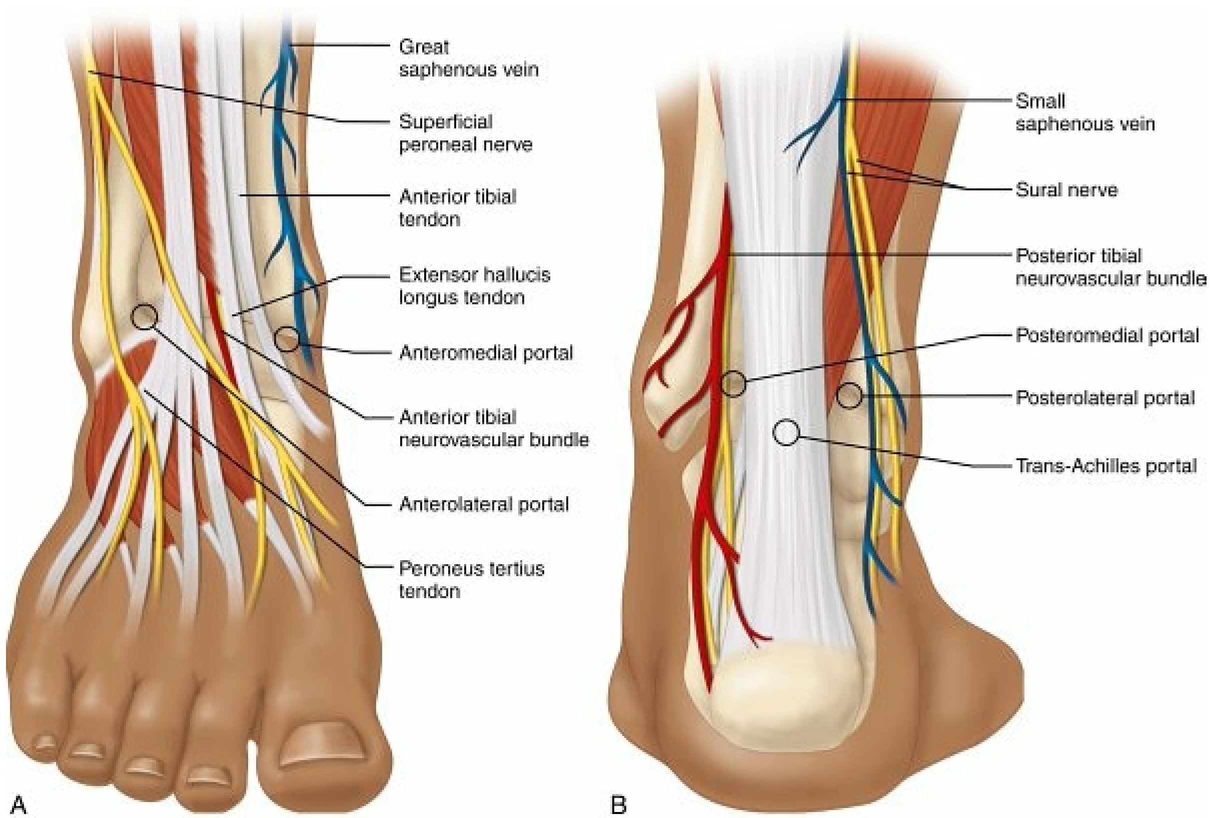


FIG. 6.103 (A) Anterior anatomy of ankle with diagram of standard portal placement. (B) Posterior anatomy of ankle with diagram of standard portal placement.
Adapted from Miller MD, Chhabra A, Safran M: *Primer of arthroscopy,* Philadelphia, 2010, Saunders.

□ Noninvasive traction devices or a sterile elastic bandage is commonly used to distract the ankle joint and allow for visualization of the joint.

□ Distraction is often unnecessary for débridement of anterior spurs or inflamed synovium.

□ **The most common complication after ankle arthroscopy is nerve injury.**

- **The superficial peroneal nerve is the most commonly injured as the anterolateral portal is established.**
  - The nerve can often be palpated and identified with plantar flexion of the ankle and fourth toe.
- The saphenous nerve may be injured with a waywardly placed

anteromedial portal.

- Posteromedial and anterocentral portals are typically avoided to limit injury to the tibial nerve/posterior tibial artery and deep peroneal nerve/dorsalis pedis artery, respectively.
- A “nick-and-spread” technique is advocated to avoid nerve injury.

The Diabetic Foot

Pathophysiology

- Blood glucose assessment is ideally evaluated with hemoglobin A1c measurement (indicative of past 3 months of glucose control)

- **Diabetic neuropathy**
  - The diagnosis of foot ulcerations results in the highest rate of hospital admissions in diabetics as well as of lower extremity amputations.
  - The combination of neuropathy and excess pressure on the plantar foot leads to ulceration.
  - Sensation
    - Polyneuropathic loss of sensation begins in a stocking distribution of the feet and progresses proximally.
    - Loss of protective sensation is most common cause of plantar foot ulcers.
      - Diagnosed by the inability to perceive the 5.07 Semmes-Weinstein monofilament.
      - 30% risk of development of an ulcer
      - Most patients (90%) who cannot feel the 5.07 monofilament have lost protective sensation to their feet and are at risk for ulceration.
    - With the 1998 Diabetic Therapeutic Shoe Bill, money is allocated for neuropathic patients to purchase extra-depth shoes and total contact inserts (three per year) for ulcer prevention.
  - Autonomic neuropathy
    - An abnormal sweating mechanism leads to a dry foot.
    - Vulnerable to fissuring cracks, which then become portals for infection
  - Motor neuropathy
    - Most commonly involves the common peroneal nerve
    - Resultant loss of tibialis anterior motor function and footdrop
    - Small intrinsic musculature of the foot also commonly affected, resulting in claw toes and subsequent toe-tip ulcerations due to excessive pressure.
- **Hypomobility syndrome**
  - Result of excessive glycosylation of the soft tissues of the extremities
  - Leads to decreased joint ROM
- **Peripheral vascular disease**
  - Occurs in 60%–70% of patients who have had diabetes for more than 10

years, involving large and small vessels

- Noninvasive vascular examination should be performed when pulses not palpable.
  - Waveforms (normal is triphasic)
  - Ankle-brachial indices (minimum for healing, 0.45; normal, 1.0)
    - Calcifications in the artery can falsely elevate ABI. A value higher than 1.3 is nonphysiologic and consistent with calcification of the vessels.
  - Absolute toe pressures (minimum for healing, 40 mm Hg; normal, 100 mm Hg)
  - Transcutaneous oxygen (TcP_{O_2}) values for the toes greater than 40 mm Hg have been found to be predictive of healing.

- **Immune system impairment**
  - Poor cellular defenses, such as abnormal phagocytosis, altered chemotaxis of WBCs, and a poor cytotoxic environment (due to hyperglycemia) to fight off bacteria, lead to difficulty in fighting off infection once it has developed.
- **Metabolic deficiency**
  - Reduced total protein less than 6.0 g/dL, WBC count less than 1500 cells/mm^3, and albumin levels less than 2.5 g/dL result in poor healing potential.
  - These parameters must be normalized with nutritional support prior to surgical intervention.

Clinical Problems

- **Ulcers**
  - Classification and treatment
    - Ulcer location (forefoot, midfoot, and heel) and the presence or absence of arterial disease influence healing rates.
    - Depth-ischemia classification (modification of Wagner-Meggitt classification)
      - Depth
        - Grade 0
          - Skin intact with bony deformity—at risk
          - Treatment
            - Extra-depth shoe and pressure-relief insoles
        - Grade 1

            - Localized superficial ulcer without tendon or bone involvement
            - Treatment
                - In-office ulcer débridement
                - Total-contact cast
        - Grade 2
            - Deep ulcer with exposed tendon or joint capsule
            - Treatment
                - Formal operative débridement of all exposed tendon and nonviable tissue
                - Followed by dressing changes and total-contact casting once wound bed is healthy
        - Grade 3
            - Extensive ulcer with exposed bone/osteomyelitis or abscess
            - Treatment
                - Surgical débridement of exposed bone/osteomyelitis and nonviable tissue
                - Followed by dressing changes and total-contact casting once wound bed is healthy
    - Ischemia
        - Grade A—normal vascularity
        - Grade B—ischemia without gangrene
            - Noninvasive vascular studies and surgical

revascularization if indicated

- Grade C—partial (forefoot) gangrene
  - Noninvasive vascular studies and surgical revascularization if indicated
  - Metabolic assessment
    - Delay surgery if albumin below 2.5 g/dL or total protein below 6 g/dL, and improve patient's nutritional status.
  - Operative intervention—partial foot amputation
- Grade D—complete foot gangrene
  - Same as for grade C
  - Operative intervention—below-knee or above-knee amputation

□ Additional treatment

- Midfoot collapse may require ostectomy of bony prominence if stable deformity, or midfoot fusion if midfoot instability is present.
- Equinus contracture is very common, and Achilles lengthening offloads the midfoot/forefoot.
- Achilles lengthening required for:
  - Recurrent forefoot/midfoot ulceration
  - Ulceration with equinus deformity
- Toe deformities often require joint resection or amputation.
- Plantar hallux IP joint for which contact casting has failed should be treated with a Keller arthroplasty.
- Presence of infection may be reason why ulcers do not heal with conservative management.
  - Débridement of infected tissue with use of negative-pressure dressings is recommended.
- The ultimate goal is an ulcer-free, functional, plantigrade foot that can fit within a brace or shoe.

▪ **Charcot arthropathy**

□ Chronic, progressive, destructive process affecting bone architecture and joint alignment in people lacking protective sensation (Figs. 6.104 and 6.105)

- Occurs in approximately 1%–1.5% of patients with diabetes; 7.5% of patients with diabetes and neuropathy
- Two theories regarding pathophysiology are neurotraumatic and neurovascular destruction.
  - The latter is thought to occur by a hypervascular phenomenon, with imbalance of osteoclastic versus osteoblastic activity.
- Classification: Eichenholtz stages of Charcot arthropathy (Table 6.4)
  - Related to the levels of warmth, swelling, and erythema
  - Continuum from bone resorption and fragmentation to bone formation and consolidation that takes 6 to 18 months
- Also classified by location (Brodsky)
  - Type 1: midfoot (most common)—60%
  - Type 2: hindfoot (subtalar, TN, CC joints)—10%
  - Type 3A: tibiotalar joint—20%
  - Type 3B: fracture of calcaneal tuberosity—less than 10%
  - Type 4: combination of areas—less than 10%
  - Type 5: forefoot—less than 10%
- Patients complain of swelling, warmth, redness, and deformity.
- Pain may be present in up to 50% of cases.
- Swelling and redness are typically resolved in morning.
- Often confused with osteomyelitis clinically
- Up to 35% present with bilateral disease.
- Treatment
  - Goal is to achieve stage 3 (resolution) while maintaining alignment and ambulatory status, and minimizing soft tissue breakdown.

FIG. 6.104 Patient with midfoot neuroarthropathy with bony and ligamentous components to the deformity. The patient had no antecedent trauma. The radiographic appearance is more suggestive of a high-energy injury, and in cases in which no prior trauma or minor trauma is noted, one should consider the presence of neuroarthropathy.

FIG. 6.105 Patient with neuroarthropathy of the hindfoot.

Table 6.4

Stages of Charcot Arthropathy (Eichenholtz). [a]

Stage	Signs and Symptoms	Radiographs
0: Clinical (prefragmentation)	Acute inflammation; confused with infection	Regional bone demineralization
1: Dissolution (fragmentation)	Acute inflammation, swelling, erythema, warmth; confused with infection	Regional bone demineralization, periarticular fragmentation, joint dislocation
2: Coalescence	Less inflammation, less swelling, less erythema	Absorption of bone debris; early bone healing and periosteal new bone formation
3: Resolution	Resolved erythema, swelling, and warmth; consolidation of healing	Smoothed bone edges, bony/fibrous ankylosis

[a] Based on the signs, symptoms, and radiographic changes that occur with the neuropathic joint/fracture over time.

- Initial treatment is immobilization and non–weight-bearing status.
    - Best with total-contact cast
    - Can transition to custom brace (AFO or Charcot restraint orthosis walker [CROW] boot) once swelling and warmth subside
- Medication management includes bisphosphonates, neuroleptic medications, antidepressants, and topical anesthetics.
    - Successful in up to 75% of cases
- Operative treatment
    - Stable deformity with recurrent ulcers secondary to prominence—exostectomy
    - Unstable/unbraceable deformity—arthrodesis
    - Hindfoot or ankle deformity can be addressed with a tibiotalocalcaneal arthrodesis to afford a braceable/plantigrade foot, while reducing risk of ulceration.
        - Ankle and hindfoot Charcot arthropathy best treated with arthrodesis, given the high likelihood of failure of nonoperative management

            - Placement of an intramedullary rod will afford internal stability and can be left indefinitely, in contrast to a multiplanar external fixator.
            - Even with radiographic evidence of nonunion, many patients can be pain free.
        - Midfoot Charcot treatment with plantar closed-wedge osteotomy to correct deformity
            - TAL almost universally required
        - Amputation as salvage
        - High complication rates—nearly 70%

- **Diabetic foot infections**
    - Occur contiguous to open skin wounds (ulceration, skin fissure, cut)
    - Hematogenous spread of infection into the foot or ankle is rare.
    - **Infections in the diabetic foot or ankle are either isolated soft tissue infections (cellulitis or abscess) or osteomyelitis.**
    - **If abscess suspected, needle aspiration or MRI is needed.**
        - Renal issues may preclude MRI with a contrast agent
        - MRI has high false-positive rate in the diagnosis of osteomyelitis, particularly with concurrent Charcot arthropathy.
        - Labeled WBC scan or dual-image technetium/indium (Tc/In) scan is more sensitive and specific for osteomyelitis than isolated Tc scan.
    - Contiguous osteomyelitis present in 67% of foot ulcerations that reach bone
    - Diabetic foot infections are polymicrobial.
        - Superficial wound culture does not identify the organism responsible for the infection and should not be performed.
        - Culture of deep surgical specimen (or bone biopsy of exposed bone) provides most accurate result.
    - Broad-spectrum antibiotic coverage begun once surgical culture specimens obtained, and therapy adjusted once sensitivity results known.
    - Abscesses require surgical drainage and antibiotics.
    - **Osteomyelitis is treated with antibiotics and surgical débridement.**
        - Specific antibiotics determined from a bone biopsy culture have proven to be an effective tool in treating osteomyelitis, without the need for bone resection. Resection of all nonviable or infected soft tissue should also be performed.
        - If culture-specific antibiotic therapy fails, surgical resection of infected bone and débridement of surrounding tissue is

required in addition to antibiotic therapy.
        - Often results in more extensive débridement, including ray resection, partial calcanectomy (calcaneal involvement), and partial or complete foot amputation

- **Amputation level**
    - Transmetatarsal
        - Lowest energy expenditure
        - No tendon transfer needed
    - Lisfranc
        - Peroneal tendons must be transferred to the cuboid to prevent varus
        - TAL to prevent equinus
    - Chopart
        - Anterior tibialis transferred to talus to prevent varus.
        - Achilles lengthening to prevent equinus
    - Syme
        - Amputation level with the next lowest energy expenditure after a transmetatarsal amputation. Superior to both Lisfranc and Chopart amputation with regard to the amount of energy required to ambulate.
        - Contraindicated if history of heel ulcers
    - Transtibial
        - Superior results with postoperative casting for 3 to 5 days, with conversion to rigid removal dressing
        - Critical to maintain full knee extension during healing
        - Typically transition made to weight bearing in a temporary prosthesis by 6 weeks postoperatively

Trauma

Phalangeal Fractures

- **Most common injuries to the forefoot**
- **Mechanism of injury**
  - Usually caused by stubbing mechanism (axial loading with varus or valgus force) or by crush mechanism (heavy load dropped on the foot)
- **Diagnosis**
  - Patients present with pain, ecchymosis, and swelling.
  - AP, lateral, and oblique radiographs are suitable to detect fractures.
- **Treatment**
  - Nondisplaced fractures with or without articular involvement
    - Stiff-soled shoes and protected weight bearing, "buddy taping"
  - Displaced fractures
    - Closed reduction can be attempted, with gravity traction or pencil reduction followed by stiff-soled shoe and "buddy taping."
  - Hallux fractures carry greater functional significance than fractures of the lesser toes.
  - Distal phalanx fractures often due to a crush mechanism
    - If concomitant nail bed injury is present, considered an open fracture
    - Irrigation and débridement, nail bed repair, and antibiotic coverage
    - Operative treatment—indicated for gross instability or intraarticular discontinuity greater than 2 mm
      - Fixation achieved with crossed Kirschner wires or mini-fragment screws.
      - Most common complication is stiffness.

Metatarsal Fractures

- **Stability achieved by the bony architecture of the midfoot and the ligamentous attachments at the metatarsal bases and necks (intermetatarsal ligaments)**
- **Severe displacement of shaft fractures is uncommon unless multiple metatarsals are fractured.**
- **First and fifth metatarsals are more mobile and susceptible to injury.**
- **Mechanism of injury**
  - Crush-type injury (which can result in severe soft tissue trauma),

twisting forces
    - When multiple metatarsals are fractured, a Lisfranc injury must be ruled out.
- **Diagnosis**
    - Patients present with pain, ecchymosis, and swelling.
    - Weight bearing is often painful and difficult.
    - AP, lateral, and oblique radiographs are usually suitable to detect fractures.
    - Plantar ecchymosis may signify a more significant injury involving the Lisfranc joint complex.
- **First metatarsal fractures**
    - First metatarsal bears approximately one-third of body weight.
        - Maintenance of alignment is very important.
        - Nondisplaced fractures—boot or hard-soled shoe, weight bearing as tolerated
        - Displaced fractures—surgical fixation; open reduction and internal fixation (ORIF) with lag screws or plate fixation
- **Second, third, and fourth metatarsal fractures**
    - Majority are minimally displaced.
        - Treated with a low-tide walking boot or hard-soled shoe with arch support
        - Isolated fractures are stable secondary to the intermetatarsal ligaments present both at the base and neck that help to prevent displacement.
    - Surgical fixation indicated in fractures with significant sagittal plane deformity (>10 degrees) or if the three central metatarsals are fractured. With multiple fractures, the intermetatarsal ligaments cannot provide stability, and therefore these fractures are inherently unstable.
        - ORIF with plate-and-screw fixation or intramedullary antegrade-retrograde pinning technique
        - Care should be taken to maintain proper metatarsal length to minimize the risk of transfer metatarsalgia or plantar keratosis.
- **Metatarsal neck fractures**
    - Most treated conservatively in boot or shoe
    - With multiple (central three) and/or complete displacement, treated with open reduction and antegrade-retrograde pinning or plate-and-screw fixation.
- **Metatarsal base fractures**
    - Primarily through metaphyseal bone; heal rapidly if stable
    - Suspicion for a Lisfranc injury should be high for these fractures.
- **Metatarsal stress fractures**

- Common, often secondary to repetitive stress or cavovarus foot posture
- **Excessive loading of the second metatarsal can lead to injury.**
  - Long second metatarsal
  - Hallux rigidus/valgus
- MRI or bone scan aids in the diagnosis, as radiographs may be normal for 3 weeks; the initial treatment should be based on the clinical findings and history.
  - Radiographs may demonstrate periosteal reaction or evidence of callus formation near diaphyseal region of affected metatarsal after 3–4 weeks. A normal radiograph prior to this time does not exclude a stress fracture.
- Second metatarsal stress fracture is the most common and is classically described in amenorrheal ballet dancers.
- In female athletes, the triad of anorexia, osteoporosis/stress injuries, and menstrual dysfunction must be considered.
- Treated in weight-bearing boot or hard-soled shoe.
- Evaluation for metabolic bone disease in these patients (especially if insidious onset) or if there is no distinct causal event (increase in training, initiation of new activity)
- Assessment of vitamin D level with treatment if needed
- Recurrent stress fracture in the presence of a cavovarus foot may require reconstruction of the cavovarus alignment to prevent recurrence.

- **Fifth metatarsal fracture**
  - Represents a unique subset of forefoot injuries
  - Classification involves anatomic description of the fracture (Fig. 6.106).
    - Zone 1—avulsion fracture of the proximal fifth metatarsal tuberosity
      - Occurs secondary to an inversion mechanism and subsequent pull of the lateral band of the plantar fascia and/or peroneus brevis tendon
      - Sometimes extends into the tarsometatarsal joint
      - Most cases treated with protected weight bearing in shoe or boot
      - Open reduction required if fifth metatarsal–cuboid articular surface is displaced or if fracture is rotated so that the fractured surface of the proximal fragment no longer faces the distal fragment
      - Tenting of the skin is also an indication for fixation.
      - A lag screw placed obliquely from base of fifth metatarsal into medial cortex of fifth metatarsal is

the surgical treatment of choice.

- Chronic pain from a previous avulsion fracture may be addressed with excision of the fragment and reattachment of the peroneus brevis.

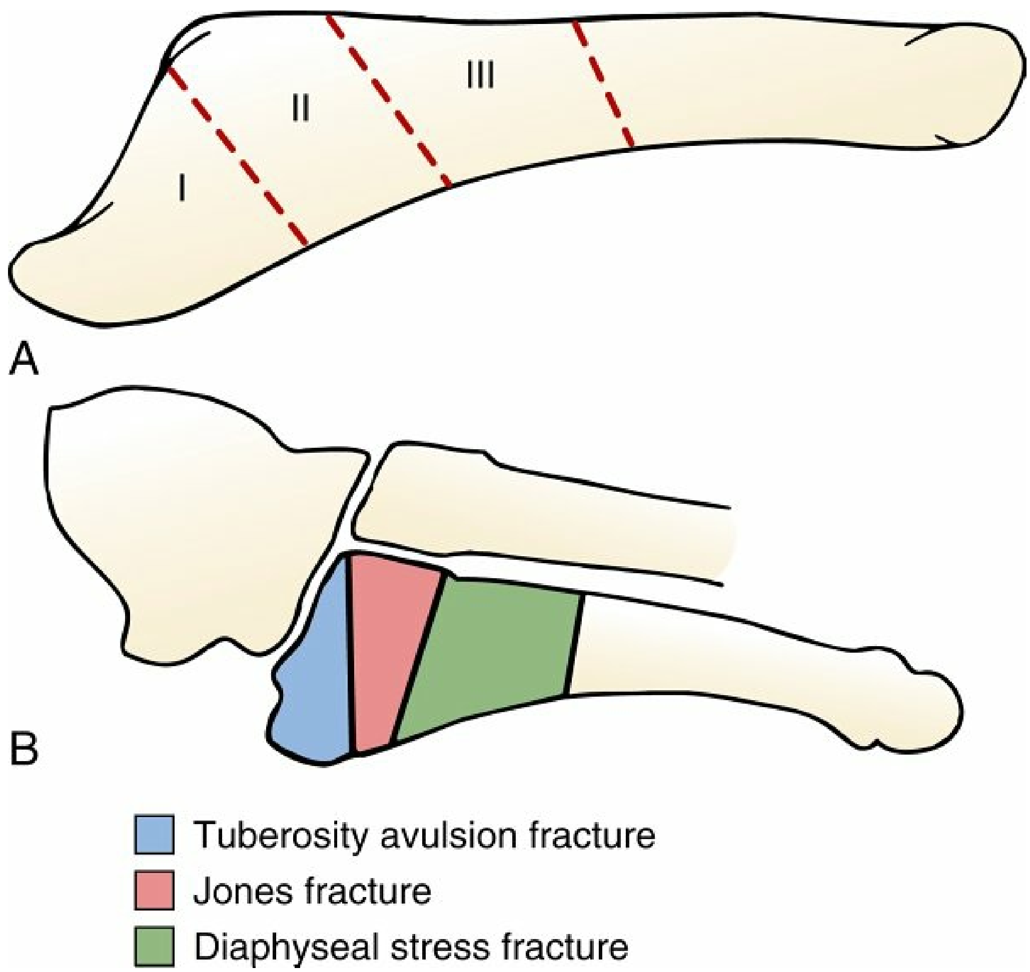


FIG. 6.106 (A and B) Three-part classification scheme for fifth metatarsal fractures as described by Botte.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby. [Courtesy M. Botte.]

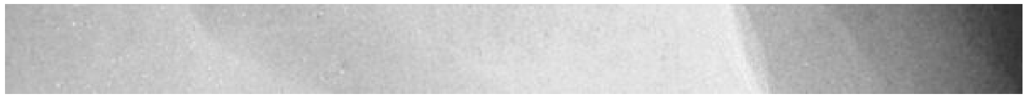


FIG. 6.107 Jones fracture of the fifth metatarsal *(arrow).*
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

- Zone 2—fractures of the metaphyseal-diaphyseal junction that extend into the fourth-fifth intermetatarsal articulation
    - Also known as a *Jones fracture* (Fig. 6.107)
    - 15%–25% risk of nonunion with nonoperative management
    - Acute zone 2 fractures can be treated with non–weight-bearing immobilization for 6 to 8 weeks.
    - Recurrent fracture after nonoperative intervention should be treated with intramedullary screw fixation.

FIG. 6.108 Watch for the Jones fracture in the varus foot. (A) This patient had a cavovarus foot deformity secondary to a stroke. Chronic lateral foot overload resulted in a fifth metatarsal fracture and subsequent nonunion. (B) The fracture appears incompletely healed after 6 months of symptoms. The patient underwent surgery, including intramedullary screw placement and hindfoot osteotomy with muscle transfers, to balance the deformity.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.

- **Acute zone 2 fractures in elite athletes should be treated with intramedullary screw fixation.**
    - Minimum screw diameter of 4 mm, with later data demonstrating that

- the mean diameter is 5 mm.
- Returning to sports activity prior to radiographic union increases risk of nonunion.

- Zone 3—fractures of the proximal diaphysis usually secondary to stress
  - Mostly in athletes secondary to repetitive microtrauma
  - Occur in the vascular watershed region of the proximal fifth metatarsal
  - Slow healing time and greater risk of nonunion
  - High risk of refracture with nonoperative treatment when fracture is stress-related (33%)
  - **Intramedullary screw fixation is surgical treatment of choice.**
  - Bone grafting may be required in case of nonunion, significant resorption.
  - Presence of a varus foot deformity is not uncommon in the patient with a zone 3 fracture, and concomitant lateral closed-wedge calcaneal osteotomy should be considered to prevent recurrence (Fig. 6.108).

First MTP Joint Injuries

- **Hallux MTP sprain (turf toe)—see Section 9, Sesamoids.**
- **Hallux MTP dislocation**
  - Usually a dorsal dislocation secondary to hyperextension
  - Results in volar plate rupture at its insertion on the metatarsal neck
  - The classification indicates which structures are injured as well as likelihood of achieving closed reduction.
    - Type I—intersesamoid ligament intact, likely plantar incarceration of the metatarsal head. Sesamoids may be intraarticular. No fracture present.
      - Irreducible by closed methods
    - Type IIA——intersesamoid ligament ruptured
    - Type IIB—associated sesamoid fracture (usually tibial sesamoid) (Fig. 6.109)
      - High possibility of closed reduction
    - Type IIC—combination of types IIA and IIB
  - Treatment
    - Type I injuries require open reduction with dorsal

longitudinal approach.
- Type II injuries are possible to reduce closed.
  - They may have associated intraarticular fracture fragments that require excision.
  - If joint is unstable after reduction, pinning of the joint for 3–4 weeks is indicated.

Tarsometatarsal Fractures and Dislocations (Lisfranc Injury)

- **The Lisfranc articulation is a stable construct because of its bony architecture and strong ligaments.**
  - The base of the second metatarsal fits into a mortise formed by the proximally recessed middle cuneiform (keystone configuration).
  - In the coronal plane, the second metatarsal base serves as the cornerstone in a Roman arch configuration (Fig. 6.110).
  - Ligamentous anatomy of the TMT joints (Fig. 6.111)
    - Intermetatarsal ligaments between the second and fifth metatarsal bases
      - No direct ligamentous attachment from the first to second metatarsals

FIG. 6.109 Type IIB dorsal dislocation of the first metatarsophalangeal joint, as seen on anteroposterior (A) and lateral (B) radiographs. Fracture through the medial sesamoid is best seen on the lateral view. (C and D) Closed reduction was performed, also reducing the sesamoid fracture.

From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

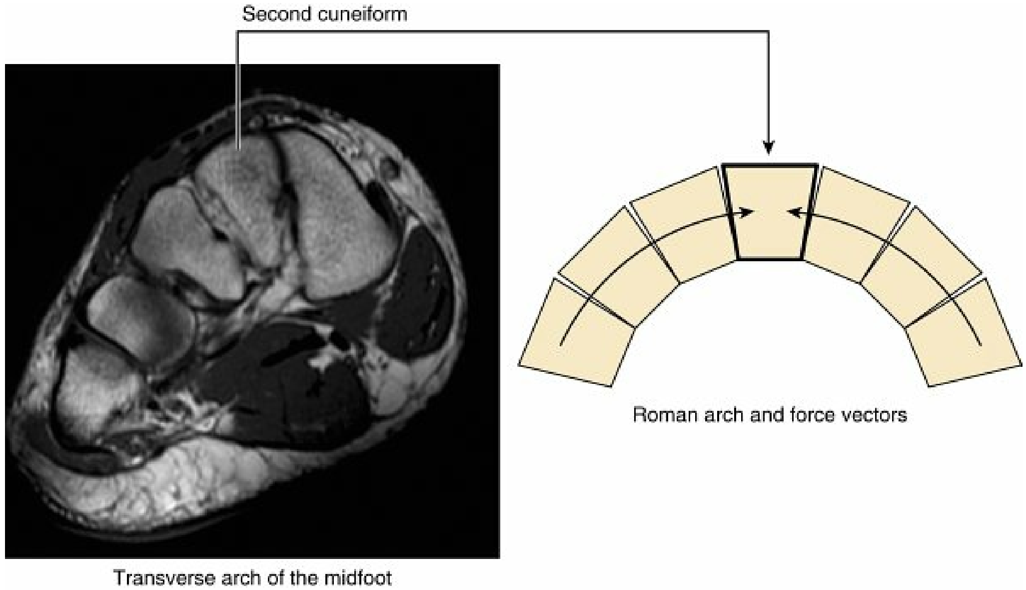
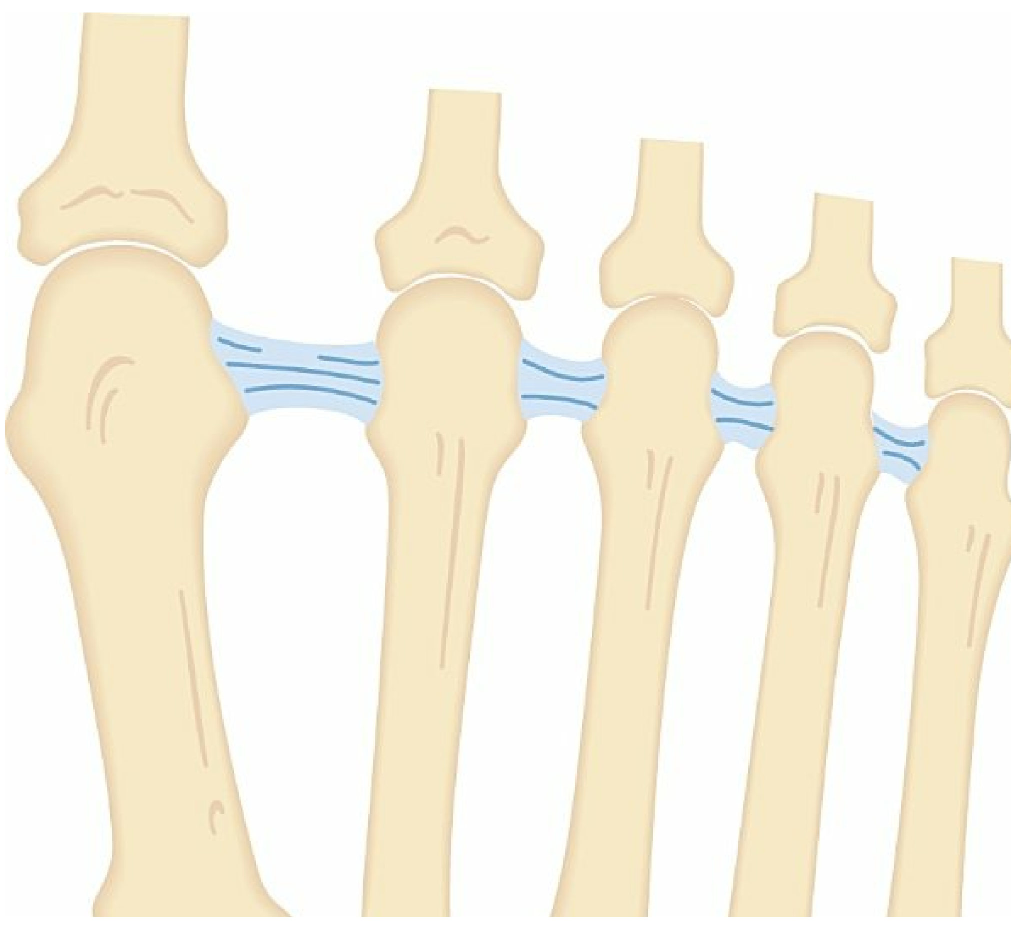


FIG. 6.110 The second cuneiform and second metatarsal base are shaped like a keystone in the coronal plane. The Lisfranc joint is shaped like a Roman arch. The anatomy and stabilization by the Lisfranc ligament are important for support of the arch of the foot. From Morrison W, Sanders T: *Problem solving in musculoskeletal imaging,* Philadelphia, 2008, Elsevier.



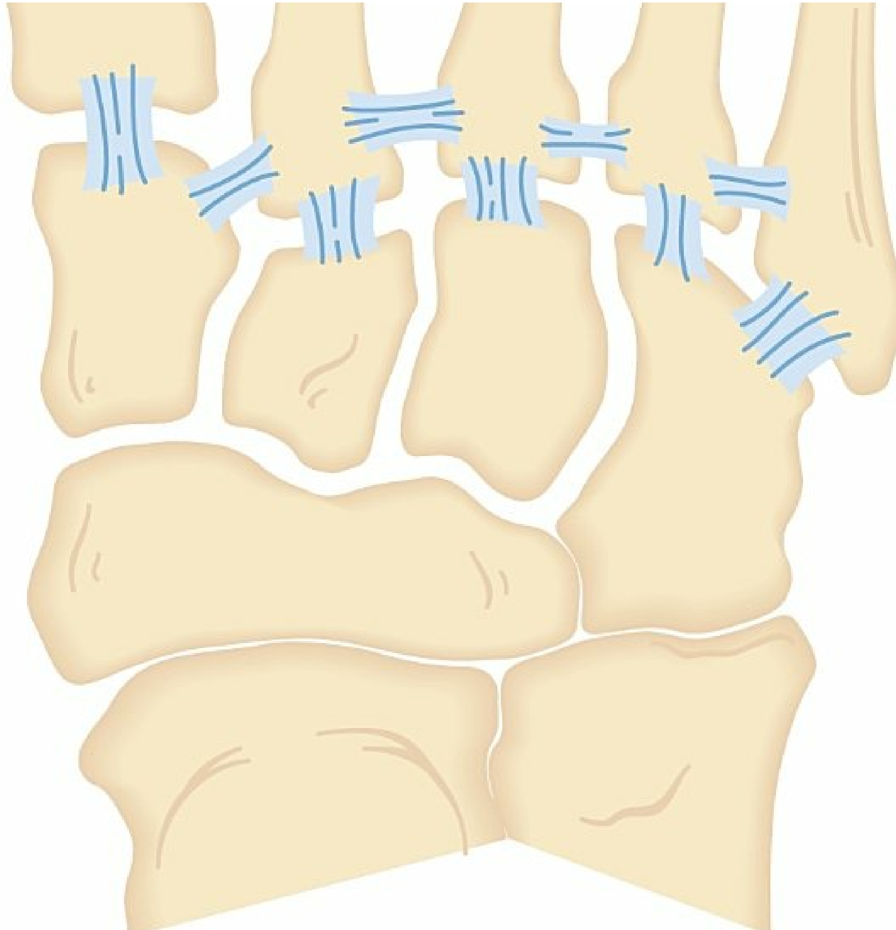


FIG. 6.111 The Lisfranc articulation with its ligamentous attachments. Note the recessed second tarsometatarsal joint and the Lisfranc ligament in place of the first-second intermetatarsal ligament.
From DeLee J: *DeLee and Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2011, Saunders.

- Lisfranc ligament—critical to stabilizing second metatarsal and maintaining midfoot arch
  - 8–10 mm wide and 5–6 mm thick
  - Between medial cuneiform and base of second metatarsal
- Interosseous ligament is stiffest and strongest, dorsal is weakest.
- Plantar ligament inserts on bases of second and third metatarsals.

▪ **Mechanism of injury**
- □ Indirect
  - Axial loading of a plantar-flexed foot
  - Athletic injury (most common), fall from height
    - Subtle and has a higher likelihood of being misdiagnosed
- □ Direct
  - Motor vehicle accidents, crush injuries
  - Significant soft tissue injury, often open

▪ **Diagnosis**

- Injuries range from nondisplaced purely ligamentous disruptions to severe fracture-dislocations (Fig. 6.112).
- More common in men

FIG. 6.112 Commonly, intertarsal instability accompanies a Lisfranc (tarsometatarsal) injury. Sometimes it is occult, so a high index of suspicion should always be maintained intraoperatively, and both clinical and radiographic stress examinations performed. (A and B) Usually, however, it is overt, as in this case. (C and D) Treatment is the same, demanding rigid anatomic ORIF. The intertarsal instability can often be initially aligned with a medial or lateral column external fixator, as was used in this patient, after which fixation is made easier for the surgeon and should begin proximally and proceed distally so that abnormal anatomy can be realigned to normal anatomy in a sequential manner. Note that this technique helped with disimpaction of the lateral cuboid nutcracker injury, which also required ORIF with bone grafting to restore integrity to the lateral column.
From Browner B et al: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier.

FIG. 6.113 Normal anteroposterior weight-bearing radiograph demonstrating the alignment relationship between the base of the second metatarsal *(arrow)* and middle cuneiform *(arrowhead).* Any lateral deviation of the second metatarsal relative to the middle cuneiform is consistent with a Lisfranc disruption and must be treated operatively.
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

- Severe pain, inability to bear weight, marked swelling, and tenderness
- Plantar ecchymosis should raise suspicion of a TMT/Lisfranc injury.

- **Radiographic evaluation**
  - AP, lateral, and oblique radiographs should be obtained (Fig. 6.113).
    - Lateral translation of the second metatarsal relative to the middle cuneiform is diagnostic of a Lisfranc injury.
    - Weight-bearing radiographs with contralateral comparison view, abduction stress views, and single-limb weight-bearing views may be necessary to confirm diagnosis when clinical suspicion is high (Fig. 6.114).
    - **Fleck sign** (Fig. 6.115)
      - Small, bony avulsion from the base of the second metatarsal seen in the first intermetatarsal space
      - Diagnostic of a Lisfranc injury
      - Proximal variant—forces transmit through the intercuneiform joint and out the NC joint; may be subtle (Fig. 6.116).
    - Cuboid injuries (nutcracker cuboid) are often sustained from an abduction force and may be associated with Lisfranc injuries.
    - CT and MRI may be valuable in detecting occult fractures or ligamentous injury; aid in preoperative planning.
- **Classification**
  - Differentiating between purely ligamentous injuries and fracture-dislocations may have treatment implications.
  - Primary arthrodesis of the TMT joints is an alternative to ORIF in a purely ligamentous injury.
  - Multiple described classification schemes are not useful for determining treatment and prognosis.
- **Treatment**
  - **If there is tenting of the skin, the injury needs to be reduced urgently to reduce risk of compartment syndrome.**
    - **Anatomic reduction is most predictive of good clinical results.**
  - Nonsurgical management is indicated only in cases with no displacement on weight-bearing and stress radiographs and no evidence of bony injury on CT (usually dorsal sprains).

- ▫ Operative treatment—any displacement on radiographs or evidence of a bony injury is treated with ORIF.
    - Should be delayed until soft tissue swelling has resolved
    - **Anatomic reduction is mandatory and open reduction is often required as opposed to closed reduction with percutaneous fixation.**
    - Fixation should proceed from proximal to distal and medial to lateral.
        - Medial and middle column (first, second, and third TMT joints; intercuneiform joints)
            - Historically stabilized with screw fixation across the involved joints (Fig. 6.117)
            - Dorsal plating is gaining in popularity—less iatrogenic articular damage.
                - No biomechanical difference between screws/plates
                - Lower risk of malreduction
            - Fixation is commonly removed after 4 months to minimize the risk of hardware failure and restore the normal joint mechanics.
        - Lateral column (fourth and fifth TMT joints)
            - Temporary fixation with Kirschner wires because of mobile segment
            - Removed at 6 weeks
    - Primary arthrodesis is an alternative treatment option, with some benefit seen in patients with purely ligamentous high-energy injury (dorsal subluxation or dislocation) or significant intraarticular comminution (Fig. 6.118).

▪ **Complications**

- ▫ Missed diagnosis or improper treatment may lead to traumatic planovalgus deformity or posttraumatic arthritis (Fig. 6.119).
    - Open reduction and midfoot arthrodesis should be considered in this setting
- ▫ Midfoot realignment with arthrodesis is the appropriate salvage procedure.
- ▫ Uncommon for fourth or fifth TMT arthrodesis to be required as part of fusion construct

Midfoot Injuries (Excluding Lisfranc Injuries)

- **Midfoot consists of the navicular, the three cuneiforms, the cuboid, and their corresponding articulations.**
- **Acts as a stout connection between the forefoot and hindfoot**
  - Relatively immobile, with strong plantar ligaments
  - Serves an important shock-absorbing function
  - Chopart and Lisfranc joints are therefore of greater functional importance than the articulations among the midfoot bones.
  - Cuboid is critical to the integrity of the lateral column.
- **Cuboid injuries**
  - Often associated with other midfoot or Lisfranc fractures/dislocations

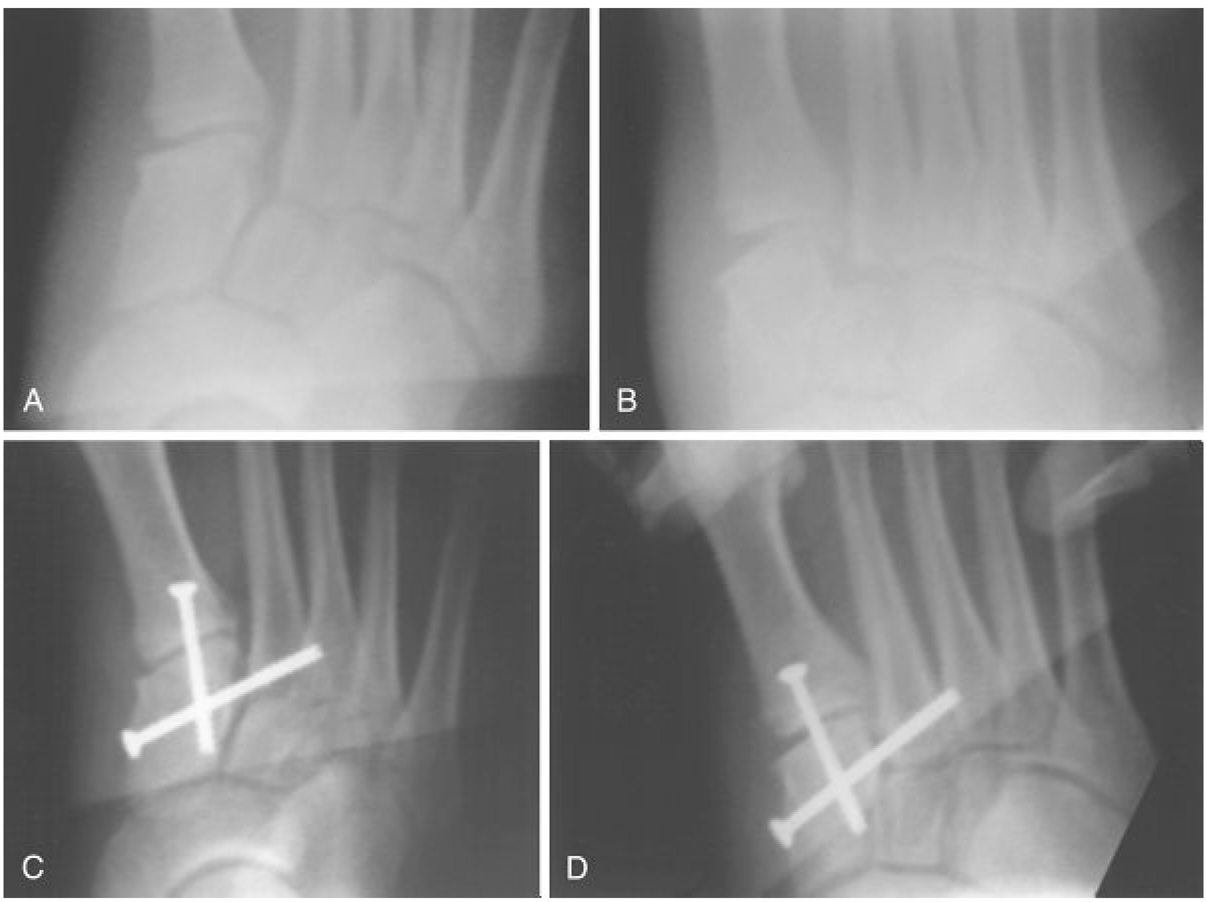


FIG. 6.114 Anteroposterior and stress radiographs of foot with subtle Lisfranc dislocation. (A) Radiographic appearance is normal. (B) With stress into everted position, metatarsals sublux laterally. (C) Postreduction radiograph reveals satisfactory reduction and internal fixation. (D) Reduction maintained on eversion stress radiograph.

From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier.

FIG. 6.115 Lisfranc injury showing the fleck sign *(arrow)*.
From Mercier L: *Practical orthopaedics,* ed 6, Philadelphia, 2008, Elsevier.

- □ Radiographic evaluation
  - AP, lateral, and oblique (30-degree medial oblique is ideal) views
  - Weight-bearing/stress views can help ascertain midfoot stability if there is clinical concern.
  - CT may be required to define fracture fragments and articular congruity.
- □ Cuboid avulsion from the CC articulation
  - Most common; due to an inversion force (lateral ankle sprain)

FIG. 6.116 Patient with a Lisfranc injury identified by the fleck sign *(arrow).* In this case, the ligament itself remained intact and the injury occurred by avulsion of the ligament from the base of the second metatarsal. The function of the ligament is compromised, and operative intervention is indicated.
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

FIG. 6.117 Postoperative radiograph of patient who was treated with screw fixation. In addition to a screw transfixing the first tarsometatarsal joint, the "Lisfranc" screw was used to hold the second metatarsal reduced. In this case instability of the intercuneiform joint was noted and required fixation.
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

- Treated conservatively, with weight bearing as tolerated in boot or brace

□ Cuboid fracture
- Results from forced plantar flexion and abduction of the forefoot leading to an axial load
- Often causes comminuted impacted fracture, or nutcracker fracture (Fig. 6.120)
- Treatment
  - Nondisplaced, minimal articular involvement—conservative treatment in boot
  - ORIF required when comminution or displacement compromises the length and alignment of the lateral column
  - Lateral column external fixation can be used as an aid to obtain length or for definitive fixation in severely comminuted cases (Fig. 6.121).

□ Cuboid syndrome
- Painful subluxation seen in athletes, especially ballet dancers
- The patient may have pain or a palpable "click" as the foot is brought from plantar flexion and inversion to dorsiflexion and eversion.

□ Complete dislocation of the cuboid
- Extremely rare, often due to higher-energy mechanisms
- Usually displaced in a plantar and medial direction

▪ **Cuneiform injuries**

□ Most occur in association with other midfoot injuries, in particular Lisfranc injuries.

□ The medial cuneiform is the most commonly injured.
- Displaced or unstable medial cuneiform injuries require anatomic reduction and stable fixation.

▪ **Navicular fractures**

□ The navicular articulates with the talar head on its concave proximal surface and with the three cuneiforms distally.

□ Rigidly fixed in the midfoot by dense ligamentous attachments

□ Blood supply—dorsalis pedis supplies the dorsum, medial plantar branch of the posterior tibial artery supplies the plantar surface, and branches of these arteries create a plexus to supply the tuberosity.

- The central portion of the bone is relatively less vascular and therefore at risk for stress injuries and nonunion.

□ Classification and treatment

- Navicular fractures classified as avulsion, tuberosity, body, and stress injuries
    - Avulsion fractures
        - Ligamentous attachments (usually from dorsal TN joint) avulse a fragment of bone during inversion, twisting, and hyper–plantar-flexion injuries.
        - Most common, treated symptomatically
    - Navicular tuberosity fractures
        - Secondary to acute eversion of the foot with simultaneous contraction of the tibialis posterior
        - Displacement usually minimal owing to broad attachment of the posterior tibial tendon
        - Concomitant lateral injury is common (anterior process of the calcaneus, cuboid fracture).
        - Treatment
            - Nondisplaced or minimally displaced fractures treated in cast or boot with protected weight bearing.
            - Fractures displaced more than 5 mm have a high chance of nonunion—surgical fixation recommended.
            - Small avulsions or symptomatic nonunion can be treated with excision.
    - Navicular body fractures
        - Axial load to a plantar-flexed foot with either abduction or adduction through the midtarsal joints
        - Type I fracture—transverse in the

coronal plane, dorsal fragment less than 50% of body

- Type II fracture—dorsolateral to plantar medial, with resultant medialization (adduction) of the fragment and forefoot
- Type III fracture—central or lateral comminution with possible lateral displacement of the foot
- Treatment
    - ORIF of even minimally displaced fractures is recommended.
    - Goal is to preserve TN and therefore hindfoot motion.
    - External fixation may be required to preserve medial column length or as aid in fracture reduction.
    - Primary or delayed arthrodesis of involved joints may be required for extensive comminution.

- Navicular stress fractures
    - Secondary to repetitive trauma, especially in running and jumping athletes
    - Cavus feet a predisposing factor
    - Typically occur in the central third of the navicular

FIG. 6.118 Lisfranc and midtarsal injury treated with primary arthrodesis of the first through third TMT joints. Anteroposterior (A), oblique (B), and lateral (C) radiographs of a Lisfranc injury with dorsolateral dislocation of all metatarsal bases without associated fracture. The lateral radiograph also shows associated injury to the midtarsal joint with plantar fracture-dislocation of the navicular, which required open reduction and internal fixation to stabilize the articulation. Primary arthrodesis may be indicated in true TMT dislocations because the long-term stability of these joints depends on ligamentous healing, which is less reliable than bony healing. (D) Oblique postoperative radiograph showing arthrodesis of the medial three TMT joints and provisional Kirschner-wire fixation of the fourth and fifth TMT joints. Weight-bearing anteroposterior (E), oblique (F), and lateral (G) radiographs obtained 1 year postoperatively.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

- Patients complain of vague dorsal midfoot or ankle pain.
- Physical examination reveals tenderness at dorsal central navicular.
- Radiographic evaluation
    - AP, lateral, and oblique foot views may or may not show fracture.

- MRI and bone scan can aid in the diagnosis.
- CT is the gold standard; defines complete and incomplete fractures, displaced versus nondisplaced.
  - Best viewed on coronal images (Fig. 6.122)
  - Fracture line extends from dorsolateral to plantar medial.

- Treatment
  - Conservative treatment recommended for nondisplaced fractures; non–weight-bearing status (usually in cast for 6–8 weeks) is critical.
  - Operative treatment with transverse screw placement recommended for displaced fractures or fractures with evidence of nonunion
    - Screw should be placed from dorsomedial to plantar lateral (Fig. 6.123).

FIG. 6.119 (A to C) This severe posttraumatic deformity was symptomatic in each of the three midfoot columns. Note the severe abduction of the entire tarsometatarsal joint complex.
From Myerson MS: *Reconstructive foot and ankle surgery: management of complications,* ed 2, Philadelphia, 2010, Elsevier.

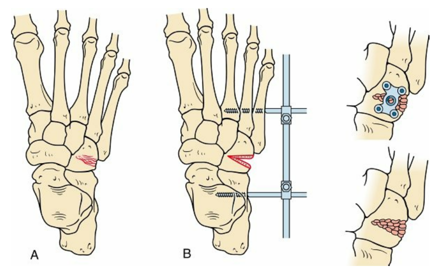


FIG. 6.120 (A) Nutcracker impaction injury of the cuboid shortens the lateral column of the foot, thereby causing a pes planus deformity because of a relative mismatch with the medial column. (B) External fixation to distract the fracture corrects the deformity but leaves a void. Stable healing requires bone grafting, often augmented with a small buttress plate.
From Browner B et al: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier.

- Bone grafting may be necessary.
- Initial operative

treatment may be considered in elite athletes, although controversy remains on this issue, and the current treatment recommendation is to consider surgery if nonoperative intervention has failed and not as a primary treatment.

- The two most common complications of navicular fractures are degenerative arthritis and AVN.

Talus Fractures

- **Constitute less than 1% of all fractures but rank second (behind calcaneus fractures) among all tarsal bone injuries**
- **Anatomy**
    - More than half of the surface area of the talus is covered by articular cartilage.
    - The neck is angled in a medial and plantar direction relative to the axis of the body.
    - There are no muscular or tendinous attachments.
    - Blood supply is provided by three main vessels: the posterior tibial artery, the dorsalis pedis artery, and the perforating peroneal artery.
        - The arteries of the tarsal sinus (br. of perforating peroneal), the tarsal canal (br. of the posterior tibial artery), and the deltoid (br. of the artery of the tarsal canal) are important branches of the main vessels.
        - The artery of the tarsal canal carries the main supply to the talar body.
    - The head and neck are vascularized by the artery of the tarsal sinus and the dorsalis pedis.
    - A thorough understanding of the relationship between fracture displacement and the vessels that are disrupted is extremely important when operative approaches and fixation are planned.
- **Mechanism of injury**
    - Most common mechanisms are a fall from a significant height and a motor vehicle collision.

FIG. 6.121 Navicular and cuboid fractures with middle (second) cuneiform dislocation. The patient sustained these injuries in a motor vehicle crash. (A and B) Anteroposterior and oblique injury radiographs. (C) Lateral injury radiograph. (D to F) Definitive ORIF of these injuries could not be accomplished acutely owing to profuse edema. Closed reduction of middle (second) cuneiform dislocation and of foot alignment was accomplished and held using a through-and-through calcaneal tuberosity pin, attached via carbon fiber rods to a distal first metatarsal pin medially and a proximal fourth and fifth metatarsal pin laterally. (G to I) Definitive ORIF was accomplished after foot edema was controlled. A single intercuneiform screw keeps the middle (second) cuneiform reduced. Plate fixation on the navicular and cuboid maintains anatomic reduction. The medial and lateral external fixator was left in place for 6 weeks to supplement fixation support.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.

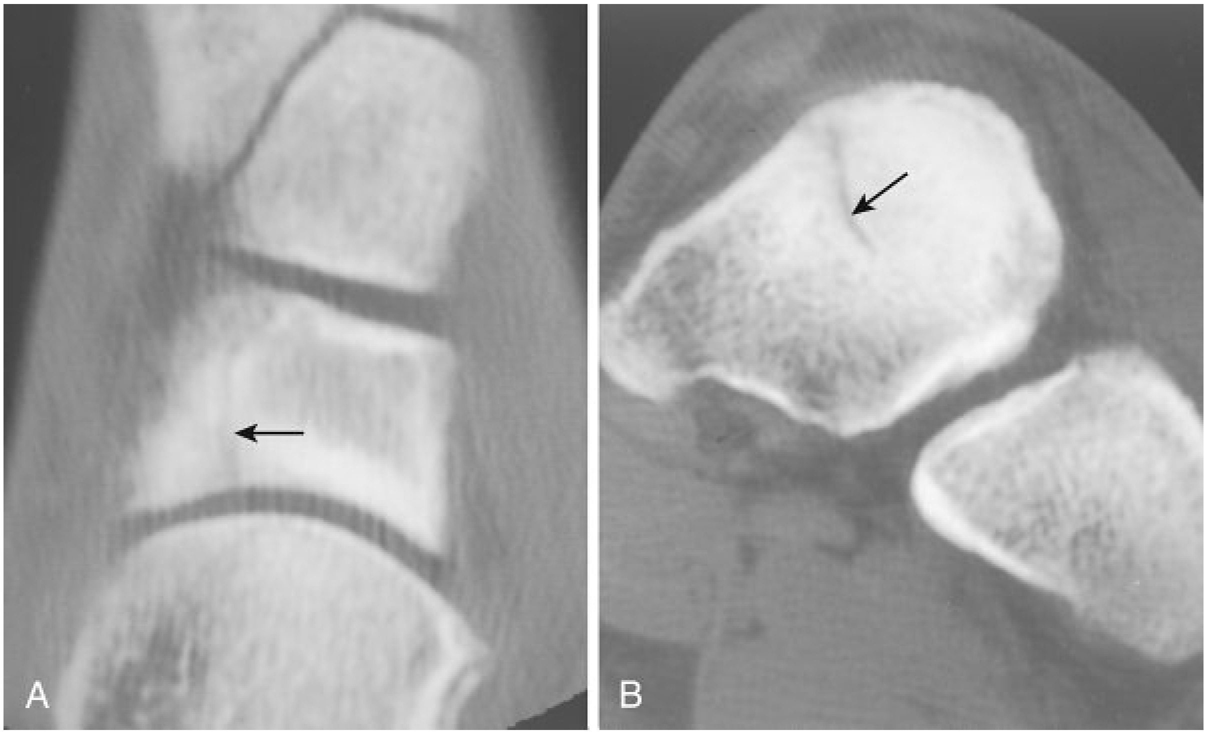


FIG. 6.122 Tarsal navicular bone stress fractures on CT scanning. Transverse (A) and coronal (B) CT scans show a typical fatigue fracture *(arrows)* of the tarsal navicular bone. These fractures are usually located in the proximal and dorsal aspects of the bone, and they have a vertical or vertical-oblique orientation.
From Resnick D: *Internal derangements of joints,* ed 2, Philadelphia, 2006, Saunders.

FIG. 6.123 Anteroposterior (A) and lateral (B) radiographs of completed screw fixation.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

- Forceful dorsiflexion of the foot leads to impaction of the narrow talar neck on the anterior tibia.
- The energy propagates through the ligaments that stabilize the subtalar joint, leading to subluxation or dislocation of the body.
- If the hindfoot deviates into supination, the talar neck can fracture the medial malleolus, become impacted and comminuted, and cause talar head rotation and displacement.

- **Diagnosis**
  - Marked swelling, gross deformity, and soft tissue compromise common

- Decreased plantar sensation may be present with posteromedial extrusion of talar body in type III injuries; due to compression on the tibial nerve.

- **Radiographic evaluation**
  - AP, lateral, and Canale oblique radiographs should be routine.
  - CT very useful in evaluating the fracture pattern, comminution, and angulation for preoperative planning.
- **Classification**
  - Talar neck fractures—Hawkins classification (Fig. 6.124)
    - Type I fracture—only one of three main sources of blood supply disrupted
      - Truly nondisplaced talar neck fractures are rare—any amount of displacement should be treated as a type II injury.
    - Type II fracture—two of three main sources of blood supply disrupted
      - Subtalar joint disruption
      - The deltoid branch of the posterior tibial artery is the only remaining blood supply, emphasizing the critical requirement to preserve the deltoid ligament during all surgical approaches.
    - Type III fracture—the blood supply has theoretically been completely compromised.
      - Subtalar and tibiotalar joint disruption
      - Talar body is usually extruded posteriorly and medially.
      - More than 50% of these injuries are open, and many result in infection.
    - Type IV fracture—may also have disrupted vascularity to the talar head and neck
      - Subtalar, tibiotalar, and TN joint disruption
      - TN dislocations need to be reduced closed rather than open; dorsal dislocation can be irreducible secondary to the posterior tibial tendon.
  - Talar body fractures
    - Lateral process acts as dividing line
      - Inferior fracture lines anterior to the lateral process are identified as talar neck fractures.
      - Fractures posterior to the lateral process are classified as body fractures.

FIG. 6.124 The Hawkins classification of talar neck fractures remains useful because it is relatively simple, guides treatment, and has prognostic value. (A) Type I fracture (minimally displaced). (B) Type II fracture, with displacement of the subtalar joint. (C) Type III fracture, with displacement of the subtalar and tibiotalar joints. (D) The type IV fracture as described by Canale includes a talar neck fracture with displacement of the subtalar, tibiotalar, and talonavicular joints.
From Browner B et al: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier.

- Talar body fractures affect both the subtalar and tibiotalar articulations.
    - Risk of arthritis of the tibiotalar joint is 65%
    - Risk of arthritis of the subtalar joint is 35%

▪ **Treatment**

- □ Goal is to obtain anatomic reduction (length, rotation, angulation) and rigid stabilization.
- □ Even slight displacement can significantly alter the contact characteristics of the subtalar joint.
- □ Controversy exists regarding the timing of surgical fixation of displaced talar neck fractures.
    - Most later studies show no correlation between time to fixation and development of osteonecrosis.
- □ Dislocations should be urgently reduced.
- □ Talonavicular incongruity or instability warrants operative fixation to minimize posttraumatic arthrosis.
    - The TN joint is critical to overall hindfoot motion.
    - TN fusion for talar head fractures should be a salvage procedure.
- □ Talar neck fractures

- Medial malleolar osteotomy *not* required for open reduction
- Type I—immobilization in a non–weight-bearing cast for 6–8 weeks
    - Frequent radiographs required to evaluate for fracture displacement.
    - CT required to ensure that the fracture is nondisplaced.
- Type II
    - Significant displacement may lead to skin compromise.
        - Closed reduction should be performed with plantar flexion and heel manipulation.
    - Medial neck comminution is common and leads to varus deformity.
        - ORIF required
            - Dual medial and lateral incisions are best approach to appropriately gauge talar length and angulation.
            - Care must be taken to preserve medial blood supply from the deltoid artery.
            - Fixation achieved with combination of screws and/or minifragment plates
    - A minimally displaced fracture without comminution is ideal for percutaneous screw fixation (Fig. 6.125).
        - **Medial compression screw may worsen varus deformity if comminution present. A fully threaded screw or plate should be used medially to avoid this complication.**
        - Care should be taken not to underestimate the extent of varus angulation and medial impaction.
        - Screws advanced from posterior to

anterior demonstrate superior stability of fracture construct but are more difficult to place.

- Type III
  - Requires immediate closed or, if necessary, open reduction
  - Definitive ORIF may be delayed following reduction of the ankle and subtalar subluxation/dislocation.

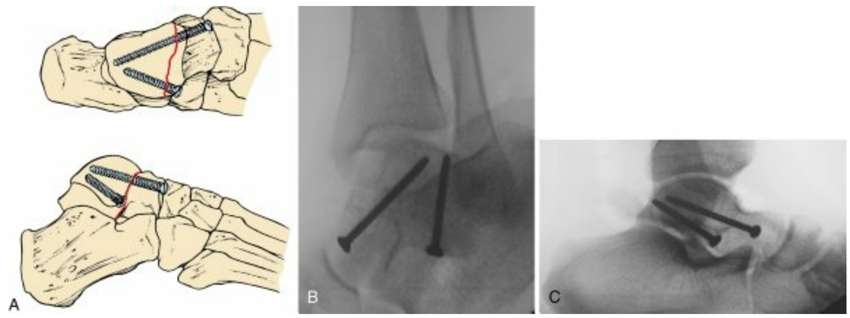


FIG. 6.125 Screws angled anterior to posterior can be placed percutaneously to stabilize a minimally displaced talar neck fracture. In this case, two 3.5-mm cortical screws are placed across a fracture located at the base of the neck of the talus. The first screw, which is placed medially, is countersunk into the articular surface. The second screw is placed through a 3.5-mm gliding hole in the sinus tarsi and a 2.5-mm thread hole in the body. (A) In this case, both screws are inserted approximately perpendicular to the fracture line and along the midaxial line of the talar neck to avoid creating dorsal or plantar gapping along the fracture line during compression. (B) Intraoperative Canale view demonstrating screw placement. (C) Intraoperative lateral view showing screw location.
From Browner B et al: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier.

  - Approach similar to that for type II injuries. Comminution is more common, and fixation with mini-fragment plate is commonly required (Fig. 6.126).
  - Associated medial malleolus fracture is common.
  - These fractures are at significant risk for AVN, subtalar and ankle posttraumatic arthritis, malunion, and nonunion.
- Type IV
  - Treatment and approach similar to those for type II and III injuries
  - May require stabilization of the TN joint

        - Nearly 50% risk of AVN of the talar head and body
        - Type IV injuries offer the worst prognosis.

- **Complications**
    - Subtalar arthritis is the most common complication.
        - If arthritis present—triple arthrodesis
        - Isolated subtalar fusion cannot correct the deformity, because the site of the deformity is distal to the subtalar joint in the talar neck (Fig. 6.127).
    - AVN
        - Risk increases with severity of injury—approaches 50% with a type III/IV injury
        - Historically, the rates of AVN have been reported to be higher, but later data based on MRI findings have demonstrated a lower rate of AVN.
        - Hawkins sign—subchondral linear lucency of the talar dome that is indicative of talar revascularization (Fig. 6.128)
            - Usually seen 6–8 weeks after reconstruction
        - Sclerosis of the talar dome (increased density) does not guarantee that AVN has occurred, although it is suggestive.
        - **In the setting of AVN and arthritis of the ankle, ankle arthrodesis should be considered because distraction arthroplasty has not been shown to have good results.**
            - Total ankle replacements are not an option in the setting of AVN.
    - Varus malunion—secondary to medial fracture comminution
        - No arthritis present—open-wedge osteotomy of medial talar neck
        - If arthritis present—triple arthrodesis as a subtalar arthrodesis is able to correct the deformity given that it is distal to the subtalar joint.
    - Talar body fractures
        - Nondisplaced fractures treated with immobilization for 6–8 weeks
        - Any displacement requires anatomic reduction and stable internal fixation.
            - Usually achieved with small-fragment or mini-fragment lag screws
        - Medial or lateral malleolar osteotomy may be required for adequate visualization.
    - Talar body extrusion
        - With minimal contamination and any remaining soft tissue attachment, talar body should be copiously irrigated, washed

(chlorhexidine), débrided, and reimplanted.
    - In the presence of gross contamination, it may be appropriate to disregard the body and perform a delayed reconstruction. However, all attempts at salvage should be made.
    - Rates of deep infection and overall failure are very high.
- Lateral process talus fractures
    - Lateral talocalcaneal ligament attaches to the lateral process.
    - Mechanism—axial load, dorsiflexion, inversion, and external rotation of the foot
        - Highly associated with snowboarding
    - Source of continued pain after a "simple" ankle sprain
    - Best seen on the AP ankle radiograph (Fig. 6.129)
        - CT should be performed to evaluate the extent of comminution.
    - Treatment depends on the degree of articular involvement, displacement, and comminution.
        - Nondisplaced fractures—immobilized in a non–weight-bearing cast or boot
        - Displaced fractures
            - ORIF if amenable to screw fixation

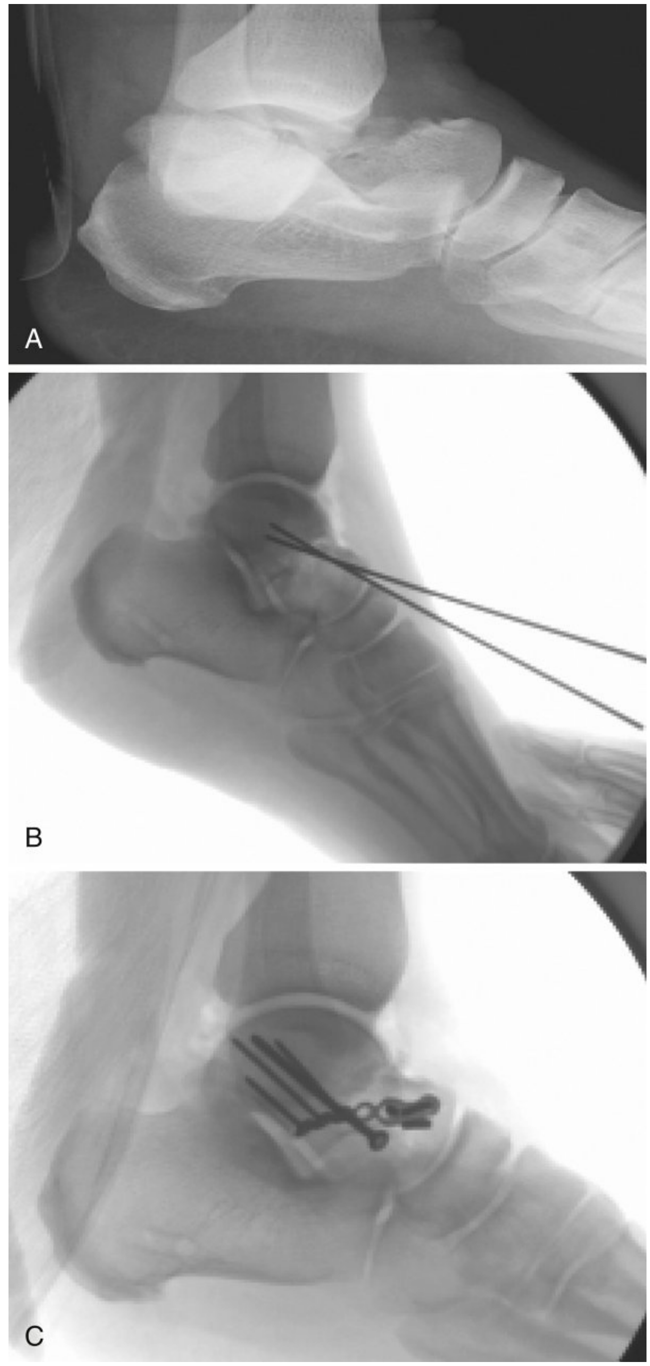


FIG. 6.126 (A) In Hawkins type III injuries, the talar body is often extruded posteromedially from the ankle and subtalar joint. (B) The fracture is then reduced through standard medial and lateral approaches, and provisional fixation is achieved with Kirschner wires. (C) Stable fixation is achieved with a 2.0-mm blade plate on the lateral side and a compression screw on the medial side.

- **Excision if small or significantly comminuted**
  - Applicable also in the

setting of chronic injury

Calcaneus Fractures

- **Extraarticular calcaneus fractures**
  - Avulsion fractures of the tuberosity
    - Caused by forceful Achilles tendon contraction
    - Nondisplaced fractures treated with immobilization
    - Displacement endangers posterior skin (Fig. 6.130)
      - Urgent operative reduction and fixation to prevent skin compromise
      - Percutaneous fixation achieved with lag screws from the posterior superior tuberosity directed inferior and distal
  - Anterior process fractures
    - Avulsions at the bifurcate ligament caused by forced inversion and plantar flexion
    - Often misdiagnosed as ankle sprains
    - Most can be treated with immobilization in boot or brace.
    - Significant displacement involving more than 25% of the CC joint may benefit from ORIF.
    - Late symptoms secondary to nonunion may benefit from excision of the fragment.
  - Sustentaculum fractures
    - Rarely present without posterior facet involvement
    - CT scan aids diagnosis when medial hindfoot pain persists after an injury.
    - Displaced fractures treated with ORIF via lag screws through a medial approach
- **Intraarticular fractures**
  - Approximately 75% of all fractures of the calcaneus are posterior facet fractures, and most of them have some displacement.
  - Mechanism of injury
    - Usually secondary to high-energy trauma such as fall from height or motor vehicle accident
    - Result in axial loading and shear forces to the calcaneus
    - One or more posterior facet fragments are impacted into the body of the calcaneus.
    - The lateral wall is “blown out,” causing subfibular impingement and peroneal tendon encroachment.
    - Heel pad crush occurs.
      - Results in shortened, widened calcaneus, and in

varus

- Collapse of the posterior facet leads to flattening of the calcaneus
  - Collapse of the posterior facet leads to loss of declination of the talus
- Significant soft tissue disruption is common, with open fractures accounting for 17% of calcaneus fractures.
  - The complication rate with ORIF for disruption of the medial soft tissue is no higher than for lateral soft tissue trauma.
  - Evaluation for concomitant injuries such as vertebral fractures needed

▪ **Radiographic evaluation**

□ AP, lateral, oblique, and axial os calcis radiographs performed initially

□ Reduction in Böhler angle or angle of Gissane, calcaneal shortening, and varus deformity to the tuberosity are common in joint depression fractures (Fig. 6.131).

□ Broden oblique view of the ankle is helpful to evaluate posterior facet displacement.

- More internal rotation of leg allows anterior portion of the joint to be seen.
- Less internal rotation of leg allows posterior portion of the joint to be seen.

□ CT scanning in the 30-degree semicoronal (posterior and middle facets displacement), axial (CC joint involvement), and sagittal (tuberosity displacement) planes is helpful in evaluating this multiplanar injury as well as in preoperative planning.

FIG. 6.127 (A and B) Malunion of a fracture of the neck of the talus treated with open reduction and internal fixation. The hindfoot was fixed in varus as a result of shortening of the medial column of the hindfoot. (C and D) Correction was accomplished with a triple arthrodesis achieved by resecting a small wedge from the lateral aspect of the calcaneocuboid joint.
From Myerson MS: *Reconstructive foot and ankle surgery: management of complications,* ed 2, Philadelphia, 2010, Elsevier.

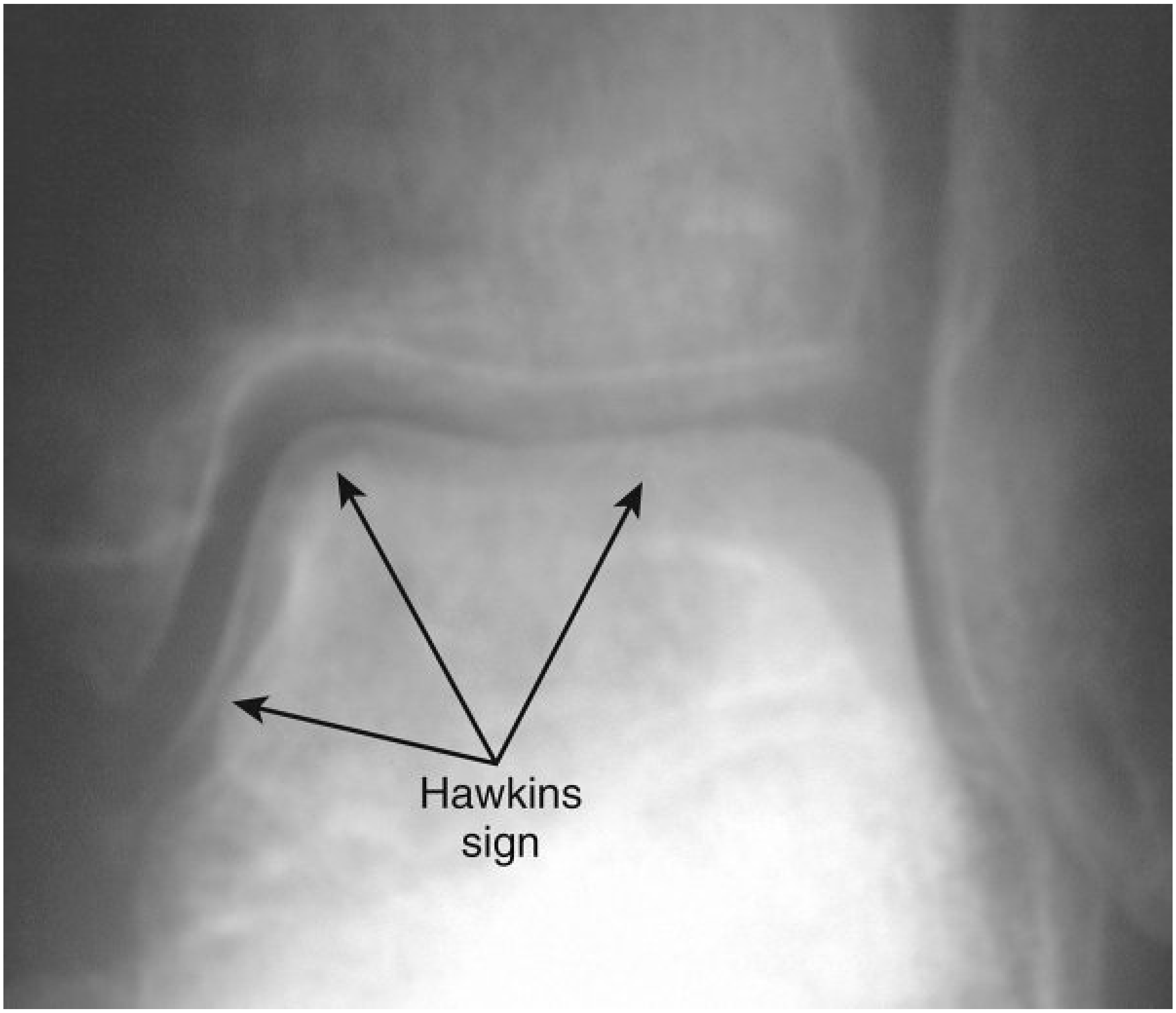


FIG. 6.128 Hawkins sign. Arrows indicate revascularization.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

FIG. 6.129 Snowboarder's ankle (fracture of the lateral process of the talus).
From Miller MD: *Core knowledge in orthopaedics—sports medicine,* Philadelphia, 2006, Elsevier.

FIG. 6.130 Radiograph shows a displaced tuberosity fracture that was tenting the skin over the posterior heel. Urgent percutaneous reduction and fixation was performed to prevent skin necrosis.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.

- **Classification**
  - Sanders classification system is most widely used (Fig. 6.132).
    - Based on CT scan in coronal plane
    - Correlates with treatment and prognosis

- Essex-Lopresti noted the difference between joint depression fractures and tongue-type fractures (articular surface attached to displaced tuberosity fragment).

- **Treatment**
  - Sanders type I—immobilization for 2–3 weeks, early motion, non–weight-bearing status for 6 weeks.
  - Sanders types II and III
    - Indications for ORIF
      - Later literature has again demonstrated that long-term function following Sanders type II and III calcaneal fractures may not be significantly improved following ORIF. Therefore, it is very difficult to provide clear-cut guidelines on when operative intervention is advised.
      - Patients with severe loss of calcaneal height, varus deformity, subtalar subluxation or dislocation, or subfibular impingement are good candidates for operative intervention. If these problems are not present, nonoperative intervention should be considered.
      - Patients with an overall normal morphology of the hindfoot with intraarticular incongruity may not benefit from operative intervention.
    - Extensile lateral exposure provides access to subtalar and CC joints and allows for lateral plate placement, but has a high rate of wound complications.
      - Delayed wound healing can occur in 25%–30% of patients treated with an extensile approach. Risk of a deep infection is much lower (1%–4%).
      - Lower rate of subtalar arthrosis than for nonoperative intervention
      - FHL at risk during placement of screws from lateral to medial—specifically at the level of the sustentaculum (constant fragment)
      - Soft tissue swelling and risks of wound complications or infection make operative intervention difficult within 2 weeks of injury. Wrinkle sign (skin wrinkles present over lateral hindfoot, indicating improvement in swelling) should be sought prior to operative intervention.
    - Less invasive techniques (sinus tarsi incision, percutaneous screws), which have lower wound healing and infection complication rates, are increasing in popularity.

- May be option within first 2 weeks following injury. More difficult to perform as time passes because of callus formation and difficulty mobilizing fracture fragments.

- Sanders type IV
  - Significant comminution and displacement leads to relatively poor prognosis.
  - ORIF with primary subtalar arthrodesis is treatment of choice (Fig. 6.133).

- **Prognosis**
  - Worse outcomes correlate to higher fracture types.
  - Clinical outcomes are better with operative than with nonoperative management for patients with the following characteristics: significant intraarticular displacement, flattened Böhler angle, female gender, age younger than 29, and injury not involved in workers' compensation process.
  - Posttraumatic subtalar arthritis is common; may require arthrodesis.
    - 50% decreased ROM of subtalar joint expected after injury, regardless of treatment
    - Patients complain of pain over the sinus tarsi with limited inversion/eversion.
    - Outcomes for arthrodesis after primary ORIF superior to those for initial treatment with nonoperative management.
      - Secondary to restoration of height and width of the hindfoot in operatively treated patients
    - In cases with significant loss of calcaneal height, horizontal talus, and resultant anterior ankle pain, bone-block distraction arthrodesis of the subtalar joint is required.
      - A posterolateral approach should be considered to avoid the soft tissue healing issues associated with application of bone block through the sinus tarsi approach.

Peritalar (Subtalar) Dislocations

- **Associated tarsal fractures in 90%**
- **Medial—dorsomedial talar head, posterior tubercles of talus, lateral navicular**
- **Lateral—cuboid, anterior process of calcaneus, lateral process of talus and lateral malleolus**
- **Medial dislocation (** Fig. 6.134)
  - More common (85%) than lateral dislocation
  - Results from forceful inversion of the hindfoot, which leads to medial

displacement of the calcaneus

    - Reduction can usually be accomplished with use of sedation or general anesthesia.
    - Most common obstacles to reduction are the EDB, the extensor retinaculum, the peroneal tendons, and the TN capsule.

- **Lateral dislocation (** Fig. 6.135)
    - Less common (15%) than medial dislocation
    - Occurs with forceful eversion of the hindfoot, which leads to lateral displacement of the calcaneus

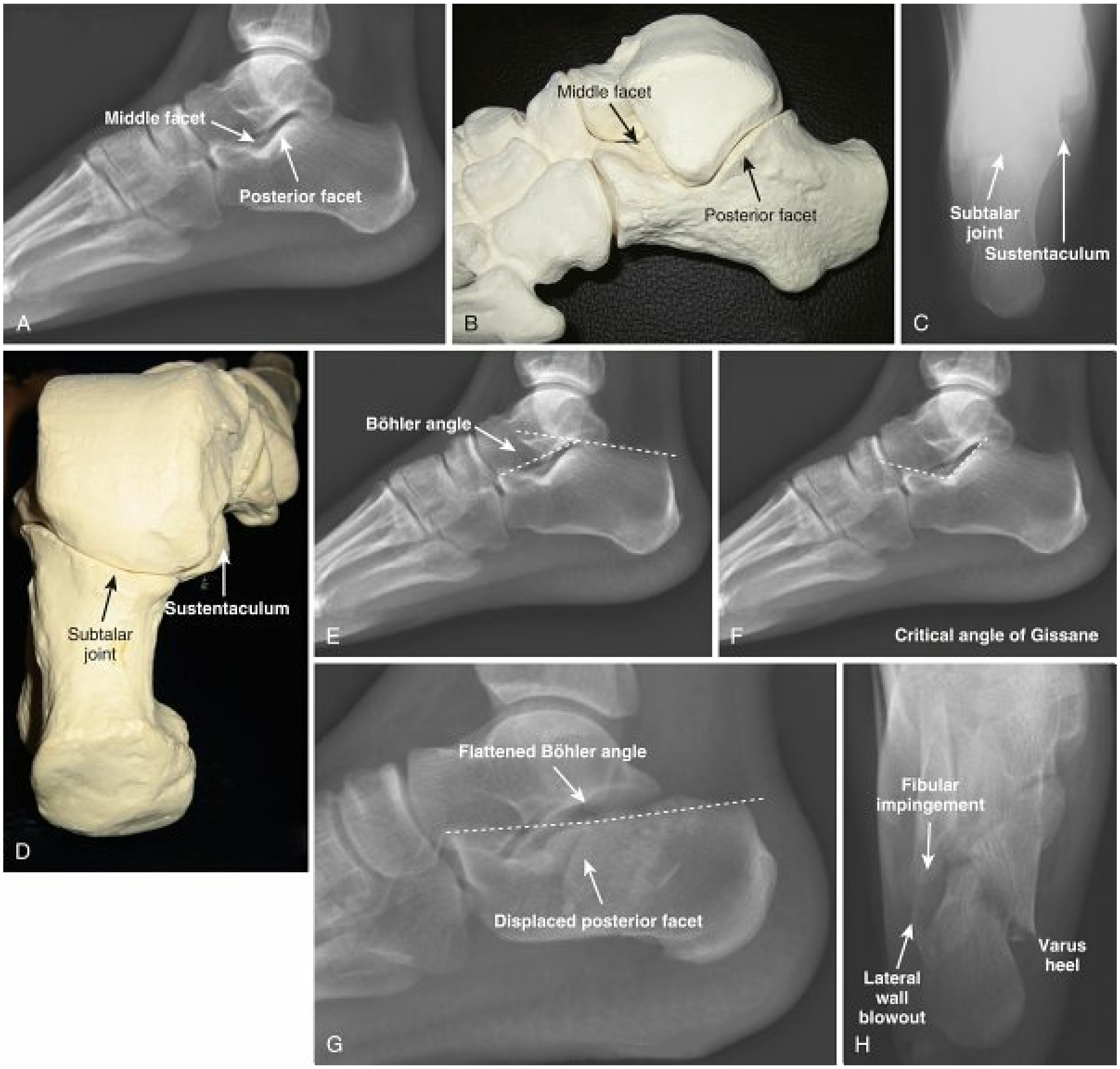


FIG. 6.131 The normal (A and C) and pathologic (G and H) radiographic anatomy of the calcaneus. The lateral (A, E, and G) and Harris axial (C and H) views of the calcaneus are useful in assessing the shape and alignment of the calcaneus. (A and E) The lateral view allows for assessment of the posterior and middle facet positions as well as of calcaneal height (Böhler angle; E). The Böhler angle is formed by drawing two lines. The first is drawn from the highest point on the anterior process to the highest point on the posterior facet. The second line is tangential to the superior edge of the tuberosity. The normal value of the Böhler angle is 25 to 40 degrees. (G) In the injured calcaneus, the Böhler angle is diminished, corresponding to the loss of height (flattening). (F) The critical angle of Gissane is the angle formed by the intersection of a line drawn along the dorsal aspect of the anterior process of the calcaneus and a line drawn along the dorsal slope of the posterior facet. The normal value of the Gissane angle is 120 to 145 degrees. (C and H) The axial view is useful for determining displacement of the tuberosity, varus angulation, fibular abutment, and displacement of the lateral wall.
From Browner B et al: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier.

- □ Most common obstacles to reduction are an interposed posterior tibial tendon and FHL tendon.

- **CT recommended in all cases to rule out small intraarticular fragments.**
- **Treatment**
  - □ Immobilization in boot or cast for 6 to 12 weeks if reduction stable
  - □ Unstable reduction requires temporary stabilization with either

Kirschner wire or external fixation.
- Intraarticular fragments should be removed surgically.

Compartment Syndrome

- **Leg compartment syndrome (see** Chapter 11, Trauma)
- **Foot compartment syndrome**
  - Anatomy (controversial)
    - Medial compartment—abductor hallucis, FHB
    - Central (calcaneal) compartments (three)
      - Superficial—FDB
      - Central—quadratus plantae
      - Deep—adductor hallucis and tibial neurovascular bundle

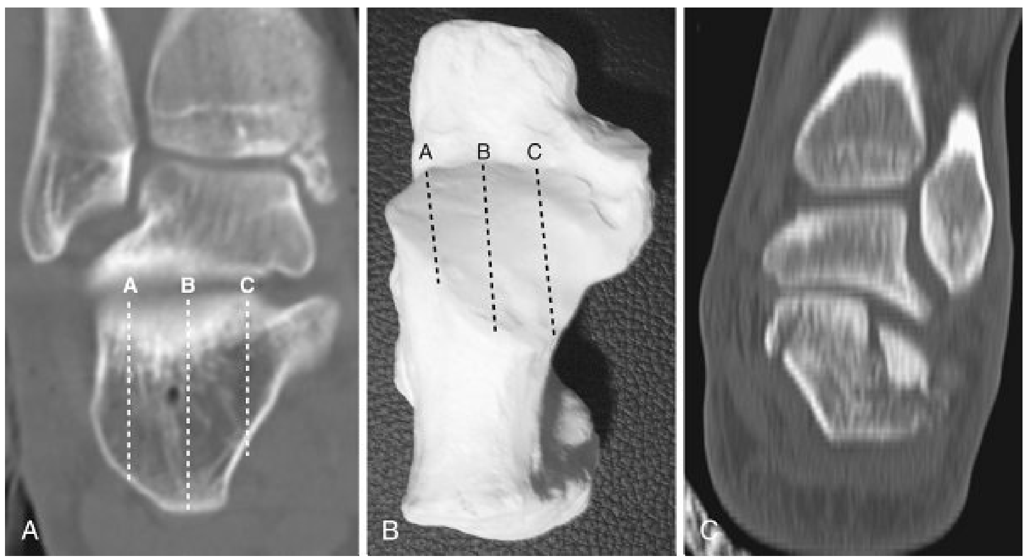


FIG. 6.132 The Sanders classification is based on the fracture pattern through the posterior facet as seen on coronal CT scan. Type 1 fractures are nondisplaced. Type 2 fractures are two-part fractures of the posterior facet. Type 3 fractures are three-part fractures of the posterior facet. Type 4 fractures are highly comminuted, with four or more fragments to the posterior facet. (A and B) Type 2 and type 3 fractures are further classified according to the location of the fracture lines (*A*, *B*, and *C*), as shown. (C) This fracture would therefore be a Sanders type 3AC. The prognosis for calcaneus fractures worsens as the comminution of the posterior facet worsens.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.

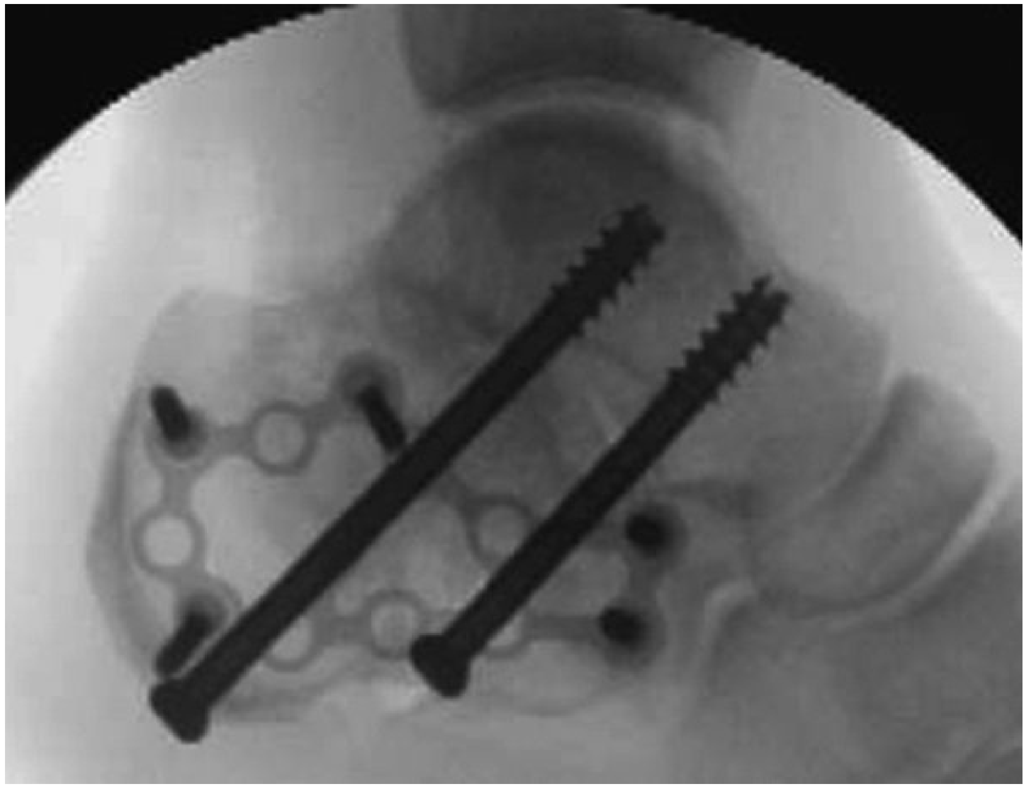


FIG. 6.133 Primary subtalar fusion may be indicated in cases of severe comminution or destruction of the articular cartilage. Once reduction and fixation of the calcaneus is complete, the subtalar joint is denuded of cartilage. Compressive fixation is then applied across the subtalar joint.
From Browner B et al: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier.

- Lateral compartment—flexors, abductors, and opponens to the fifth toe
- Interosseous compartments (four)—interossei muscles
- The dorsalis pedis artery forms an anastomosis with the plantar arch by passing between the first and second metatarsal bases.

□ Mechanism of injury

- When the intracompartmental fluid pressure meets or exceeds the capillary filling pressure (perfusion pressure), irreversible muscle and nerve damage can occur.
- In the foot, crush injuries are the most common cause.
- The incidence of compartment syndrome in calcaneus fractures approaches 17%.

□ Diagnosis

- Diagnosis is made from constellation of clinical findings and a high index of suspicion.
- Clinical findings include massive swelling, pain out of proportion to the injury that is not relieved by immobilization or appropriate analgesics, severe pain with passive motion of the toes (stretching the intrinsic muscles), and paresthesias and/or loss of light-touch perception and

two-point discrimination.

- Presence of normal capillary refill time and palpability and/or Doppler detection of pulses do not rule out compartment syndrome.
- Compartment pressures can be measured to aid in the diagnosis.
    - Values greater than 30 mm Hg or those within 20 mm Hg of the diastolic pressure should raise suspicion of compartment syndrome.

□ Treatment

- Fasciotomies can be performed through three incisions (see Fig. 6.67).
- Dorsomedial incision
    - Medial to second metatarsal
    - Releases first and second interosseous, medial, and deep central compartments
- Dorsolateral incision
    - Lateral to fourth metatarsal
    - Releases third and fourth interosseous, lateral, superficial, and middle central compartments
- Medial incision
    - Plantar medial border of hindfoot
    - Releases calcaneal compartment
- The wounds should be left open initially, with delayed closure or skin grafting performed as swelling improves.
- Definitive treatment is compartment release.
    - The result of unrecognized and untreated compartment syndrome is *not* simply isolated claw toes.
    - Damage is not isolated to the musculature but also affects peripheral nerves, commonly resulting in chronic pain with hypersensitivity that can be difficult or impossible to treat.

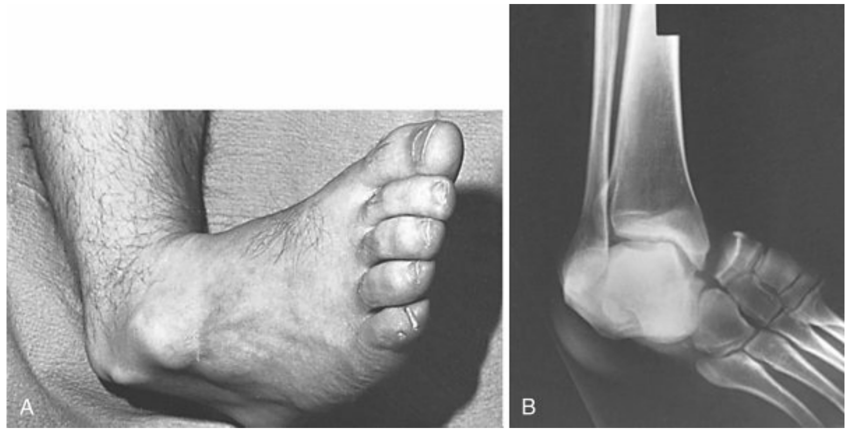


FIG. 6.134 Medial subtalar dislocation. (A) Posture of foot. Note prominence of head of talus. (B) Radiographic appearance of dislocation.
From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier; DeLee JC, Curtis R: Subtalar dislocation of the foot, *J Bone Joint Surg* 64A:433, 1982.

FIG. 6.135 Anteroposterior (A) and lateral (B) radiographs of lateral subtalar dislocation.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

- Benign neglect of a foot compartment syndrome is not appropriate management.

Ankle Fractures

- **Typically a low-energy mechanism of injury, rotational as opposed to axial load**
- **Must always be evaluated for deltoid or syndesmosis injury**
- **Diagnosis**
    - Varied presentations depending on severity of injury
- **Radiographic evaluation**

- AP, mortise, and lateral radiographs often sufficient to identify fracture pattern
- External rotation stress or gravity stress radiographs assess for deltoid integrity (Fig. 6.136).
    - Medial clear space widening with stress indicates deep deltoid disruption and implies unstable fracture pattern.
- CT performed for complex fracture patterns, posterior malleolar fractures (Fig. 6.137)
- Radiographic measurements helpful, but wide range of normal—comparison contralateral ankle radiographs may identify subtle instability of deltoid or syndesmosis.
    - Medial clear space less than 4 mm
    - Talocrural angle 83 (±4) degrees
    - Talar tilt less than 2 mm
- Measurements for syndesmotic issues are made at 10 mm above the plafond
    - Tibiofibular clear space less than 6 mm on AP and mortise views.
        - Abnormality of this is most predictive of syndesmotic disruption.
    - Tibiofibular overlap more than 6 mm on AP view and more than 1 mm on mortise view.
        - Tibiofibular overlap less than 10 mm or 42% the width of fibula.
    - Continuous curve along lateral talus and tip of distal fibula (Shenton line or dime sign)
    - Ankle fracture spur sign (at the inferomedial tibial metaphysis) is indicative of a hyperflexion variant injury; after reduction of injury, CT scan should be obtained to evaluate articular surface more clearly.

- **Classification**
    - Lauge-Hansen classification
        - Describes position of foot (first word) and injury motion of the foot relative to the leg. Higher stages include injuries additional to those of stage I.
        - Supination-adduction (vertical medial malleolar fracture with low transverse fibular fracture) (Fig. 6.138)
            - Stage I—transverse distal fibula fracture at or below level of ATFL or lateral ligament injury
            - Stage II—oblique or vertical fracture of medial malleolus
                - Medial tibial plafond impaction occurs in up to 50% of cases and

must be addressed.

- Supination–external rotation (SER; oblique distal fibula at level of syndesmosis with or without transverse medial malleolar fracture) (Fig. 6.139)
    - Most common fracture pattern
    - Stage I—rupture of anterior inferior tibiofibular ligament (AITFL)
    - Stage II—oblique or spiral fracture of distal fibula
    - Stage III—rupture of posterior inferior tibiofibular ligament (PITFL) or avulsion fracture of posterior malleolus
    - Stage IV—transverse or oblique fracture of medial malleolus or deltoid disruption
    - Stress test typically performed to determine whether fracture pattern is stable (SER-II) or unstable (SER-IV)
- Pronation-abduction (PAB; comminuted fibular fracture above the level of the syndesmosis, obvious disruption of the syndesmosis, with or without medial malleolar fracture) (Fig. 6.140)
    - Stage I—rupture of deltoid ligament or transverse fracture of medial malleolus
    - Stage II—rupture of the AITFL or avulsion of anterolateral tibia
    - Stage III—oblique or spiral fracture of fibula above level of syndesmosis
    - Stage IV—rupture of PITFL or avulsion fracture of posterior malleolus
- Pronation–external rotation (PER; oblique fracture of the fibula above the level of syndesmosis, with slight widening of the syndesmosis, with or without medial malleolar fracture) (Fig. 6.141)
    - Stage I—medial malleolus fracture
    - Stage II—anterior lip of tibial plafond fracture
    - Stage III—fracture of fibula above level of malleolus
    - Stage IV—rupture of PITFL or avulsion fracture of posterior malleolus

□ Danis-Weber/Orthopaedic Trauma Association (OTA) classification

FIG. 6.136 Gravity stress ankle radiograph showing medial clear space increase and fibular fracture displacement. Medial clear space widening with stress indicates deep deltoid disruption and implies an unstable fracture pattern.

- Based on location of fibula fracture (in relation to the syndesmosis)
  - 44-A—infrasyndesmotic
  - Stable, rarely requires operative intervention
  - 44-B—transsyndesmotic
    - Variably unstable; must be tested with external rotation or gravity stress radiographs.
  - 44-C—suprasyndesmotic

- Inherently unstable; requires operative intervention

- **Posterior malleolar fractures/posterior pilon**
  - Significant emphasis has been placed on the role of the posterior malleolus in ankle fracture.
    - Greater than 2 mm of displacement of the articular surface is associated with worse functional outcomes 1 year after injury.
      - Regardless of size of the posterior malleolar fragment
    - Stabilization of the posterior malleolus restores 70% of the stability of the syndesmosis.
    - Associated with spiral fractures of distal third of the tibia
    - Indications for ORIF are controversial because the historical criteria based on size may not be sufficient.
      - Displacement of the fracture more than 2 mm or size more than 25% of the articular surface is ideally treated with ORIF.
    - Posterior pilon
      - Newly described fracture pattern with comminution of posterior malleolus
      - Indicative of more severe articular injury but commonly has rotational mechanism of injury
      - Includes fracture of distal fibula and avulsion fracture of PITFL as well as variable patterns of posteromedial plafond and medial malleolus fractures (Fig. 6.142)
      - Inherently unstable owing to syndesmosis instability
      - Most commonly addressed with posterolateral approach with or without a posteromedial approach with direct fixation of posterior malleolar fractures and articular impaction

FIG. 6.137 Fractures with a posterior malleolar component or fracture/dislocations are best evaluated with a CT scan to assess for the presence and displacement of articular fragments. The severity of this fracture on plain radiographs (A) can be underestimated in comparison with appearance on the CT scans (B). Often, after review of the CT scans for these types of fractures, the operative approach is altered.

FIG. 6.138 Supination adduction injury with a vertical fracture line through the medial malleolus. Use of an antiglide plate is critical in this injury to prevent malunion.

FIG. 6.139 Oblique fibula fracture at level of syndesmosis seen on mortise radiograph, consistent with a supination–external rotation fracture pattern.

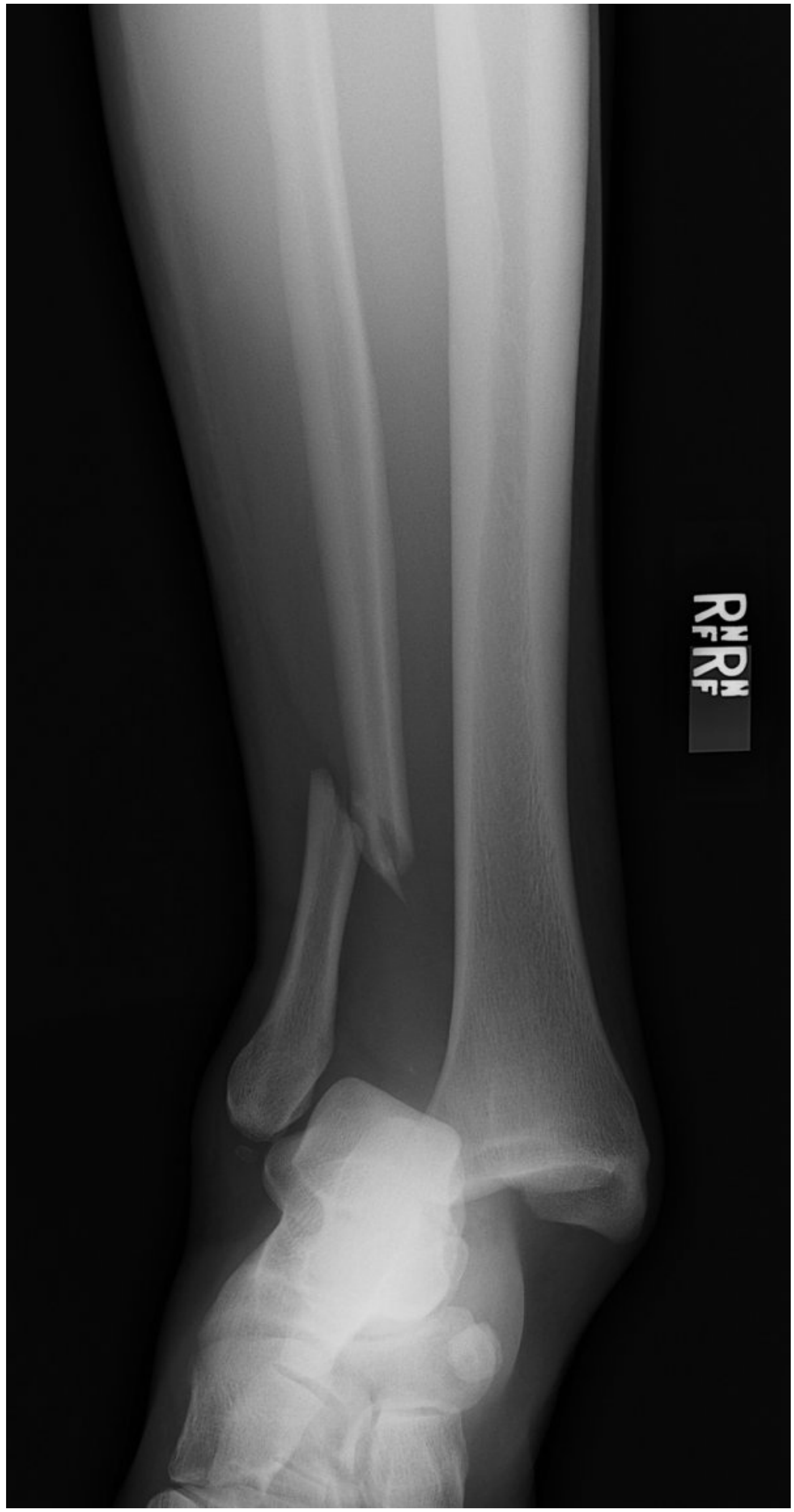


FIG. 6.140 Transverse fibular fracture with obvious disruption of the syndesmosis and nearly complete subluxation of the talus. This injury pattern (or a comminuted fibula) is consistent with a pronation-abduction injury that consists of a large lateral translator force to the foot.

- □ Bosworth fracture-dislocation
  - Distal fibula entrapped behind incisura of distal tibia
  - Irreducible with closed methods, because interosseous membrane is intact

- **Treatment**
  - Stable reduction of ankle mortise must be obtained.
  - **One millimeter of lateral talar shift is associated with a 42% decrease in tibiotalar contact area.**
  - Syndesmosis instability must be addressed after fixation of fractures.
  - **Braking response time for vehicle driving returns (on average) 9 weeks after operative fixation of ankle fractures.**
  - Nonoperative treatment
    - Indications
      - Systemic conditions precluding anesthesia, poor protoplasm for healing (severe diabetes, vascular disease), limited baseline weight-bearing activity
      - Isolated stable distal fibula fractures without deltoid insufficiency (Danis-Weber A or B)
      - Isolated avulsion fractures of tip of medial malleolus
      - Nondisplaced bimalleolar fractures in selected high-risk patients
    - Weight-bearing CAM boot for 6 weeks
    - Frequent radiographic follow-up indicated.
  - Operative treatment
    - Indications
      - Displaced bimalleolar or trimalleolar fractures
      - Displaced distal fibula fractures with deltoid insufficiency (so-called bimalleolar equivalent fractures)
      - Displaced isolated medial malleolus fractures

FIG. 6.141 Suprasyndesmotic oblique fibula fracture with associated lateral talar translation that is consistent with a pronation–external rotation (PER) fracture pattern. Ankle dislocation is less common in a PER injury than in a pronation-abduction (PAB) pattern.

- Fracture patterns with syndesmosis disruption
- Posterior malleolar fractures with greater than 25% articular involvement or more than 2 mm step-off (controversial)
- Bosworth fracture-dislocations
- Open fractures

- Techniques for ORIF
  - Fibula
    - AP lag screw with lateral neutralization plate—spiral or oblique fracture patterns (Fig. 6.143)
    - Posterolateral antiglide plate—biomechanically superior to lateral plate, increased risk of peroneal irritation
    - Anatomic locking plate—helpful for very distal fractures, osteoporotic bone, or comminution
      - This type of plate is not

routinely required.

- Medial malleolus
  - Partially threaded 4-mm screws most commonly used
    - Bicortical 3.5-mm screws demonstrated better biomechanical strength than unicortical 4.0-mm partially threaded cancellous screws. No proven clinical superiority has been demonstrated.
  - Medial buttress plate/screws parallel to joint—vertical fracture patterns (supination-adduction)
- Posterior malleolus (Fig. 6.144)
  - Use of AP lag screws has been described; best indicated for nondisplaced fractures.
  - Posterior buttress plate—displaced fractures, posterior pilon fractures

- Syndesmosis (Fig. 6.145)
  - Anatomic reduction of syndesmosis is critical. May be directly visualized with dissection over anterior tibiofibular ligaments.

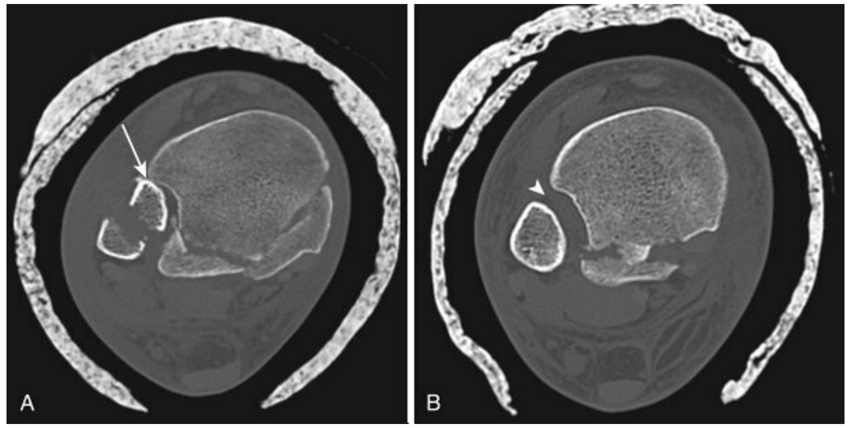


FIG. 6.142 (A) Axial CT scan of a patient with a posteromedial and posterolateral fragment with preserved integrity of the AITFL, as signified by lack of diastasis *(arrow)*. In this case, with fixation of the posterolateral fragment, the stability of the syndesmosis should be restored. (B) The obvious widening of the anterior aspect of the syndesmosis *(arrowhead)* is consistent with injury to the AITFL that will not be restored with reduction of the posterolateral fragment. In this case, supplemental fixation of the syndesmosis is required in addition to reduction and fixation of the posterior malleolus. Also, given the interposed fragment between the posterolateral fragment and tibia, an indirect reduction of that piece is impossible.

- Malreduction of the syndesmosis is the most common complication after syndesmotic fixation.
- Although many studies report 0%–16% risk of malreduction, it may be as high as 52%.
- When a clamp is used, it should be externally rotated 15 degrees relative to the foot in line with the axis of the syndesmosis.
- Dorsiflexion of the ankle is not critical during reduction.
- The fibula is most unstable in the sagittal plane, and therefore a sagittal as well as coronal stress test should be performed.
- Obtaining a true lateral view of the contralateral, unaffected limb allows comparison to verify fibular reduction of the affected limb.
    - This technique has been compared to intraoperative CT scan and has demonstrated high reproducibility in ensuring accurate syndesmotic reduction.
- Controversies regarding fixation techniques
    - One versus two screws

- Three versus four cortices
- 3.5-mm versus 4.5-mm screws
- Screws versus suture devices
    - Newer literature has shown higher radiographic reduction rates and better functional outcomes for the use of suture button devices than of screws.
- Maisonneuve injuries without fixation of the fibula should be treated with at least one screw in order to ensure length stability.
- Hardware removal versus retention of screws
    - If screws are to be removed, they should be in position for at least 12 to 16 weeks.
    - **No proven benefit to screw removal; retained screw and broken screws have not been proven detrimental to function.**
        - Radiographic improvement in tibiofibular alignment has been demonstrated after syndesmotic screw removal, however.

FIG. 6.143 ORIF of fibula performed with lag screws and a lateral neutralization plate. Either 2.7-mm or 3.5-mm screws may be used.

- Complications
  - Malunion
    - Associated with insufficient fibular length (short fibula), medial clear space widening, and malreduction of the syndesmosis
    - Treatment
      - Fibular osteotomy to restore length, medial gutter débridement, and

reconstruction of the syndesmosis

- Wound complications—5%
- Deep infection—1% to 2% (up to 20% in diabetic patients)

FIG. 6.144 Anteroposterior and lateral views of a patient with a "posterior pilon" fracture. (A) On the preoperative x-rays, a positive double-contour sign can be appreciated, indicating involvement of the whole posterior tibial metaphysis. (B) This is confirmed on axial CT scans, on which additional posteromedial comminution can be seen

(white arrow), with syndesmotic gapping *(white arrowhead)* excluded. (C) Postoperative x-rays demonstrate double plating of the posterior malleolar fragment.

- Posttraumatic arthritis
  - Associated with malreduction or persistent mortise instability
  - Increased risk with higher-stage fracture patterns or involvement of tibial plafond (trimalleolar fractures worse than bimalleolar fractures)

□ Special circumstances

- Diabetic patient
  - Non–weight-bearing period must be double that in nondiabetic patients.
    - 3 months
  - Additional points of fixation (i.e., a syndesmotic ladder) or external fixation to augment stability and prevent construct failure must be considered
  - High rate of complications with both nonoperative and operative treatment
  - Biggest risk factor for complications is presence of neuropathy.
  - Skin complications, loss of reduction, and nonunion noted with cast treatment
  - Wound complications, deep infection, loss of reduction, and hardware failure noted with operative treatment
  - Failure of fixation construct may necessitate arthrodesis
  - Up to 30% amputation rate
- Open fractures
  - Emergent irrigation and débridement indicated
  - Immediate ORIF if contamination is limited
  - **Chronic infection scenarios require débridement, antibiotics, and staged arthrodesis.**

Pilon (Tibial Plafond) Fractures

- **Frequently comminuted intraarticular fractures of distal tibial plafond**
- **High-energy mechanism of injury, often associated with fall from a height or motor vehicle collision (axial load)**
- **Most common in fourth decade of life, more common in men**
- **Poor outcomes more common in patients with lower income or education levels**

or preexisting medical comorbidities, in males, and injuries associated with workers' compensation claims

- **Continued clinical improvement may be noted for up to 2 years**
- **Diagnosis**
    - Significant swelling, fracture blisters, and open injuries may be present.
- **Radiographic evaluation**
    - AP, mortise, and lateral x-rays of the ankle typically sufficient to evaluate fracture; tibia-fibula and foot x-rays may be required with concern for more extensive injury.
    - CT valuable to determine extent of intraarticular involvement and fracture planes for preoperative planning
        - Obtained after reduction of fracture; fragments frequently shift position after manipulation (Fig. 6.146).
    - Three common fragments identified; are due to ligamentous attachments
        - Medial—deltoid ligament
        - Volkmann—posterior tibiofibular ligament
        - Chaput—anterior tibiofibular ligament
- **Classification—common classifications include Ruedi-Allgower and AO/OTA and describe degree of comminution but are generally not helpful in determining operative plan.**
- **Nonoperative treatment**
    - Indicated for patients unable to tolerate anesthesia or with severe soft tissue or vascular compromise
    - Stable fracture patterns without articular displacement may be amenable to nonoperative treatment.
- **Operative treatment**
    - Limited internal fixation with external fixation is not the most effective treatment method for these injuries. If external fixation is performed, thin wire frames are ideal because they can be used to stabilize the articular surface and provide rigid fixation.
    - Primary temporary external fixation with delayed ORIF is the most commonly used method. Fixation of the fibula is not required at the index operation.
        - Immediate ORIF is associated with an unacceptable rate of wound complications and therefore is not advocated.

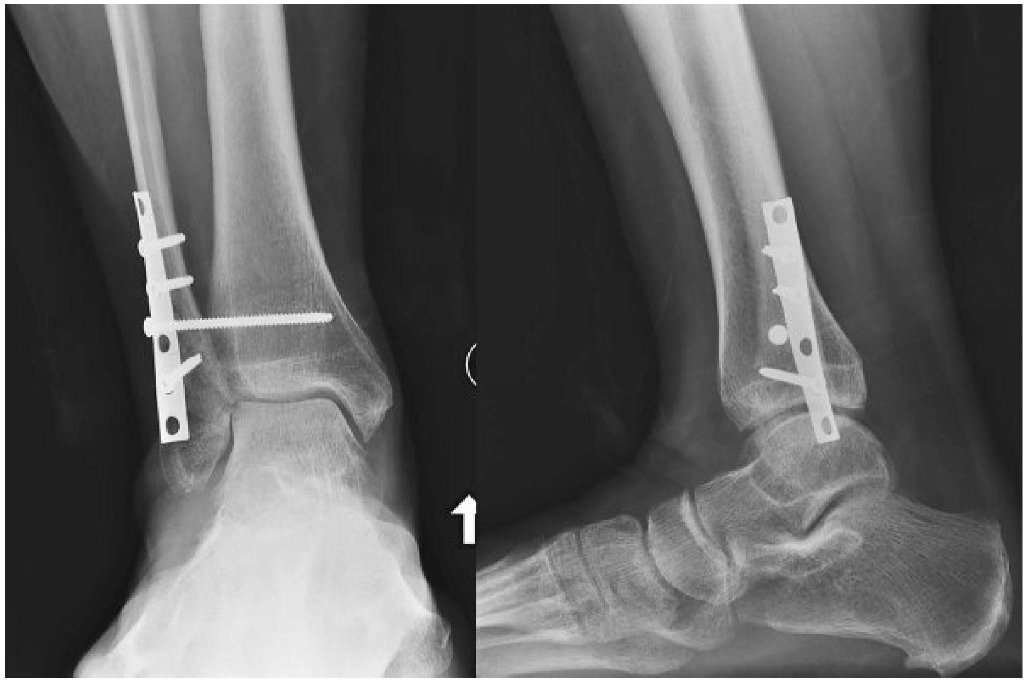
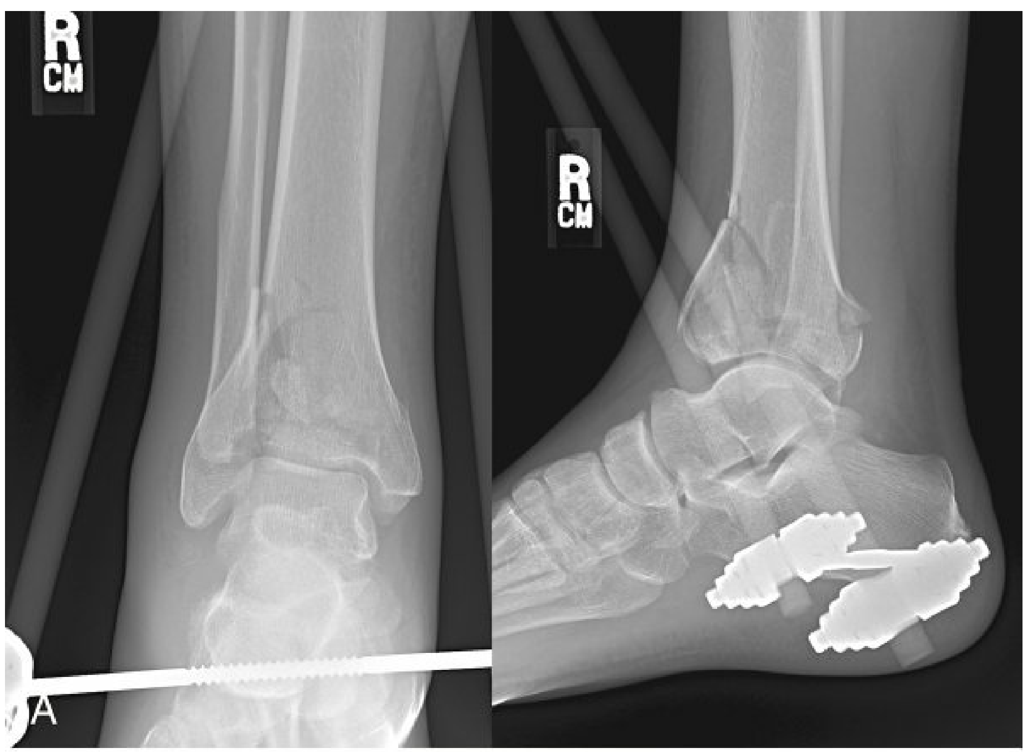
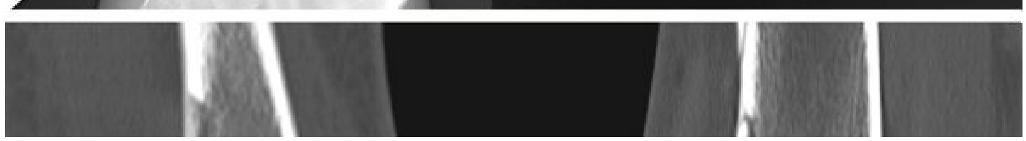


FIG. 6.145 Single 3.5-mm tricortical screw for stabilization of the syndesmosis following ORIF of the fibula.





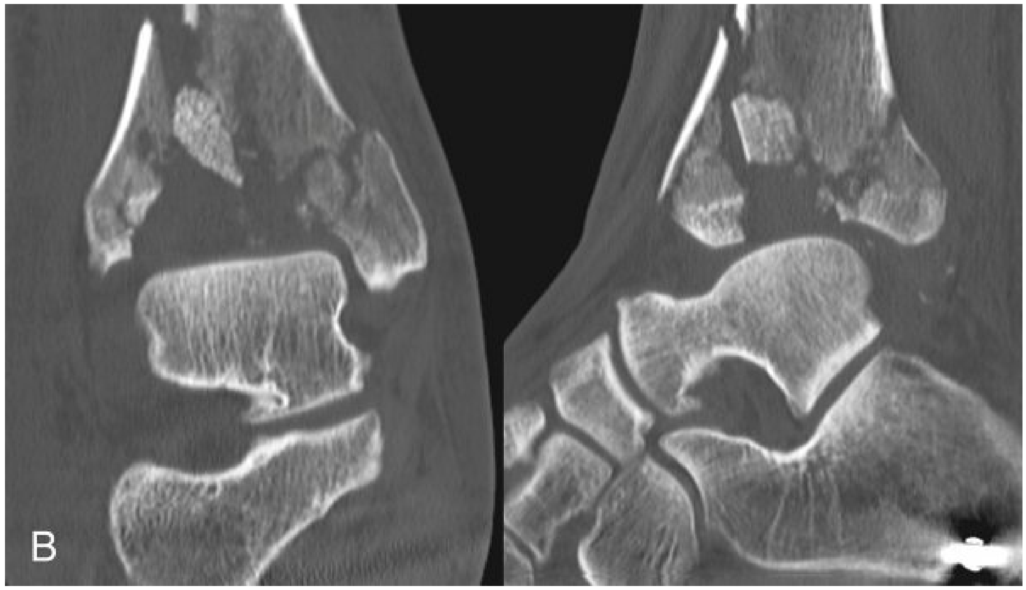
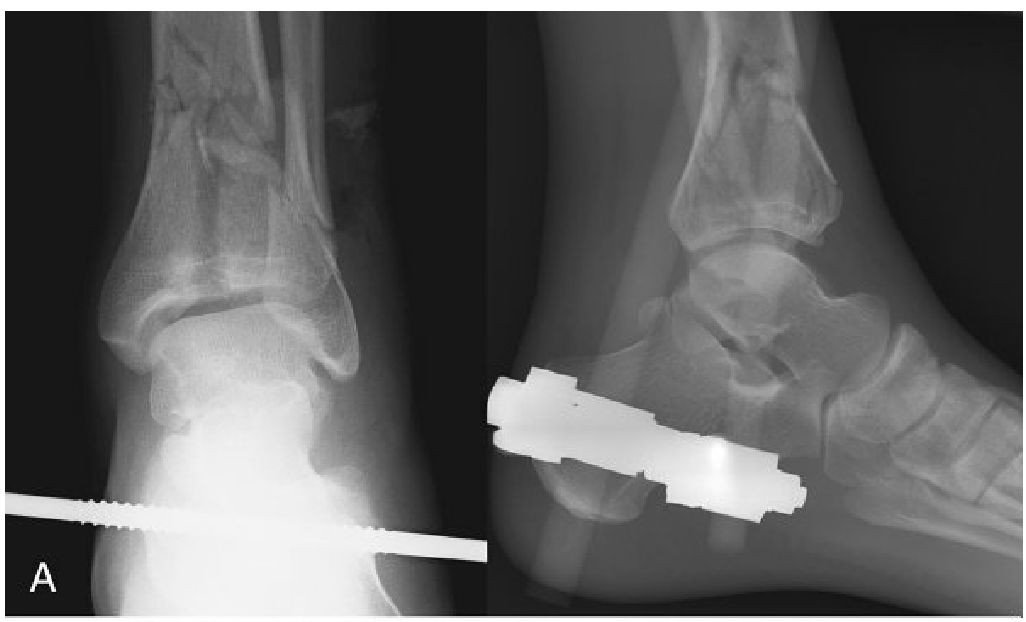
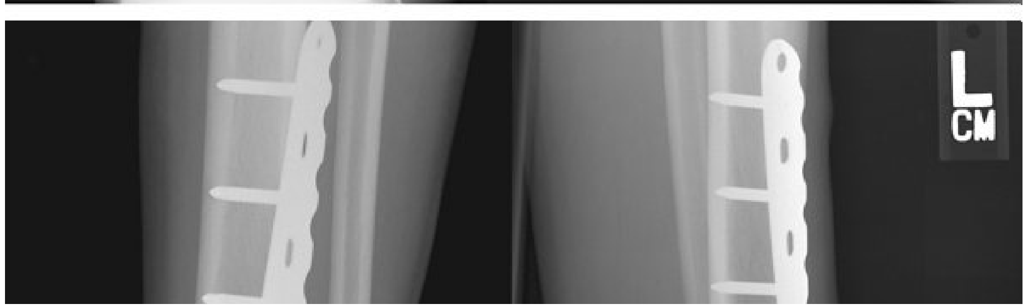


FIG. 6.146 (A) Given the severity of the injury, obtaining radiographs after placement of an external fixator is valuable in better understanding the fracture pattern in a tibial plafond fracture. (B) A CT scan is critical and should be performed only after placement of external fixator, so as to evaluate the position of the intraarticular fragments that require reduction.





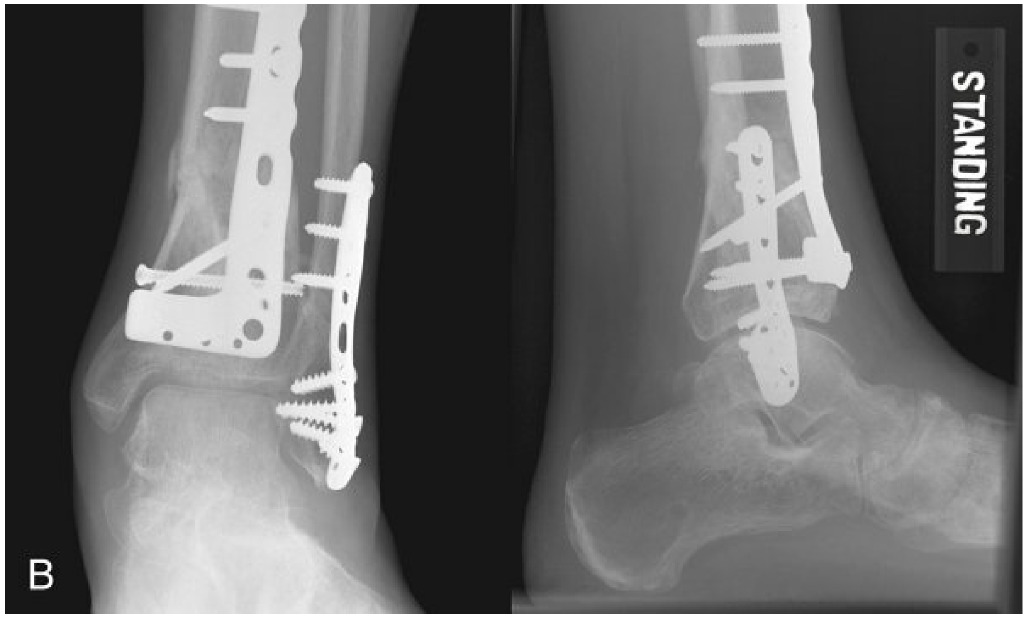


FIG. 6.147 (A) Preoperative radiographs of a pilon fracture that underwent initial spanning external fixation without ORIF of the fibula. (B) Final fixation is shown 1 year postoperatively with ORIF of the tibia and fibula and restoration of the articular surface.

- ORIF of tibia and fibula is delayed until soft tissue swelling resolves and any hemorrhagic blisters have epithelialized.
- Principles of ORIF (Fig. 6.147)
  - Anatomic reduction and absolute rigid fixation of articular surface
  - Preservation of tibial length
  - Reconstruction of metaphyseal shell
  - Bone grafting of metaphyseal defects
  - Reattachment of metaphysis to diaphysis
  - Bridge plating technique is appropriate, without requirement to achieve anatomic reduction. Restoration of length, alignment, and rotation is critical.

□ Complications
- Wound dehiscence reported in 9%–30%—decreased risk if soft tissue swelling allowed to resolve prior to tibial fixation.
- Infection—5%–15%
- Malunion or nonunion—increased risk with hybrid fixation, nicotine use, diabetes, poor bone quality
  - Nonunion most common at metadiaphyseal junction
- Posttraumatic arthritis—may appear as early as 1 to 2 years following injury

□ Although primary arthrodesis has been described, ORIF is the most commonly performed method at this time.

□ **Normal return of braking response time for vehicle driving**

- 6 weeks after initiation of weight bearing

Testable Concepts

SECTION 1 Biomechanics of the Foot and Ankle

- Hindfoot consists of talus, calcaneus, and cuboid; subtalar, calcaneocuboid (CC), and talonavicular (TN) joints are included. Hindfoot functions primarily in inversion and eversion.
- There are three parts to the Lisfranc ligament—dorsal, plantar, and interosseous; interosseous is strongest.
- In hammer toes/crossover toes, the plantar plate is disrupted. It is the most important static stabilizer of the lesser metatarsophalangeal (MP) toe joint.
- Intrinsic tendons pass plantar to MTP joint axis proximally (providing a flexion force) and pass dorsal to the axis distally (providing an extension force). Plantar migration of this metatarsal head after a Weil (oblique shortening) osteotomy leads to a relatively dorsal position of the intrinsic tendons. The tendons now lie dorsal to the axis of rotation, leading to a "floating" toe.
- One full gait cycle from heel strike to heel strike is termed a *stride*. Each stride is composed of a stance phase (heel strike to toe-off; 62% of cycle) and a swing phase (toe-off to heel strike; 38% of cycle)
- There are multiple soft-tissue contributions to gait mechanics. During swing phase, the anterior tibialis contracts concentrically; loss of function results in a footdrop and steppage gait.
- At heel strike, the anterior tibialis contracts eccentrically. This motion controls the rate at which the foot strikes the ground. In patients with footdrop, the rapid strike of the foot can result in a loud "slap" during heel strike. The hindfoot is locked/inverted at initial strike; it will passively evert during transition from heel strike to foot flat. This eversion facilitates energy absorption. Failure of hindfoot eversion in patients with cavovarus deformity increases forces to the lateral foot, resulting in stress fractures (fifth metatarsal), callus formation, and ankle instability.
- During foot flat, the gastrocnemius-soleus complex contracts eccentrically. The contraction helps to control forward progression of body over the foot. Loss of function results in a calcaneus gait with heel pain. During foot flat, the hindfoot is unlocked/everted for ground accommodation. At terminal stance, the FDL tendon is most active.
- During toe-off, the gastrocnemius-soleus complex contracts concentrically. Additionally, as foot progresses from heel strike to toe-off, the foot undergoes changes allowing it to convert from a flexible shock absorber to a rigid propellant. The plantar fascia, which attaches to plantar medial heel and runs the length of the arch to the bases of each proximal phalanx, is tightened as MTP joints extend. The longitudinal arch is accentuated; this is known as the windlass mechanism. The hindfoot supinates, with firing of the PTT. The transverse tarsal

joint locks and provides a rigid lever arm for toe-off. Creation of the rigid lever is limited if the PTT is dysfunctional.

- There are multiple etiologies of flatfoot, and it is important to tease out where the apex of deformity is. It typically is midfoot or hindfoot driven.

SECTION 2 Physical Examination of the Foot and Ankle

- Inability to sense a Semmes-Weinstein 5.07 monofilament (10 g) is consistent with neuropathy.
- Deep peroneal nerve (anterior tarsal tunnel syndrome) at the anterior ankle and hindfoot; may be compressed at inferior extensor retinaculum.
- Stability of the lateral ankle ligaments can be assessed with the anterior drawer and varus talar tilt tests; inversion of the ankle in dorsiflexion evaluates the CFL. The anterior drawer test is used to check the competence of the ATFL; inversion of the ankle in plantar flexion may also evaluate the ATFL.
- In determining whether source of contracture is Achilles tendon, gastrocnemius-soleus complex, or ankle soft tissue, a lack of tension on the Achilles with attempted Silfverskiöld test makes the posterior capsule the likely source.

SECTION 4 Adult Hallux Valgus

- In assessing radiographs for hallux valgus, one needs to evaluate the hallux valgus angle (HVA; nml <15 degrees), the intermetatarsal angle (IMA; nml <9 degrees), the distal metatarsal articular angle (DMAA; nml <10 degrees) and the hallux valgus interphalangeus angle (HVI; nml <10 degrees; associated with congruent deformity). One should also evaluate the congruency of the joint, to gauge soft tissue contracture versus elevated DMAA. The position of the sesamoids, which are often lateral (relative to the adducted metatarsal), should be checked.
- In treatment of hallux valgus, soft tissue releases in isolation, medial eminence resection, and isolated osteotomy without soft tissue correction are associated with high rates of recurrence.
- With an IMA of 13 degrees or less and/or HVA of 40 degrees or less, distal osteotomy (i.e., chevron) should be considered. With an IMA of 13 degrees or higher and/or HVA of more than 40 degrees, proximal metatarsal osteotomy should be considered. In the setting of hyperlaxity or instability of the first TMT, arthrodesis of the first TMT should be considered. Soft tissue release should be done in all scenarios.
- Hallux valgus recurrence can follow any procedure but is highly associated with undercorrection of the IMA, isolated soft tissue correction, isolated resection of the medial eminence, and persistent lateral subluxation of the sesamoids.

SECTION 5 JUVENILE AND ADOLESCENT HALLUX VARGUS

- In treatment of juvenile/adolescent hallux valgus, recurrence is most common postoperative complication.
- If the IMA is greater than 13 degrees with an elevated DMAA, a proximal osteotomy (or open-wedge medial cuneiform osteotomy) must be completed in conjunction with a medial closed-wedge osteotomy distally (biplanar chevron) to tilt the joint back into position.

SECTION 6 Hallux Varus

- Hallux varus can occur from fibular sesamoidectomy, overcorrection of the IMA, overresection of the medial eminence, or excessive lateral soft tissue release.
- Operative management of hallux varus depends in part on flexibility of the deformity; with flexible deformities, a medial capsulotomy and abductor hallcis tenotomy need to be completed in conjunction with an extensor (EHL or EHB) tendon transfer. The tendon transfer may be augmented with suture button techniques.

SECTION 7 Lesser-Toe Deformities

- FDL contracture is the dynamic component contributing to development of a hammer-toe deformity. Treatment of claw toes or hammer toes depends on flexibility. Flexible deformities can be treated with flexor to extensor transfer or an FDL tenotomy; this may be done in conjunction with a PIP arthroplasty. Fixed deformities should be treated with PIP arthrodesis.
- Flexor-to-extensor tendon transfer can lead to stiffness of the lesser toe MTP joint.
- Crossover toe (second toe) deformity develops from disruption of the plantar plate (key component) and attenuation of the lateral collateral ligament.
- For hammer-toe/claw-toe deformities, if there is skin breakdown at the PIP dorsally, surgical débridement (with obtaining of specimen cultures) and delay of definitive treatment must be considered.
- Anterior drawer test of the lesser hallux MTP joint is the most sensitive physical examination test to evaluate for plantar plate injury.
- For plantar plate injury, nonoperative management with toe taping and metatarsal pads/lesser toe orthotics should be considered.
- In high-level athletes, repair of the plantar plate tear has been advocated.
- In Freiberg disease/infarction, a dorsal closed-wedge osteotomy of the metatarsal head has been shown to have good results; this brings the often preserved plantar cartilage surface dorsally to articulate with the proximal phalanx.

SECTION 8 Hyperkeratotic Pathologies

- Bunionette deformity can cause shoewear issues and is commonly see in conjunction with ipsilateral hallux valgus (splayfoot).
- Type I is bony exostosis, type II is lateral curve to the distal metatarsal shaft/metatarsal head, and type III is a widened fourth–fifth IMA (nml 7–8 degrees or less).
- Surgical management is based on the type: for type I, lateral exostectomy; for type II, fifth MT head osteotomy; for type III, diaphyseal osteotomy (poor blood supply proximally); for recurrence or salvage, fifth MT head resection.

SECTION 9 Sesamoids

- When there is concern for sesamoid injuries (i.e., turf toe), radiographs of the contralateral side should be obtained to compare position of sesamoids relative to the base of the proximal phalanx. The tibial sesamoid should be 10.4 mm from the base, and the fibular sesamoid should be 13.4 mm from the base; both measurements should be within 3 mm of those of the contralateral extremity.
- Turf toe often develops from forced dorsiflexion of the foot in equinus, along with an axial load. Another less common mechanism is a hyper–plantar flexion of the hallux MTP, with valgus force. This can be seen in beach volleyball players.
- Turf toe comes in three grades (grade 1: capsular strain; grade 2: partial capsular tear; grade 3: complete plantar plate tear). Better results have been demonstrated with operative repair of the plantar plate than with conservative care. Traumatic hallux valgus that involves the medial capsule and medial sesamoid with acute deformity of the hallux is best treated with immediate surgical repair as opposed to late reconstrution.
- For persistent sesamoid issues refractory to nonoperative measures, sesamoidectomy has the most predictable results. If the fracture pattern allows, resection of nonunited segment (proximal or distal pole) can be performed. Complications of tibial or fibular sesamoidectomy include hallux valgus or hallux varus, respectively. Resection of both sesamoids leads to a cock-up toe.

SECTION 11 Neurologic Disorders

- Interdigital neuromas have a higher predilection in female patients; this is likely related to shoewear with forced plantar flexion of the metatarsal heads. Symptoms can be alleviated with metatarsal pads placed proximal to the focus of pain, to prevent pressure and widen the intermetatarsal space during weight bearing.
- Neuromas often demonstrate perineural fibrosis.
- Lateral plantar nerve may be injured during surgical approaches that require a

plantar incision, such as a tibiotalocalcaneal (TTC) arthrodesis with an intramedullary nail. However, if no evidence of paresthesias and persistent hindfoot pain, evaluation for nonunion of the ankle or subtalar joints is needed.

- Patients with anterior tarsal tunnel syndrome present with burning pain and paresthesias along the medial second toe, lateral hallux, and first web space, or even vague dorsal foot pain.
- The superficial peroneal nerve can also be damaged or entrapped in scar tissue at the anterolateral portal following ankle arthroscopic procedures.
- Popliteal nerve blocks do not typically include the saphenous nerve.
- Charcot-Marie-Tooth disease is a hereditary sensory motor neuropathy. Type I is most common and is usually autosomal dominant. The basis of CMT is an abnormality of the PMP22 (peripheral myelin sheath protein) as a result of duplication of chromosome 17. There is a genetic anticipation component; the earlier the age of onset, the more severe the findings.
- Deformity and awkward gait are common initial complaints, with weakness, lateral ankle instability, and lateral foot pain presenting later. Often patients may have bilateral pes cavovarus, which results from overpull of the PTT/PL relative to the TA/PB. The PL overpull causes plantar flexion of the first ray. The hindfoot varus develops from the overpull of the PTT. Intrinsic muscles are often affected first because they have the longest axons; this leads to dorsiflexion of the phalanges across all of the toes, and the phalanx drives the metatarsals in plantar flexion. The loss of MTP flexion facilitates development of claw toes.
- Correction of cavovarus deformity depends on flexibility of the deformity and whether the varus is hindfoot or forefoot driven.

SECTION 12 Arthritic Disease

- Gout involves deposition of monosodium urate crystals into synovium-lined joints or into soft tissues. May be caused by trauma, alcohol, purine-rich foods, postoperative state, or certain medications. Great toe MTP joint is most commonly involved (podagra). Definitive diagnosis is based on needle aspiration of the joint; pathognomonic microscopic signs include needle-shaped monosodium urate crystals, which under polarized light are strongly negatively birefringent. Treatment of acute attacks involves use of colchicine (microtubule inhibitor); chronic disease is treated with allopurinol (xanthine oxidase inhibitor, use of which acutely can actually precipitate gout).
- In pseudogout, polarized light microscopy examination of joint aspirate reveals weakly positive birefringent crystals with varied shapes.
- Seronegative spondyloarthropathies are defined as inflammatory arthritides in which the rheumatoid factor is absent. Often have a higher incidence of entheses involvement (where collagen is inserting onto bone); implicated in psoriatic arthritis, Reiter syndrome, inflammatory bowel disease. Are often more

destructive of collagen and fibrocartilage. May manifest as plantar fasciitis/Achilles tendinitis/posterior tibial tendinopathy. Surgical intervention may be required for small joint erosion, refractory Achilles tendon issues, and plantar fasciitis.

- Nonoperative treatment of osteoarthritis of the foot/ankle should include antiinflammatory drugs, orthotics, bracing, and corticosteroid injections. In hallux rigidus, a carbon fiber shank with a extension for the great toe (Morton extension) is often used. Midfoot arthritis can be treated with a stiff-soled or carbon fiber shank–modified shoe with a rocker bottom; hindfoot arthritis with an Arizona brace or an AFO. For ankle arthritis, NSAIDs, AFO/Arizona brace, and a rocker-bottom shoe may be of benefit.
- For hallux rigidus grades I and II (pain at extreme ROM only), operative management often involves dorsal cheilectomy (removal of all osteophytes including portion of dorsal metatarsal head with loss of cartilage).
- Failure of partial or total joint replacement of the hallux (osteolysis/implant loosening) may necessitate implant removal and arthrodesis with structural grafting. The same is true if ostoectomies are completed, leading to implant failure, avsacular necrosis, and subsequent fragmentation of the metatarsal head.
- Ankle arthrodesis malunion may lead to anterior talar translation of the talus. This can elongate the lever arm of the foot and needs a revision arthrodesis of the ankle. If fibula was taken as part of ankle fusion, total ankle replacement is not possible.
- Syndesmotic fusion when the Agility ankle replacement system was previously used was associated with lower rate of failure. Medialization of extramedullary tibial cutting guides can lead to fracture of the medial malleolus.
- Salvage of implant failure is difficult given the amount of bone loss and current lack of available revision components. The most reliable current technique is a bone-block ankle arthrodesis (femoral head) with or without additional subtalar fusion.
- Wound breakdown in the acute period (3 weeks) after TAR requires débridement and polyethylene exchange; if 6 weeks or longer after TAR, removal of implant and placement of antibiotic spacer should be considered.

SECTION 13 Postural Disorders

- Most common cause of adult-acquired flatfoot is posterior tibial tendon dysfunction.
- The spring (calcaneonavicular) ligament is the primary static stabilizer of the TN joint; most commonly the superomedial band (70%).
- Patients may complain of medial ankle foot pain, progressive arch collapse, and lateral hindfoot pain (subfibular impingement). Physical examination may demonstrate asymmetric hindfoot valgus, depressed arch, and an abducted

forefoot. Pain or inability to perform single-limb heel rise indicates insufficient PTT. The patient may have lateral impaction syndrome or subfibular impingement with significant valgus of the heel, such that it abuts the fibula; abutment of the lateral process of the talus and the calcaneus can occur as well.

- Operative management of PTTD is reserved for patients for whom 6 months or more of conservative measures have failed. Lateral column lengthening addresses hindfoot valgus and improves the longitudinal arch of the foot/medial column of the foot. Cotton osteotomy (dorsal open-wedge osteotomy of the cuneiform) is used to plantar flex the first ray, to correct forefoot varus.
- If subtalar arthrodesis (alone or as part of triple) has been malunited in valgus, with tenderness in the lateral subfibular region, arthrodesis takedown and revision arthrodesis may be required. Severely abducted deformities may need an all medial approach, to limit the risk of wound healing issues with the sinus tarsi approach. Some authors argue that the calcaneocuboid joint is challenging to see, but cadaveric studies have demonstrated the ability to see more than 90% of each joint from the medial approach alone.
- Patients with pes cavus may complain of painful calluses under the first metatarsal, fifth metatarsal, and medial heel. There may be pain along the peroneal tendons as well.
- On an adequate weight-bearing, lateral foot radiograph, visibility of the middle facet of the subtalar joint indicates hindfoot varus. Often associated with lateral ankle ligament instability, peroneal tendon pathology.
- Nonoperative modalities include orthotics with lateral heel wedge, accomodative arch, and depressed first ray.

SECTION 14 Tendon Disorders

- Peroneal tendons are the most common cause of chronic pain following an ankle sprain or with chronic instability.
- Peroneal tendon subluxation-dislocation is caused by forced eversion and dorsiflexion leading to disruption of superior peroneal retinaculum (SPR). MRI may demonstrate displacement of peroneal tendons anterolateral to the retrofibular region.
- If conservative management (immobilization/physical therapy) has failed, operative management of degenerative tears of the peroneal tendons includes tenosynovectomy, débridement, and repair.
- For anterior tibial tendon ruptures, primary repair generally improves functional results regardless of patient age. Tendon grafting augmentation may be warranted if there is adequate excursion of the myotendinous unit and the muscle is healthy.

SECTION 15 Heel Pain

- In evaluation of plantar fasciitis, weight-bearing x-rays are an important first diagnostic step to evaluate for stress injuries, subtalar arthritis, tumor, and insertional enthesophytes. Advanced imaging (MRI) may demonstrated thickening of the plantar fascia and surrounding inflammation.
- Nonoperative management is the cornerstone of management; this involves cushioned heel inserts, night splints, and Achilles/plantar fascia–specific stretching. Cortisone injections may alleviate symptoms but can lead to fat pad atrophy/plantar fascial rupture; number leading to rupture is 2.67.
- Operative treatment indicated in less than 5% of patients. Gastrocnemius recession has been advocated, and should be considered in isolation in patients with clear evidence of a gastrocnemius contracture without evidence of jogger's foot/Baxter neuritis. Baxter neuritis is entrapment of the first branch of the lateral plantar nerve that often manifests as heel pain akin to that seen in plantar fasciitis. There is pain over the medial aspect of the abductor hallucis. EMG/NCV tests may demonstrate increased motor latency within the abductor digiti quinti. MRI may show fatty infiltration of the abductor digiti quinti. Nonoperative treatment consists of heel cord stretching and cushioned inserts. Operative treatment includes open release of the nerve and fascial release of the abductor hallucis.
- Sever disease is a calcaneal apophysitis seen in young males (10–14 years old) either prior to or during a growth spurt. Treatment includes activity modification, gastrocnemius stretching, and cushioned heel orthotics. No correlation between symptoms and fragmentation of apophysis.
- In management of insertional Achilles tendinosis, evaluation of the Achilles tendon should include a physical examination; bony prominence, tendon thickening, and area of tenderness should be checked. The Silfverskiöld test should be used to evaluate for contracture. Activity and shoewear modification, heel lifts, stretching, physical therapy with heavy load eccentric training, and use of silicone heel sleeves/pads to decrease pain from direct pressure are mainstays of conservative treatment.
- Patients with noninsertional Achilles tendinopathy often present with pain, swelling, and impaired performance, especially with running. There is often a tender area of fusiform thickening localized about 2 to 6 cm proximal to the insertion of the tendon. MRI demonstrates thickening of the tendon, with intrasubstance intermediate signal intensity consistent with the disorganized tissue. In the setting of a chronic rupture, a large gap is present between the hypoechoic (dark) tendon ends. Nonoperative management with heavy load eccentric strengthening has demonstrated the highest success rate.
- Operative management of a chronic Achilles tendon rupture with a gap between the ends (after débridement) greater than 5 cm is with an FHL transfer and possible turndown procedure. If the gap between ends is between 2 and 5 cm, a V-Y reconstruction is possible. If the gap is less than 2 cm, an end-to-end repair is possible.

- Lateral ankle sprains, which often result from plantar flexion/inversion mechanisms, can lead to injury to branches of the superficial peroneal nerve and cause numbness over the dorsal midfoot. If nerve symptoms persist, neurotomy and burial may be needed. Initial management should involve RICE (rest, ice, compression, elevation) protocol with limited weight bearing if there is marked ankle joint–line tenderness or pain with weight-bearing activity.
- In lateral ankle sprain, physical therapy is important for balance and proprioception and peroneal strengthening, and is associated with a decreased rate of reinjury. Functional bracing along with neuromuscular (i.e., proprioceptive) training decreases risk of recurrence of low ankle sprains more than neuromuscular training alone.
- Additional physical therapy should be considered if there is no evidence of peroneal tendon injury on examination or if the patient has not completed an adequate amount of rehabilitation.
- Ankle instability can occur without ligamentous issues (peroneal tendinopathy, osteochondral defects, fracture nonunion, anterior ankle impingement).
- Posterior ankle impingement is common in ballet dancers, gymnasts, soccer players, and downhill runners. Pain is exacerbated and reproducible with maximum plantar flexion of ankle and push-off maneuvers. (An anomalous soleus muscle can cause similar symptoms.) Operative intervention includes arthroscopic or open débridement of posterior inflamed synovium and excision of symptomatic os trigonum/impinging bone.
- Osteochondral defects are commonly treated with arthroscopic management. For lesions smaller than 1.5 cm^2, operative management has an 80%–85% success rate. Débridement of the lesion back to a stable border is important.
- Large lesions need alterative treatment; autologous osteochondral grafting produces hyaline cartilage with minimal degradation over time, chondroplasty/microfracture generate type 1 collagen–based fibrocartilage, and osteochondral allograft contains high volume of viable chondrocytes if transplanted less than 2 weeks from time of harvest (high rates of collapse/resoprtion reported; 60% of patients have joint space narrowing 44 months postoperatively). Autologous chondrocyte implantation (ACI) can lead to hyaline cartilage or fibrocartilage.
- Larger lesions with cystic component may require medial malleolar osteotomy and bone grafting.
- Chronic exertional compartment syndrome manifests in runners/cyclists. It results from pressure buildup in the anterior compartment, most commonly during running. Compartment pressures are measured before, during, and after exercises. Pressures higher than 30 mm Hg 1 minute after exercise, 20 mm Hg 5 minutes after exercise, or absolute values higher than 15 mm Hg during rest can help establish the diagnosis. Fasciotomy is indicated in refractory cases.

- The most common complication after ankle arthroscopy is nerve injury, with the superficial peroneal nerve being most commonly affected.

SECTION 17 The Diabetic Foot

- Glucose assessment is ideally evaluated with HbA1c measurement (indicative of past 3 months of glucose control).
- Loss of protective sensation (inability to perceive the 5.07 Semmes-Weinstein monofilament) is most common cause of plantar foot ulcers; this loss is associated with a 30% risk of development of an ulcer.
- Peripheral vascular disease can lead to falsely elevated ankle brachial indices. It is present in 60%–70% of patients who have had diabetes for more than 10 years. Transcutaneous oxygen ($TcPo_2$) values for the toes greater than 40 mm Hg have been found to be predictive of healing.
- Classifying ulcers can help guide management. Depth grade 0: extra-depth shoe and pressure relief insoles. Grade 1 (no bony involvement, superficial): office débridement and total contact cast (TCC). Grade 2 (deep ulcer with soft tissue exposure): operative débridement to healthy tissue followed by dressing changes/TCC. Grade 3 (extensive ulcer with osteomyelitis or abscess and exposed bone): surgical débridement of bone/soft tissue followed by dressing changes/TCC.
- Ischemia-based classification; grade A (nml vascularity), grade B (ischemia without gangrene), grade C (partial forefoot gangrene), grade D (complete foot gangrene).
- Treatment often requires Achilles lengthening to prevent recurrence of forefoot/midfoot ulceration. Toe deformities often require joint resection or amputation. Plantar hallux IP joint ulcers for which contact casting has failed should be treated with a Keller arthroplasty.
- Presence of infection may be reason why ulcers do not heal with conservative management. Débridement of infected tissue with use of negative-pressure dressings is recommended.
- Charcot arthropathy is common in patients with diabetic neuropathy. Patients complain of swelling, warmth, redness, and deformity. Pain is present in up to 50% of patients. Midfoot is most commonly affected, followed by ankle and then hindfoot. Fragmentation to consolidation may take 6.18 months.
- Initial treatment of Charcot arthropathy is non–weight-bearing status with a total contact cast.
- Unstable/unbraceable deformities should be addressed with a tibiotalocalcaneal arthrodesis to afford a braceable/plantigrade foot while reducing risk of ulceration. Use of an intramedullary rod will afford internal stability and can be left indefinitely, in contrast to a multiplanar external fixator. Even with radiographic evidence of nonunion, many patients can be pain free.

- Infections in the diabetic foot or ankle are either isolated soft tissue infections (cellulitis or abscess) or osteomyelitis. If abscess is suspected, completed needle aspiration or MRI (renal issues may preclude MRI) is needed.
- Osteomyelitis is treated with antibiotics and surgical débridement.
- To avoid deformity of Chopart amputation, anterior tibialis must be transferred to the talus to prevent varus, and Achilles lengthening must be completed to prevent equinus.

SECTION 18 Trauma

- Excessive loading of second metatarsal can lead to stress injury. Risk factors include a long second metatarsal and hallux rigidus/valgus. Radiographs may demonstrate periosteal reaction or evidence of callus formation near diaphyseal region of affected metatarsal after 3–4 weeks. A normal radiographic appearance prior to this time does not exclude a stress fracture.
- Second metatarsal stress fracture is the most common and is classically described in amenorrheal ballet dancers.
- In female athletes, the triad of anorexia, osteoporosis/stress injuries and menstrual dysfunction must be considered.
- Jones fracture of the base of the fifth metatarsal base is a fracture that extends into the fourth-fifth intermetatarsal articulation. There is a 15%–25% risk of nonunion with nonoperative management. Elite athletes should be treated with intramedullary screw fixation. The minimum screw diameter is typically 4 mm, with later data demonstrating that the mean diameter is 5 mm.
- Diaphyseal stress injuries of the fifth metatarsal should be treated with intramedullary screw fixation.
- The Lisfranc articulation is a stable construct because of its bony architecture and strong ligaments. The base of the second metatarsal fits into a mortise formed by the proximally recessed middle cuneiform (keystone configuration). Lisfranc ligament is critical to stabilizing the second metatarsal and maintaining midfoot arch. It runs between the medial cuneiform and the base of the second metatarsal; the interosseous component is stiffest and strongest, dorsal is the weakest. Plantar ecchymosis should raise suspicion for a TMT/Lisfranc injury.
- AP, lateral, and oblique radiographs should be obtained. Lateral translation of the second metatarsal relative to the middle cuneiform is diagnostic of a Lisfranc injury. The fleck sign (a small, bony avulsion from the base of the second metatarsal seen in the first intermetatarsal space) is diagnostic of a Lisfranc injury.
- Cuboid injuries (nutcracker cuboid) are often sustained from an abduction force and may be associated with Lisfranc injuries.
- If there is tenting of the skin, the injury needs to be reduced urgently to reduce risk of compartment syndrome.

- Anatomic reduction is most predictive of good clinical results.
- Anatomic reduction is mandatory and open reduction is often required as opposed to closed reduction with percutaneous fixation. Historically stabilized with screw fixation across the involved joints.
- Missed diagnosis or improper treatment may lead to traumatic planovalgus deformity or posttraumatic arthritis. Open reduction and midfoot arthrodesis should be considered in this setting.
- Navicular stress fractures often happen in the central third of the navicular and are secondary to repetitive trauma. Cavus foot is a risk factor. Plain radiographs may not be revealing. CT is the gold standard of identification. Fracture line often extends from dorsolateral to plantar medial. Conservative measures for nondisplaced fractures are non–weight-bearing status and a cast for 6–8 weeks. For displaced injuries, operative fixation with screw placement is necessary. Initial operative treatment may be considered in elite athletes, although controversy remains, and the current treatment recommendation is that surgery be considered if nonoperative intervention has failed and not as a primary treatment.
- Talonavicular dislocations need to be reduced closed rather than open; dorsal dislocation can be irreducible secondary to the posterior tibial tendon.
- Lateral process acts as dividing line between talar body and talar neck injuries.
- For treatment of talar neck fractures, medial compression screw may worsen varus deformity if comminution is present. A fully threaded screw or plate should be used medially to avoid this complication.
- The most common complication after a talar neck fracture is subtalar arthritis.
- In the setting of AVN of the talus and arthritis of the ankle, consider ankle arthrodesis because distraction arthroplasty has not been shown to have good results; total ankle replacement is not an option.
- Talar body extrusions need to be evaluated closely. With minimal contamination and any remaining soft tissue attachment, talar body should be copiously irrigated, washed (chlorhexidine), débrided, and reimplanted. In the presence of gross contamination, it may be appropriate to disregard the body and perform a delayed reconstruction. However, all attempts at salvage should be made. Rates of deep infection and overall failure are very high.
- Small or comminuted lateral process fractures can be excised.
- Avulsion fractures of the calcaneal tuberosity are caused by forceful Achilles contraction. Endangers posterior skin with displacement. These injuries necessitate urgent operative reduction and fixation to prevent skin compromise. Percutaneous fixation achieved with lag screws from the posterior superior tuberosity directed inferior and distal.
- With calcaneal fractures one must evaluate for concomitant injuries such as vertebral fractures. The Broden oblique view of the ankle is helpful to evaluate posterior facet displacement. The more internal rotation of leg allows anterior portion of the joint to be seen; less internal rotation of leg allows posterior

portion of the joint to be seen.

- Patients with an overall normal morphology of the hindfoot but intraarticular incongruity may not benefit from operative intervention.
- Clinical outcomes are better with operative than with nonoperative management in patients with the following characteristics: significant intraarticular displacement, flattened Böhler angle, female gender, age younger than 29, and injury not involved in workers' compensation process. Posttraumatic subtalar arthritis is common; may require arthrodesis.
- In cases with significant loss of calcaneal height, horizontal talus, and resultant anterior ankle pain, bone-block distraction arthrodesis of the subtalar joint is required. A posterolateral approach should be considered to avoid the soft tissue healing issues associated with application of bone block through the sinus tarsi approach.
- Diagnosis of ankle fractures is based on plain radiographs. Stress radiographs (gravity/external rotation) are used to identify evidence of deep deltoid injury and an unstable injury pattern. CT can be used for evaluating more complex injury patterns and posterior malleolar fracture.
- Measurements for syndesmotic issues are made at 10 mm above the plafond. The tibiofibular clear space should be less than 6 mm on AP and mortise views (abnormality of this value is most predictive of syndesmotic disruption). The tibiofibular overlap should be more than 6 mm on AP and more than 1 mm on mortise views.
- Ankle fracture spur sign (at inferomedial tibial metaphysis) is indicative of a hyperflexion variant injury; after reduction of injury, CT scan should be obtained to evaluate articular surface more clearly.
- Multiple classifications systems of ankle fractures. Lauge-Hansen and Danis-Weber are commonly used. Lauge-Hansen system describes position of foot/deforming mechanism. Danis-Weber system describes fibular fracture line in relation to the syndesmosis.
- One millimeter of lateral talar shift is associated with a 42% decrease in tibiotalar contact area.
- Braking response time for vehicle driving returns (on average) 9 weeks after operative fixation of ankle fractures.
- Malreduction of the syndesmosis is the most common complication after syndesmotic fixation. Although many studies report 0%–16% risk of malreduction, it may be as high as 52%.
- No proven benefit to syndesmotic screw removal; retained screw and broken screws have not been proven detrimental to function.
- Malunion of ankle fracture is associated with insufficient fibular length (short fibula), medial clear space widening, and malreduction of the syndesmosis. Treatment consists of fibular osteotomy to restore length, medial gutter débridement, and reconstruction of the syndesmosis.
- For ankle fractures in diabetic patients, one needs to consider additional points of

fixation (i.e., a syndesmotic ladder) or external fixation to augment stability and prevent construct failure. Failure of fixation construct may necessitate arthrodesis.

- For open ankle fractures, chronic infection scenarios require débridement, antibiotics, and staged arthrodesis.
- Operative treatment of pilon injuries involves primary external fixation with staged open reduction/internal fixation (ORIF). Fibular fixation is not necessary at the index procedure. ORIF of pilon injuries should involve anatomic reduction/rigid fixation of articular surface with preservation of tibial/fibular length. Metaphyseal defects should be bone grafted, and the metaphysis reattached to the diaphysis. Restoration of length, alignment, and rotation is critical.

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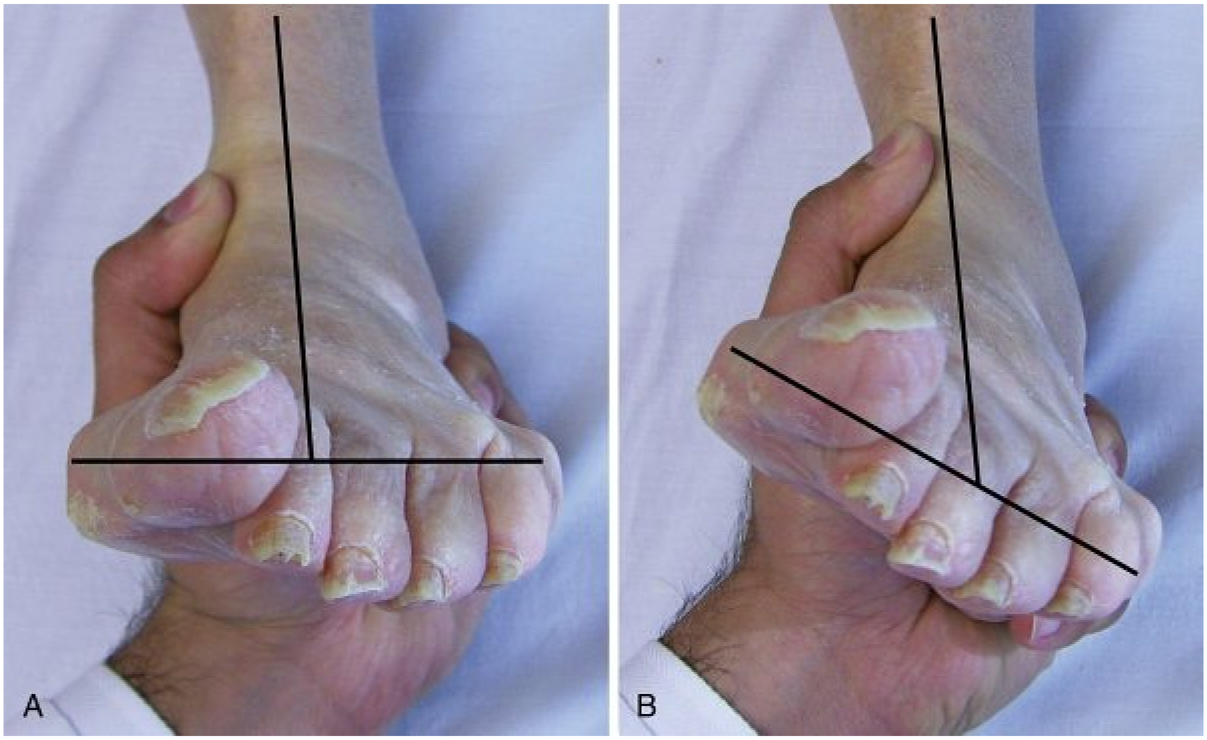


FIG. 6.9 A patient with long-standing pes planovalgus deformity. (A) With the hindfoot in valgus, the foot is plantigrade to the ground. (B) With the hindfoot corrected to neutral, the forefoot supination becomes evident with the elevated first ray. Failure to correct this deformity will cause any surgical correction to fail because the hindfoot will go back into valgus so that the first ray can contact the ground.

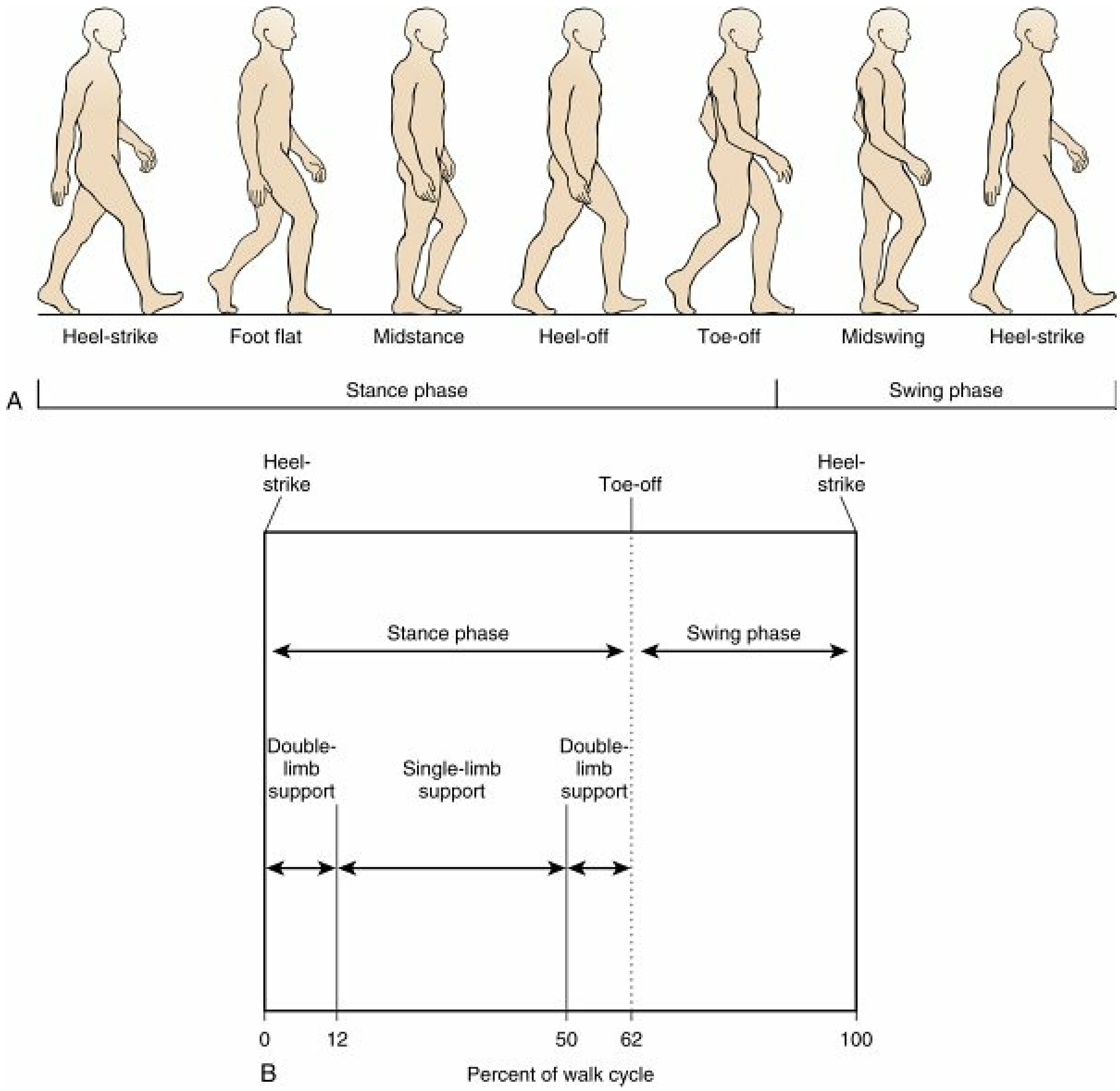


FIG. 6.10 The gait cycle. (A) The normal phases of gait. (B) Time dimensions of normal gait cycle. From Miller MD: *Core knowledge in orthopaedics—sports medicine,* Philadelphia, 2006, Elsevier.

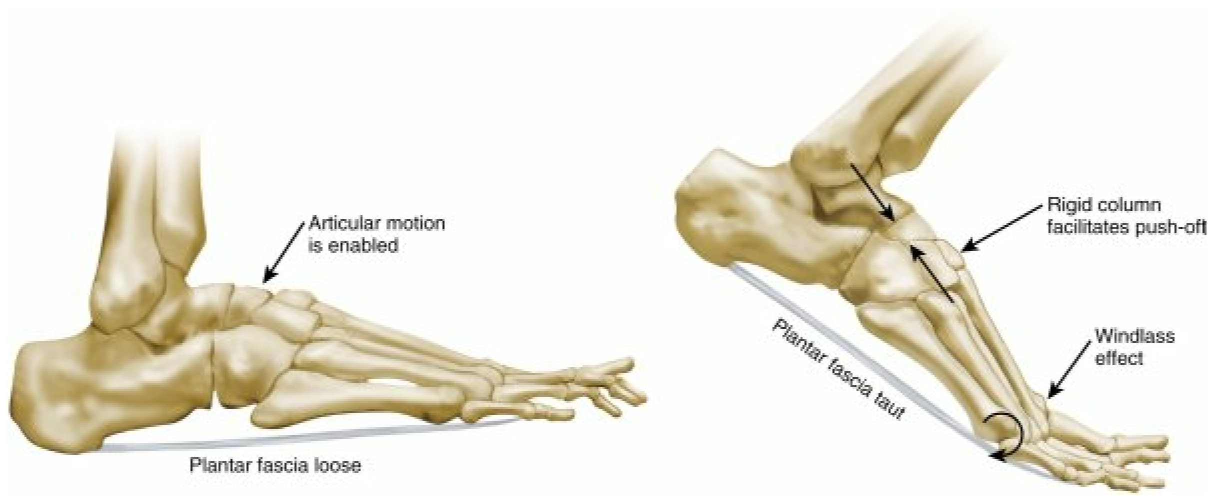


FIG. 6.11 Windlass mechanism and function of the plantar fascia. When the foot is at rest, there is some mobility between the bones of the midfoot, allowing flexibility. During the push-off phase of gait, this flexibility would be detrimental. The plantar fascia, which inserts distal to the metatarsophalangeal joints, tightens as the toes are dorsiflexed, thereby pulling the tarsal bones together and “locking” them into a rigid column. This effect has been likened to a windlass, which is a rope or chain extending over a drum used to raise and lower sails and anchors on a ship.
From Morrison W, Sanders T: *Problem solving in musculoskeletal imaging,* St. Louis, 2008, Mosby.

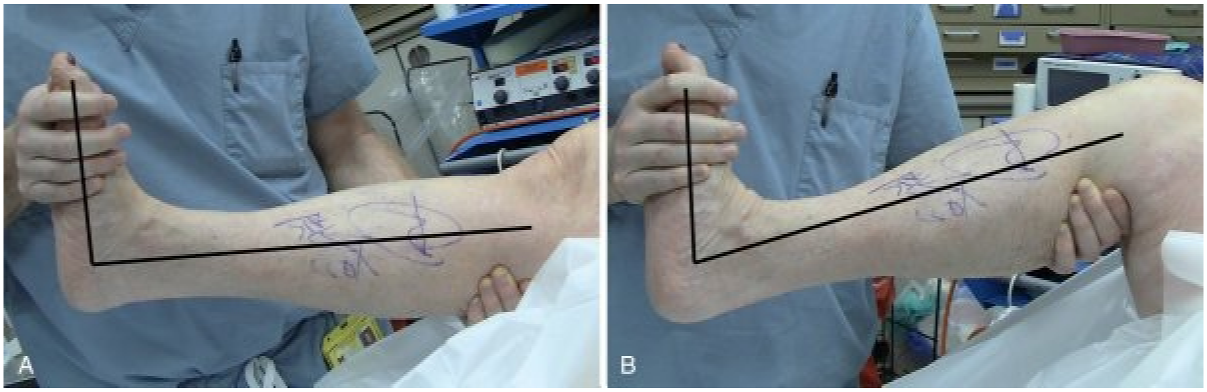


FIG. 6.22 Testing for a gastrocnemius contracture. (A) With the knee extended, equinus of the ankle is noted, with an inability to dorsiflex past neutral. (B) With knee flexion, the soleus muscle is isolated, and in this case an increase of 5 degrees of dorsiflexion is noted. This increase is consistent with an isolated contracture of the gastrocnemius. If no change in dorsiflexion occurred, both the soleus and gastrocnemius would be contracted, and Achilles lengthening would be required.

FIG. 6.38 (A) Juvenile hallux valgus recurrence in a patient who underwent a prior isolated proximal osteotomy. The deformity was associated with a large intermetatarsal angle and increased distal metatarsal articular angle (indicated by *white lines*). In addition, on examination the patient was noted to have hyperlaxity. (B) A Lapidus procedure with a medial closed-wedge osteotomy of the distal metatarsal was required to achieve a long-lasting correction.

FIG. 6.39 (A) Recurrence of a hallux valgus deformity in a patient who had undergone a Lapidus procedure. The increased IMA occurred secondary to disruption of the intercuneiform joint. (B) A revision procedure with arthrodesis of the intercuneiform joint resulted in overcorrection of the IMA, leading to hallux varus. The deformity was flexible, however, and the patient was able to wear shoes without pain.

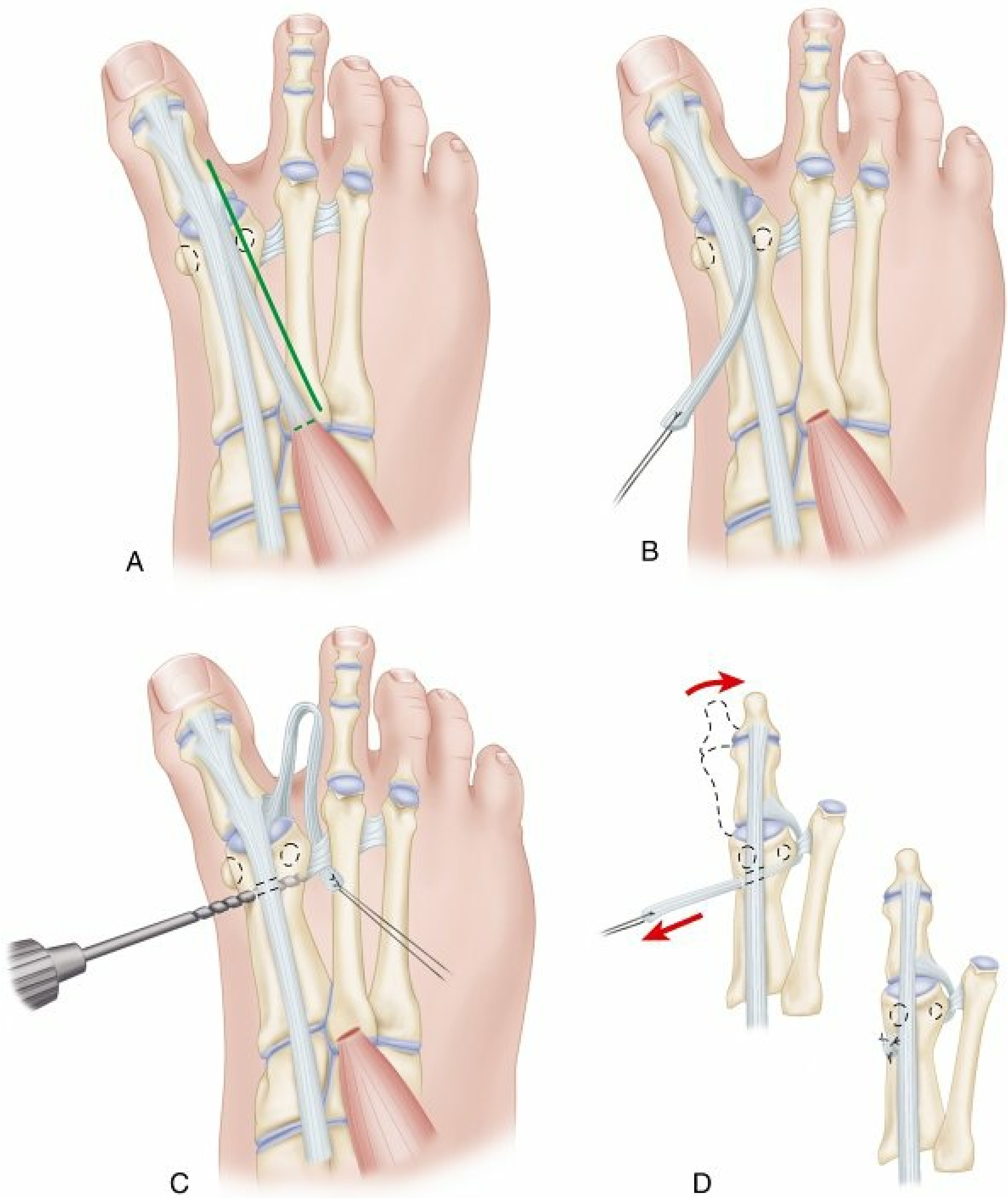


FIG. 6.40 Hallux varus correction using extensor hallucis brevis tenodesis. (A) Dorsal incision and transection of extensor hallucis brevis tendon. (B) Transected tendon is passed deep to the transverse metatarsal ligament from distal to proximal. (C) Hole is drilled in dorsomedial first metatarsal. (D) Extensor hallucis brevis tendon is pulled through drill hole and secured with sutures to periosteum or bone.

From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier. Redrawn from Juliano PJ et al: Biomechanical assessment of a new tenodesis for correction of hallux varus, *Foot Ankle Int* 17:17, 1996.

FIG. 6.52 Oblique radiograph of a patient with Freiberg disease (A) with the characteristic flattening of the metatarsal head *(arrow)* treated with a dorsal closed-wedge osteotomy (B). Note how the contour of the metatarsal head has been re-created *(arrowhead).*
From Miller MD, Sanders T: *Presentation, imaging and treatment of common musculoskeletal conditions,* Philadelphia, 2011, Elsevier.

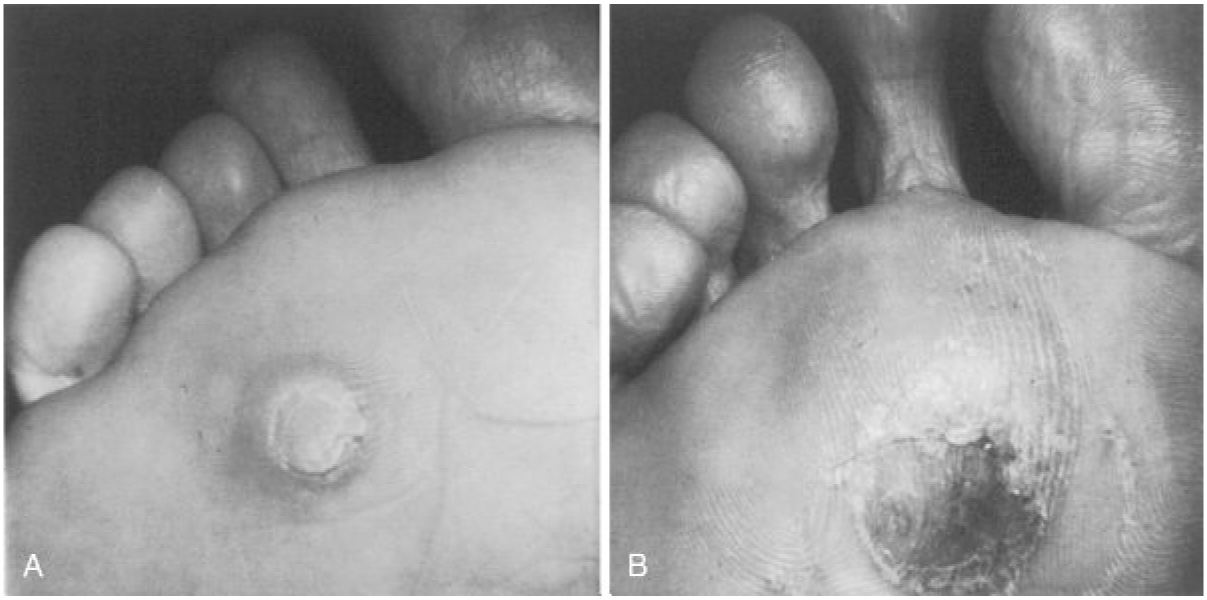


FIG. 6.53 (A) Discrete callus in a tennis player with an enlarged fibular condyle. (B) Diffuse callus in a runner.
From Porter D, Schon L: *Baxter's the foot and ankle in sport,* ed 2, Philadelphia, 2007, Elsevier.

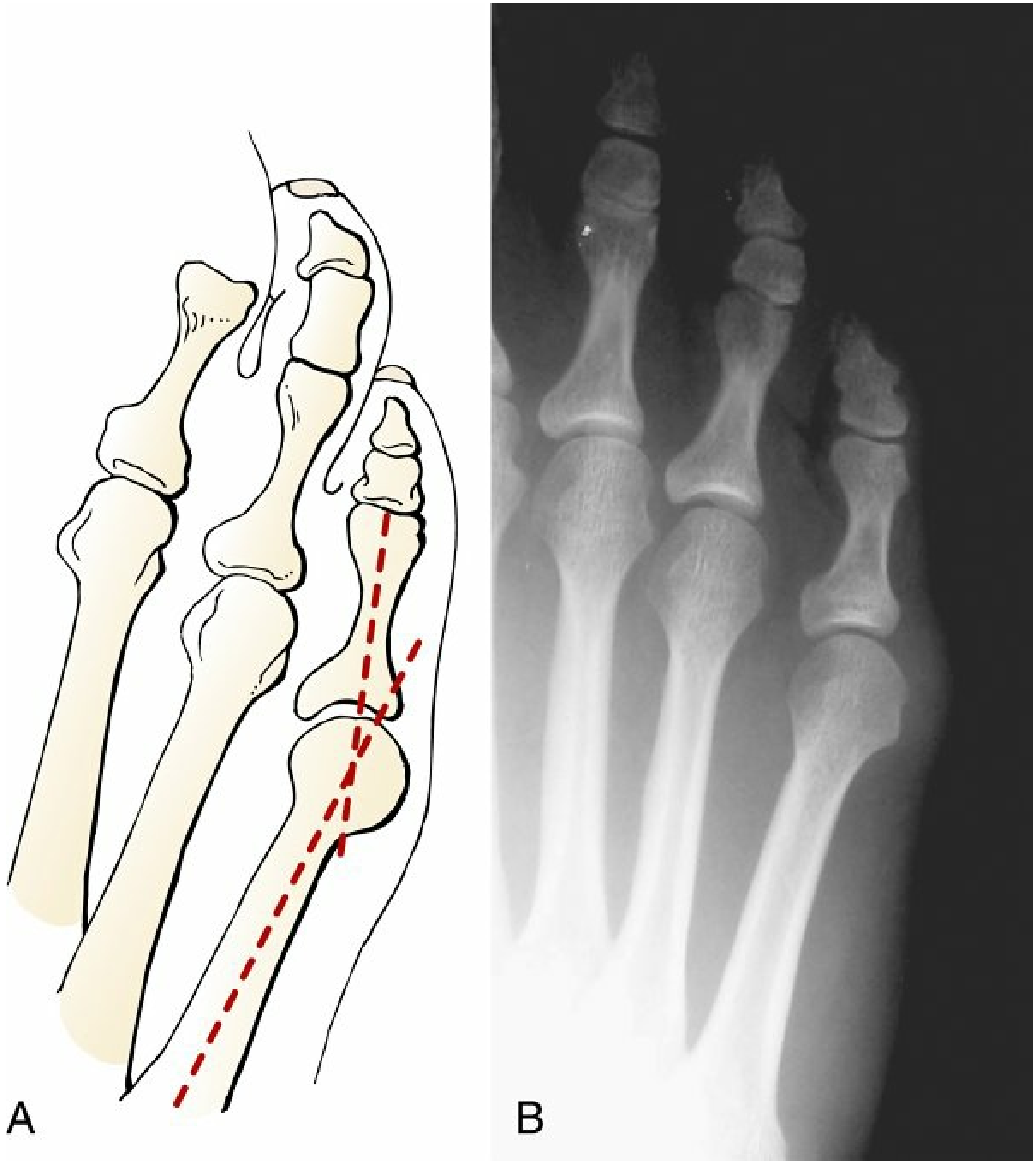


FIG. 6.54 (A and B) Type I bunionette deformity is characterized by an enlarged fifth metatarsal head.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

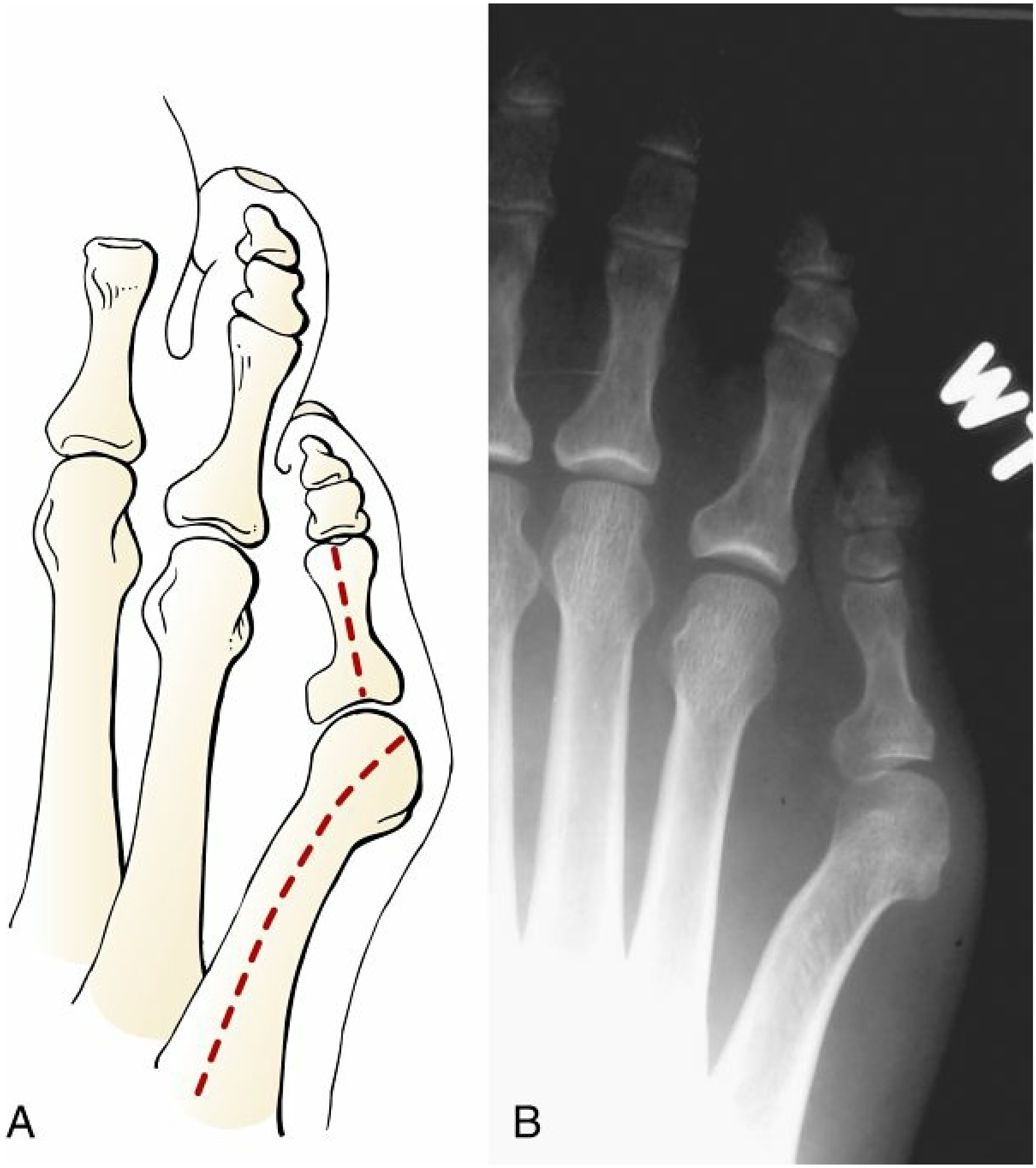


FIG. 6.55 (A and B) Type II bunionette deformity is characterized by lateral bowing of the fifth metatarsal head.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

FIG. 6.56 (A and B) Type III bunionette deformity is characterized by an abnormally wide fourth-fifth intermetatarsal angle.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

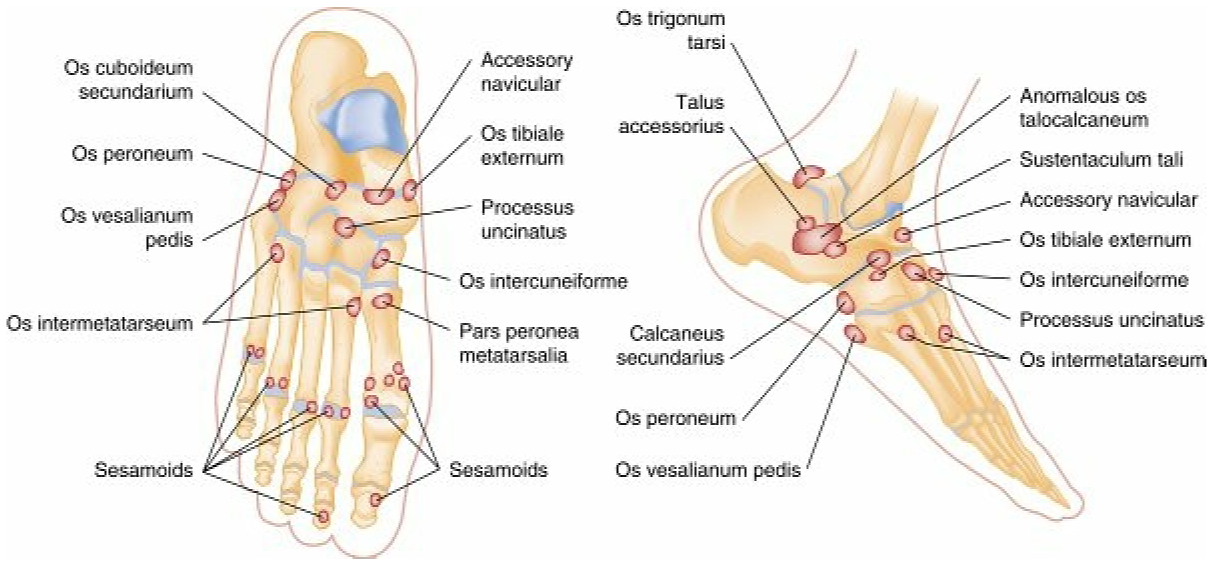


FIG. 6.59 Accessory ossicles of the foot.
From Berquist TH, editor: *Radiology of the foot and ankle,* New York, 1989, Raven Press. In Mark J et al: *Rosen's emergency medicine,* ed 7, Philadelphia, 2009, Elsevier.

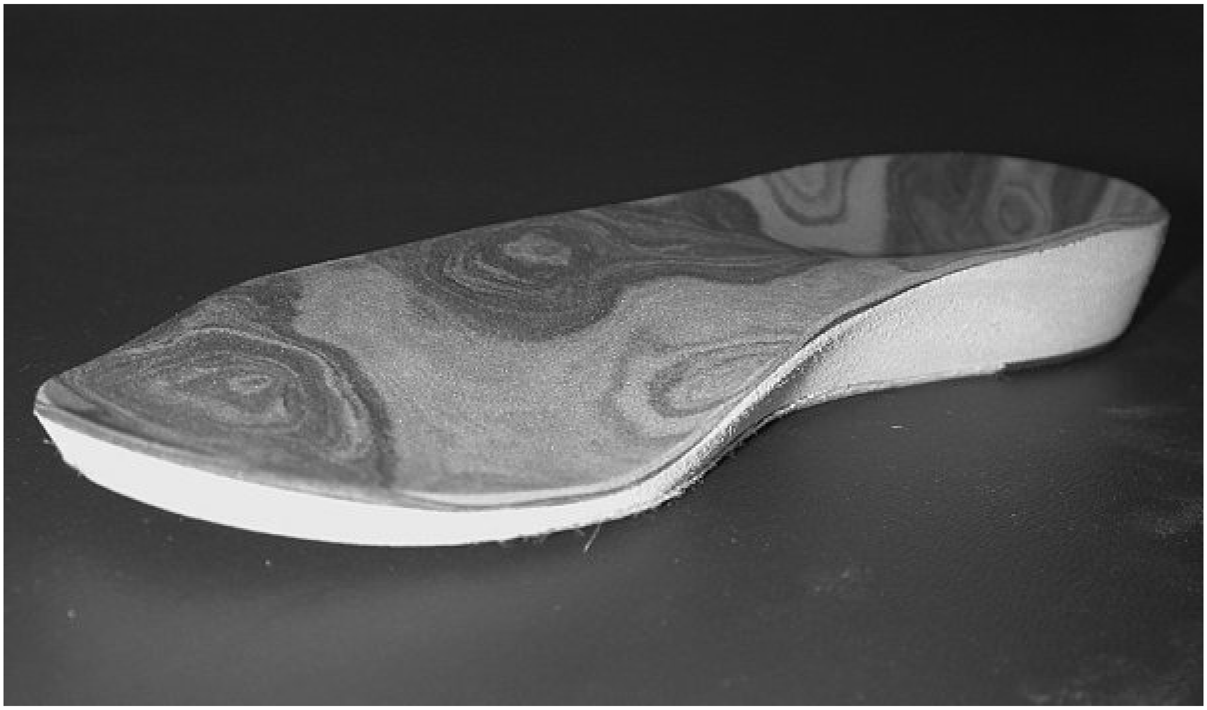


FIG. 6.93 Cavus foot orthotic. Note the hollowed-out recess under the first metatarsal head, laterally based forefoot wedge, and lowered medial arch.
From DiGiovanni C: *Core knowledge in orthopaedics—foot and ankle,* Philadelphia, 2007, Elsevier.

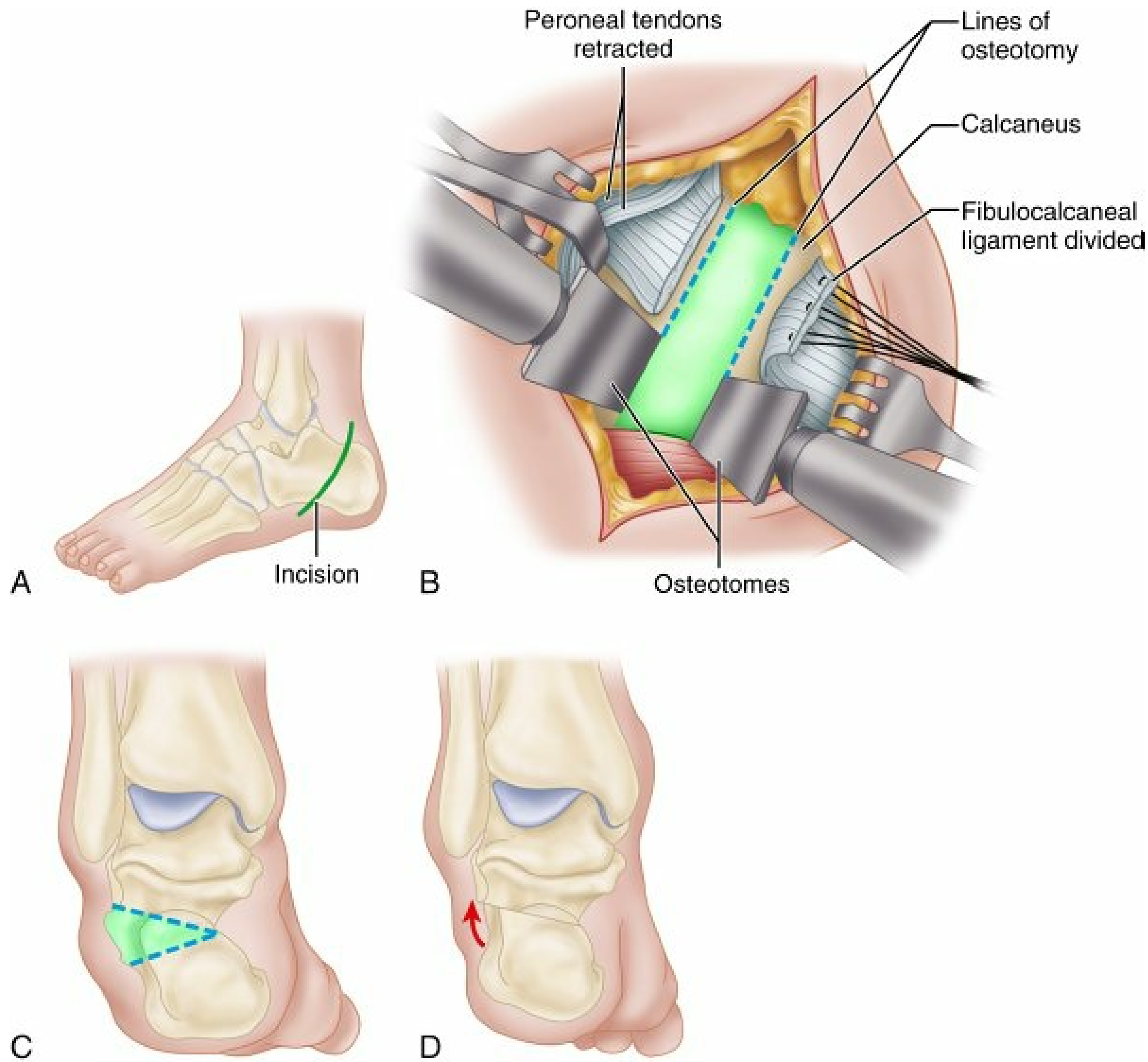


FIG. 6.94 Dwyer closed-wedge osteotomy of calcaneus for varus heel. (A) Lateral skin incision is made inferior and parallel to peroneal tendons. (B) Wedge of bone is resected with its base laterally. (C) Wedge of bone is tapered medially. (D) Calcaneus is closed after bone has been removed, and varus deformity is corrected to slight valgus.

From Canale ST, Beaty J: *Campbell's operative orthopaedics,* ed 11, Philadelphia, 2007, Elsevier.

FIG. 6.95 (A) True lateral talar position of cavus foot. The radiograph is parallel to the axis between the medial and lateral malleoli. This view clearly shows the relationship of the talus to the calcaneus and the relative amount of dorsiflexion of the talus from the tibia. This view, however, distorts the forefoot, making the first metatarsal appear vertical. (B) Postoperative radiograph demonstrates corrections of the foot. Hindfoot was repaired with a calcaneal slide transfixed with two screws. Note the slight cephalad positioning of the posterior fragment of the calcaneus. A majority of the correction was achieved by sliding this fragment laterally (out of varus). Midfoot was corrected with internal fixation with a dorsal closed-wedge osteotomy of the first metatarsal. In the forefoot correction, a single screw transfixes the interphalangeal joint of the hallux. The lesser toes were not corrected for this patient whose radiographs are shown.
From Coughlin MJ et al: *Surgery of the foot and ankle,* ed 8, Philadelphia, 2006, Mosby.

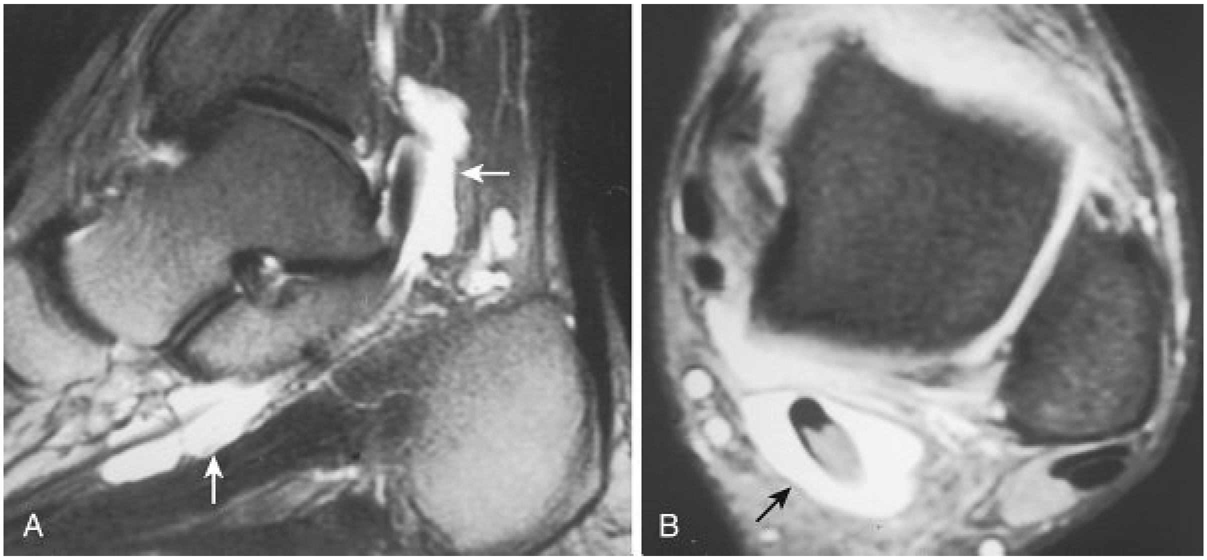


FIG. 6.97 Abnormalities of the flexor hallucis longus tendon: tenosynovitis. (A and B) Sagittal (TR/TE, 3400/98; A) and transverse (TR/TE, 4000/14; B) fast spin-echo MR images reveal considerable fluid within the sheath *(arrows)* about the flexor hallucis longus tendon. The amount of fluid is out of proportion to that present in the ankle joint.
From Resnick D: *Internal derangements of joints*, ed 2, Philadelphia, 2006, Saunders.

CHAPTER 7

Hand, Upper Extremity, and Microvascular Surgery

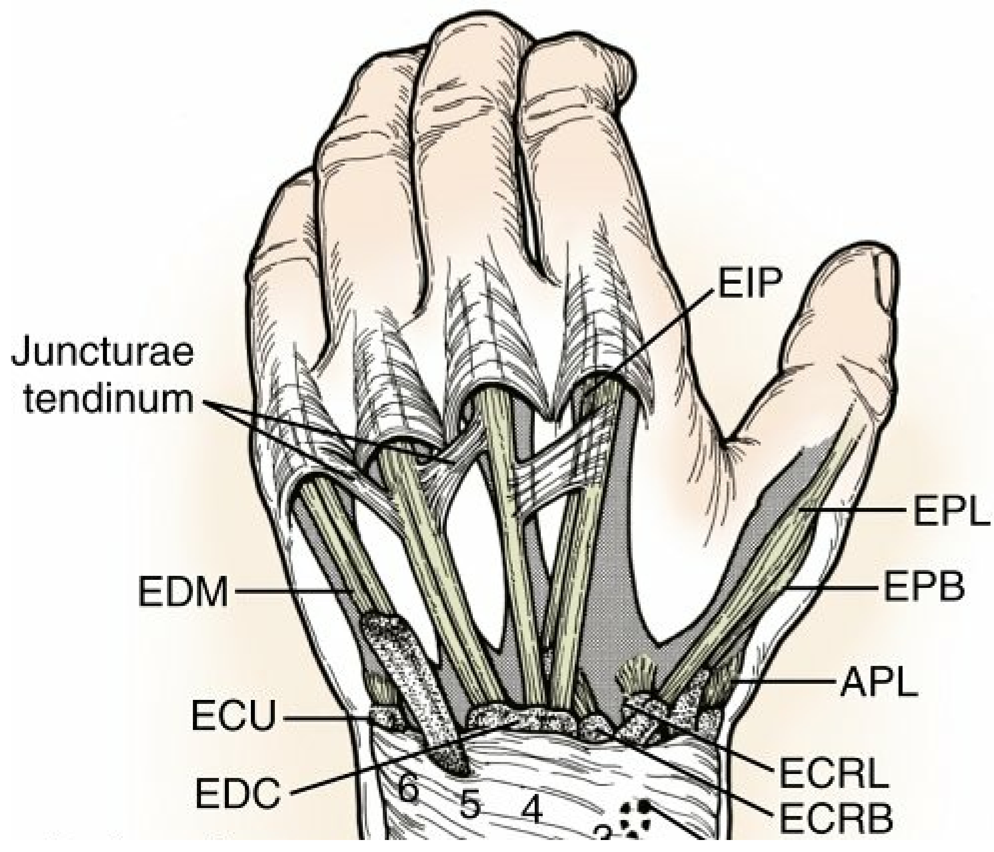
Eric R. Wagner, and Sanjeev Kakar

Anatomy

- **Extensor anatomy is shown in** Figs. 7.1 and 7.2.
  - Extensor (dorsal) compartments of the wrist are listed in Table 7.1.
  - **Extensor retinaculum**: Prevents extensor tendon bowstringing at wrist
  - **Juncturae tendinum**: Extensor tendon interconnections in hand that may mask proximal tendon lacerations
  - **Sagittal bands**: Centralize the extensor mechanism and attach to the volar plate at the metacarpophalangeal (MCP) joint
  - **Central slip**: Terminal extensor digitorum communis tendon; inserts at the base of middle phalanx (P2) and aids in proximal interphalangeal (PIP) joint extension
  - **Lateral bands**: Common extensor and intrinsics converge to form terminal extensor tendon, which inserts on base of distal phalanx (P3) and extends distal interphalangeal (DIP) joint.
  - **Transverse retinacular ligament**: Prevents dorsal subluxation of lateral bands in PIP extension, while pulling lateral bands volarly in PIP flexion. Injury may result in swan neck deformity.
  - **Triangular ligament**: Prevents volar subluxation of lateral bands. Injury may result in boutonnière deformity.
  - **Oblique retinacular ligament** (ligament of Landsmeer): Helps link PIP and DIP joint extension
    - In PIP flexion is relaxed to allow DIP flexion
    - In PIP extension is tight to allow DIP extension
  - **Grayson/Cleland ligaments**: Fibrous skin and neurovascular stabilizers lying volar (Grayson) and dorsal (Cleland) to digital neurovascular bundles, respectively (mnemonic: Grayson is *g*round; Cleland is *c*eiling)
- **Flexor anatomy (**Figs. 7.3 through 7.5)
  - **Flexor digitorum profundus (FDP**): Inserts at metadiaphyseal region of the distal phalanx (P3), flexes DIP joint, aids in PIP and MCP flexion
    - FDP tendons of the middle, ring, and small fingers have a common muscle belly in the forearm.
    - Index FDP often has a distinct muscle belly.
  - **Flexor digitorum superficialis (FDS**): Inserts at metadiaphyseal of the middle phalanx (P2), flexes the PIP joint, aids in MCP flexion
    - Small finger FDS: absent approximately 20% of the time
    - Campers chiasm: FDS splits at level of proximal phalanx (P1) to allow FDP to pass through it.
  - **Flexor tendon sheath**: Tunnel encompasses tendons distal to MCP

joint, creating a closed system separate from surrounding structures.

- **Vascular supply**: Both *intrinsic* (direct feeding vessels) and *extrinsic* (diffusion via synovial sheath to flexor tendons)
- **Pulleys**: Each digital flexor tendon sheath has five annular pulleys (A1–A5) and three cruciate pulleys (C1–C3)
    - A2 and A4 pulleys critical to preventing flexor tendon bowstringing
    - A1 involved in trigger finger
    - Thumb: 2 or 3 annular pulleys (A1, A2, Av [annular variable]) and an oblique pulley in between that prevents bowstringing of flexor pollicis longus (FPL) tendon,
- **Carpal tunnel**: Contains the median nerve and nine flexor tendons (FPL, four FDS, and four FDP tendons)
    - FPL tendon most radial structure in carpal tunnel
    - Long and ring FDS tendons are volar to index and small FDS.
    - Transverse carpal ligament (TCL): Roof of carpal tunnel



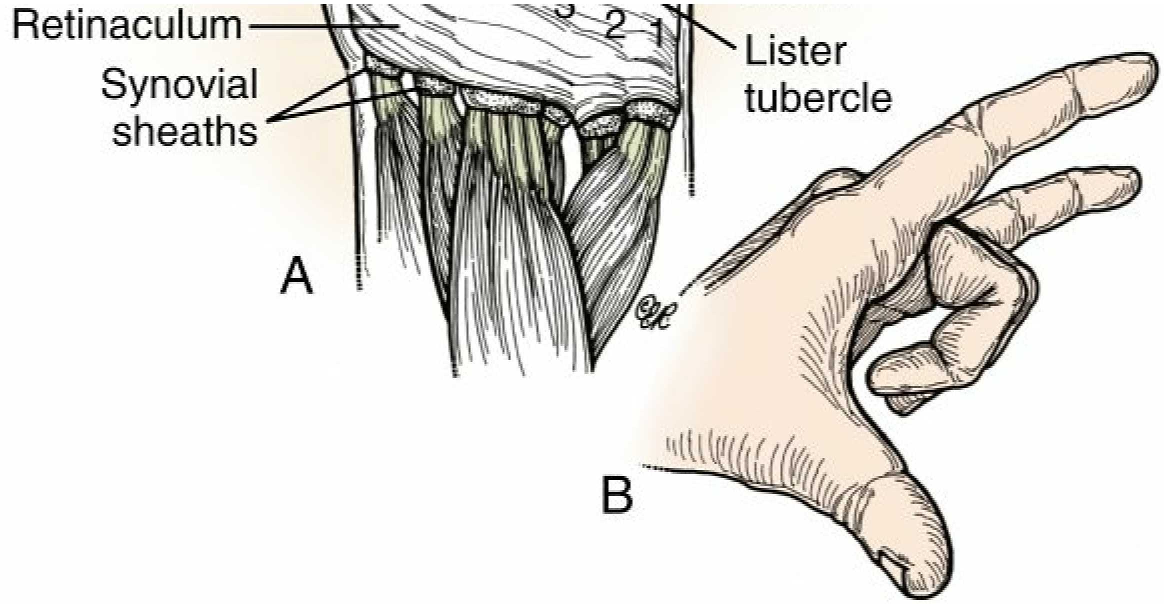


FIG. 7.1 (A) Extensor (dorsal) compartments of the wrist. The first compartment contains the abductor pollicis longus (APL) and extensor pollicis brevis (EPB); the second contains the radial wrist extensors, extensor carpi radialis longus (ECRL), and extensor carpi radialis brevis (ECRB); the third contains the extensor pollicis longus (EPL); the fourth contains the extensor digitorum communis (EDC) and extensor indicis proprius (EIP); the fifth contains the extensor digiti minimi (EDM); and the sixth contains the extensor carpi ulnaris (ECU). (B) Depiction of independent index and small digit extension from EIP and EDM.
From Doyle JR: Extensor tendons—acute injuries. In Green DP et al, editors: *Green's operative hand surgery*, ed 5, New York, 2005, Churchill Livingstone, p 1881.

- □ **Ulnar tunnel (Guyon canal):** Contains ulnar nerve and artery
  - Borders: Volar carpal ligament (roof) and TCL (floor)

- **Forearm flexor anatomy**
  - □ Linburg sign: interconnections between FPL and index FDP in forearm; unilateral in up to 30%, bilateral in up to 15%
  - □ Palmaris longus (PL) tendon: Present up to 85% of the time; is common source of autograft and lies superficial to the antebrachial fascia. Deep to the antebrachial fascia is the median nerve, which can be mistakenly harvested as a tendon graft.
  - □ Flexor carpi radialis (FCR) and flexor carpi ulnaris (FCU): Primary wrist flexors; insert on base of second metacarpal and pisiform, respectively
- **Intrinsic anatomy (** Fig. 7.6)
  - □ **Interosseous:** Dorsal interosseous (n = 4; digit abductor) and palmar interosseous (n = 3; digit adductor) muscles
    - Function: MCP flexion and interphalangeal (IP) extension
    - Innervated by ulnar nerve
  - □ **Lumbrical muscles**: Originate on radial aspect of FDP tendons, and pass volar to transverse metacarpal ligaments (TMLs) to insert on the radial lateral bands (extensor hood)
    - Function: IP joint extension, relaxation of extrinsic flexor system
    - Innervation: Radial two lumbricals (median n.), ulnar two

lumbricals (ulnar n.)

- □ **Intrinsic tightness:** Limited PIP flexion with MCP joints held in extension (intrinsics on stretch, extrinsics [extensor tendons] relaxed)
- □ **Extrinsic tightness**: Limited PIP flexion with MCP joints held in flexion (extrinsics on stretch, intrinsics relaxed)

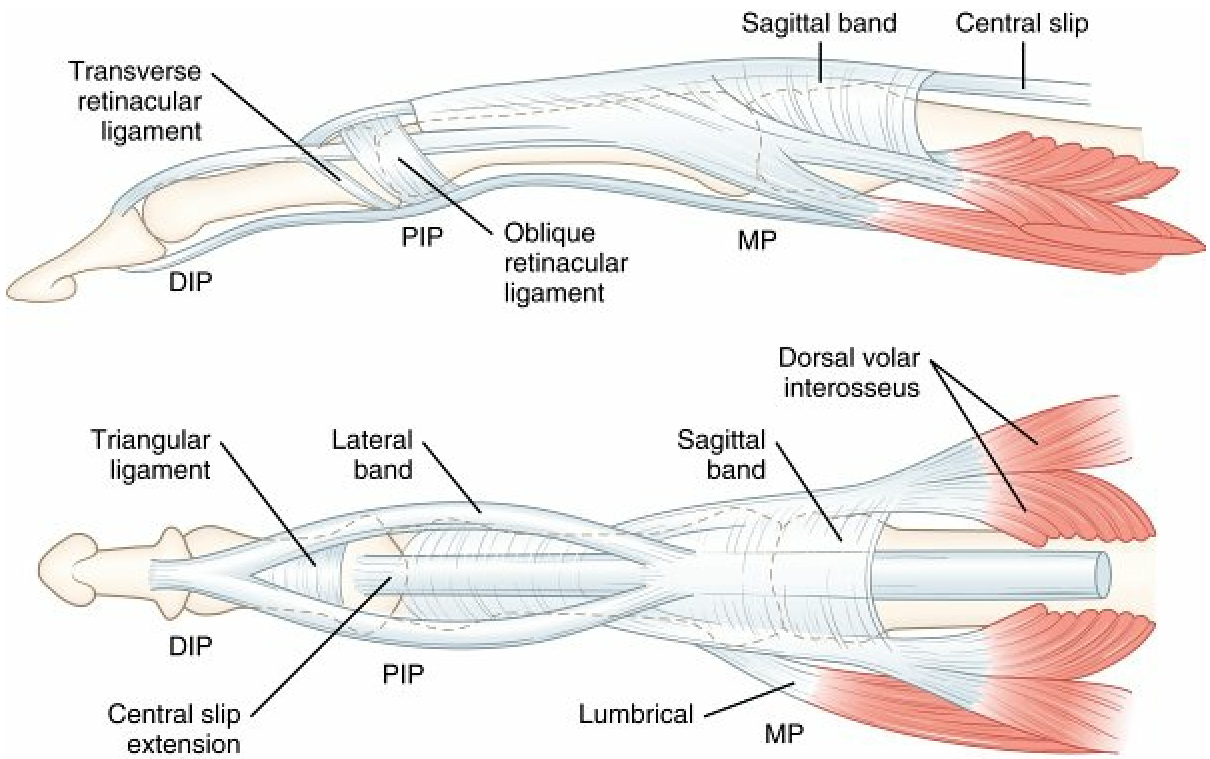


FIG. 7.2 Depiction of the digital extensor mechanism. *MP,* Metacarpophalangeal joint. From Tang JB, editor: *Tendon surgery of the hand*, Philadelphia, 2012, Elsevier Saunders, p 356.

Table 7.1

Extensor (Dorsal) Compartments of the Wrist

Compartment	Tendons	Associated Pathology	Other Points
1	APL/EPB	de Quervain tenosynovitis	APL may have multiple slips, and EPB may have a separate compartment
2	ECRL/ECRB	Intersection syndrome	Radial to Lister tubercle
3	EPL	Late rupture after closed treatment of distal radius fracture	Ulnar to Lister tubercle; tested by having patient place palm flat on table and lift thumb
4	EDC/EIP	Extensor tenosynovitis	EIP ulnar to index EDC Small EDC present in only 25%
5	EDM	Vaughn-Jackson syndrome (initial)	EDM ulnar to small EDC
6	ECU	ECU instability	ECU subsheath part of triangular fibrocartilage complex

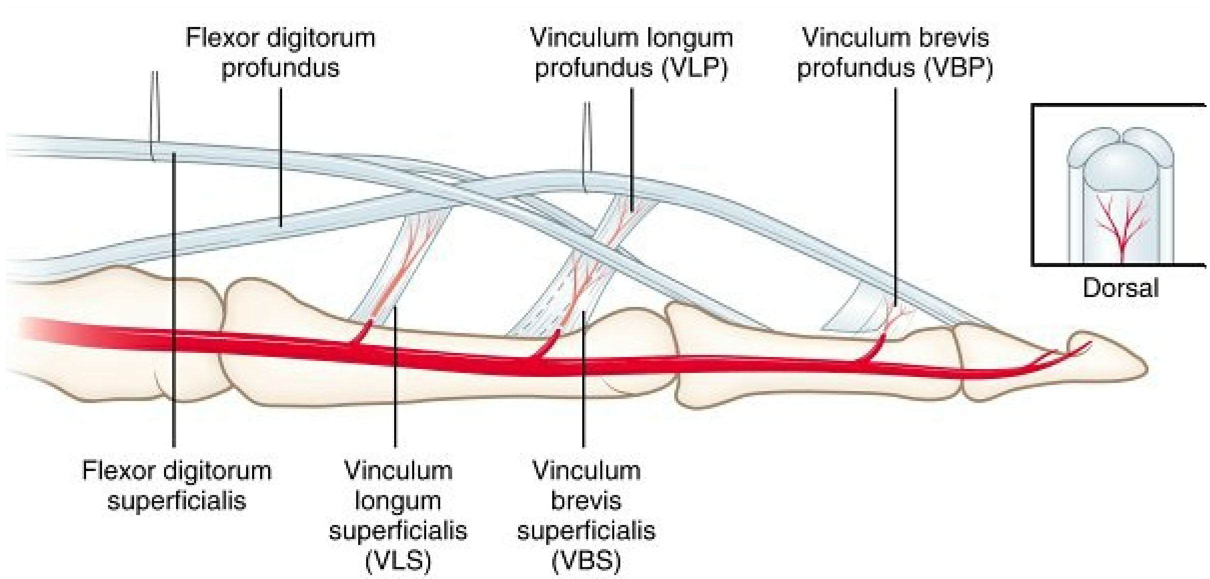
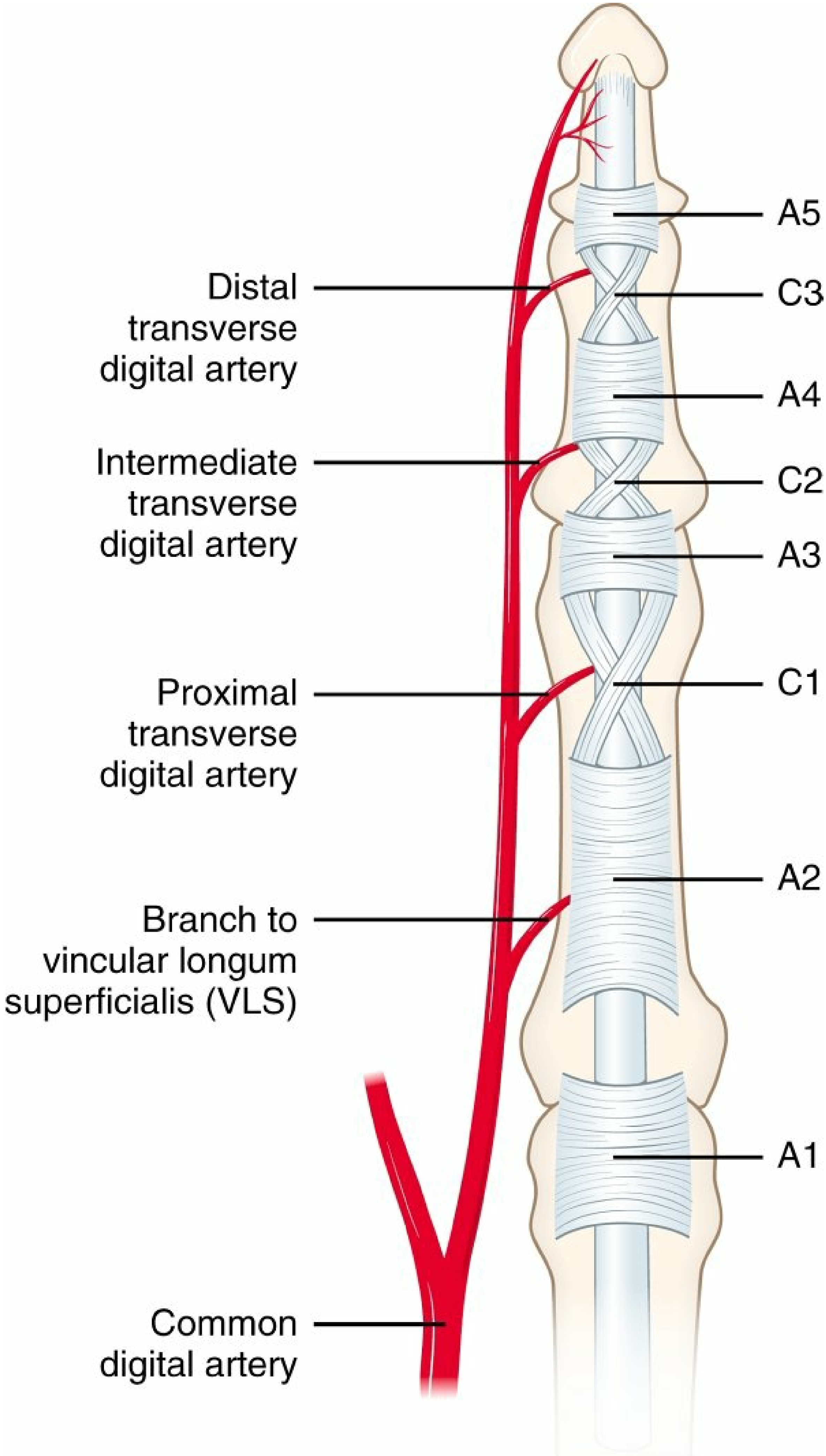


FIG. 7.3 The blood vessels enter the flexor tendons through the vincular system.
From Tang JB, editor: *Tendon surgery of the hand*, Philadelphia, 2012, Elsevier Saunders, p 7.



A5
Distal transverse digital artery
C3
A4
Intermediate transverse digital artery
C2
A3
Proximal transverse digital artery
C1
A2
Branch to vincular longum superficialis (VLS)
A1
Common digital artery

FIG. 7.4 The tendon sheath contains the annular pulleys A1 through A5 and the cruciate pulleys C1 through C3.
From Tang JB, editor: *Tendon surgery of the hand,* Philadelphia, 2012, Elsevier Saunders, p 7.

- **Neurovascular anatomy**
  - All motor and sensory innervation of hand supplied by branches of the median, radial, and ulnar nerves
    - Sensory innervation of the hand is depicted in Fig. 7.7.
    - Within the fingers, the digital nerves lie volar to the digital arteries.
  - **Median nerve**: Innervates pronator teres, FDS, FCR, PL, radial two lumbricals (Fig. 7.8)
    - Anterior interosseous branch of median nerve (AIN): Innervates FPL, index and long FDPs (50% of the time), pronator quadratus
    - Palmar cutaneous branch of median nerve: Usually lies between PL and FCR at distal wrist flexion crease and can be injured during the modified FCR Henry approach in treating distal radius fractures
  - Recurrent motor branch of median nerve: Innervates abductor pollicis brevis (APB), opponens pollicis, and superficial head of flexor pollicis brevis (FPB)
  - **Ulnar nerve**: Innervates FCU, ring/small FDPs, long FDP (50% of the time), and ulnar two lumbricals (see Fig. 7.8)
    - Deep motor branch of ulnar nerve: Innervates dorsal and volar interossei, abductor digiti minimi (ADM), flexor digitorum minimi, palmaris brevis, and deep head of FPB
  - **Martin-Gruber anastomoses**: Interconnections between motor fibers of the median and ulnar nerves in the forearm
    - Incidence: 17% of people
    - Type 1 (most common of four variations): Motor branches from the median nerve to the ulnar nerve that innervate median intrinsic muscles is most common.

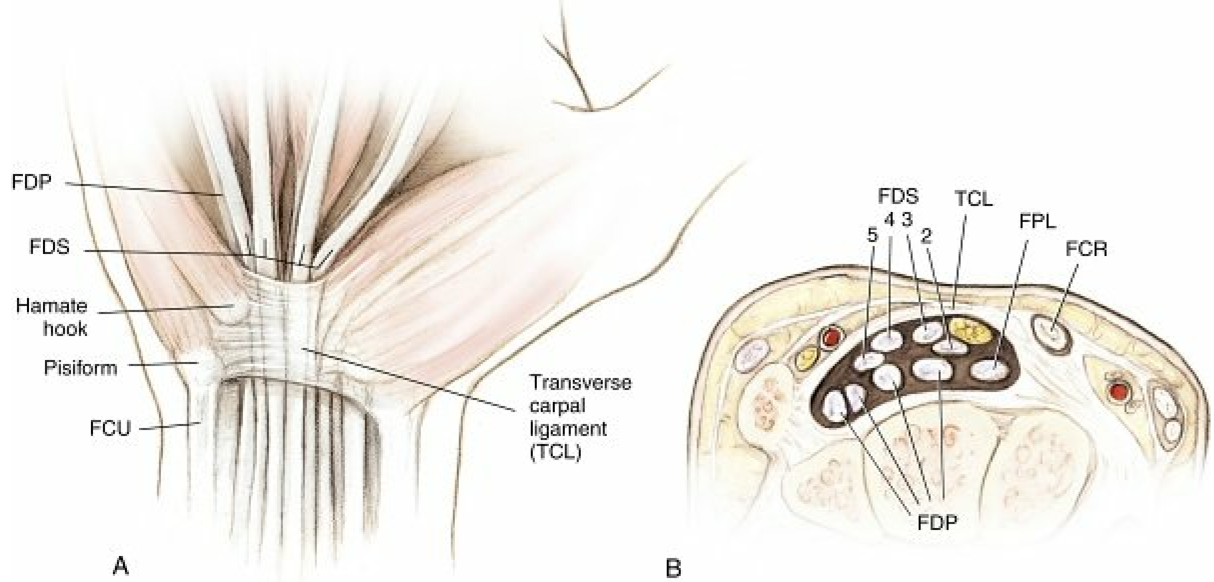


FIG. 7.5 Components of the carpal tunnel. (A) Palmar view. (B) Cross-sectional view. The roof of the carpal tunnel is the flexor retinaculum, which is composed of the deep forearm fascia, the transverse carpal ligament (TCL), and the distal aponeurosis between the thenar and hypothenar muscles. The carpal tunnel contains the median nerve and nine tendons: one flexor pollicis longus (FPL) and four each of the flexor digitorum superficialis (FDS; nos. 2 through 5) and flexor digitorum profundus (FDP) tendons. The FPL is dorsal to the flexor carpi radialis and is the most radial tendon within the carpal tunnel. *FCU,* Flexor carpi ulnaris. From Miller MD et al, editors: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders.

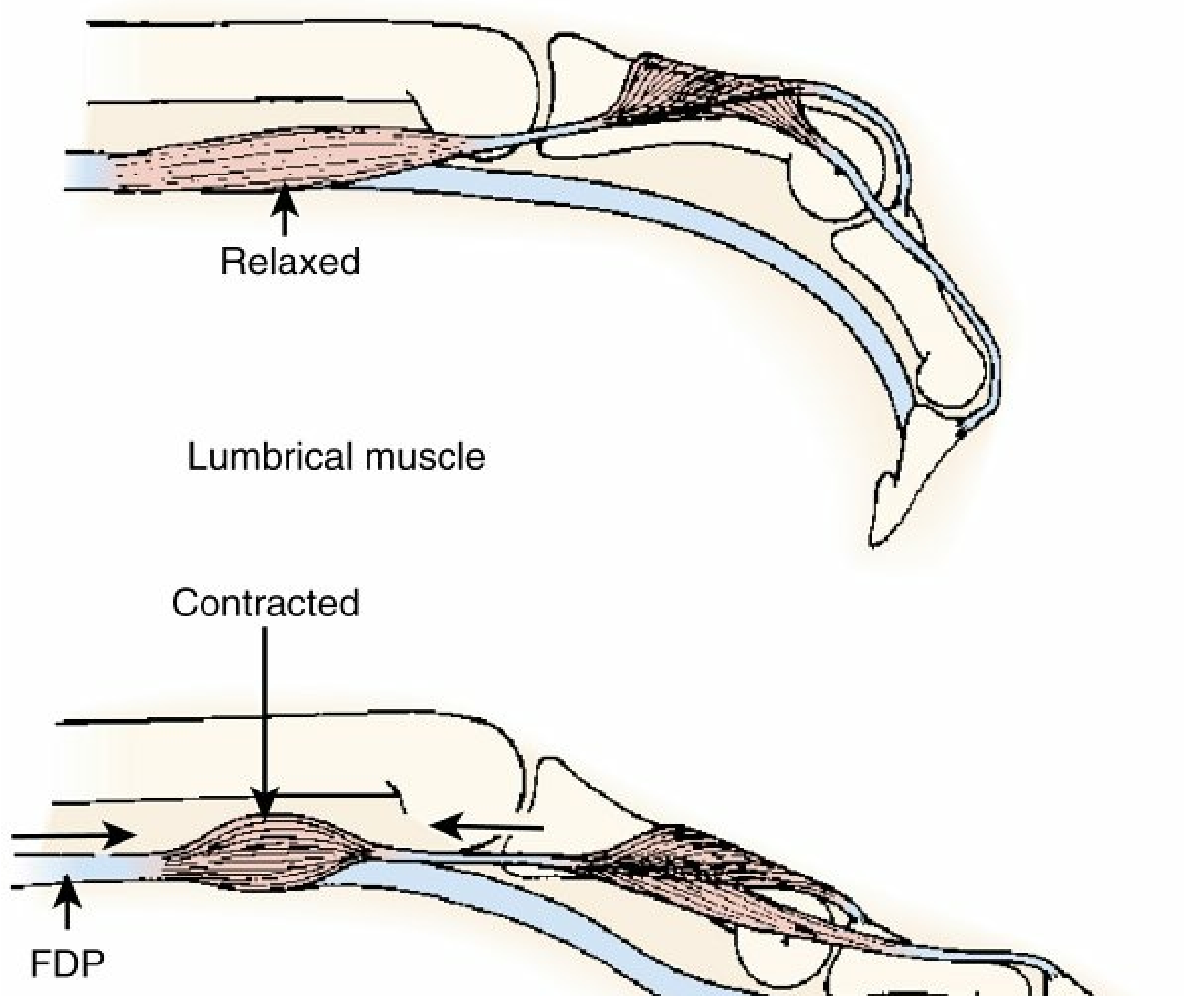


FIG. 7.6 The lumbrical muscles flex the metacarpophalangeal joint and extend the proximal interphalangeal joint.
From Trumble TE, editor: *Principles of hand surgery and therapy,* Philadelphia, 2000, Saunders.

    - **Riche-Cannieu anastomoses:** Interconnections of motor fibers of the median and ulnar nerve within the palm
    - **Radial nerve proper**: Innervates lateral portion of brachialis (also musculocutaneous), triceps, anconeus, brachioradialis, and extensor carpi radialis longus (ECRL) (see Fig. 7.8)
        - Divisions: Superficial sensory branch (SBRN) and posterior interosseous nerve (PIN)
        - PIN: Innervates all remaining extensor muscles
        - Extensor carpi radialis brevis (ECRB): Variable innervation from either radial nerve proper or PIN
        - Terminal branch of PIN: Lies on the floor of fourth extensor compartment and is excised as part of a partial denervation procedure for wrist arthritis

Distal Radius Fractures

- **Demographics**
    - Most common fractures of the upper extremity (>300,000 per year) in the United States, with bimodal distribution
        - Young patients: High-energy trauma (e.g., motor vehicle accident, fall from height)
        - Elderly patients: Low-energy falls; most common upper extremity osteoporotic fracture
- **Anatomy**
    - Distal radius articular surface: Biconcave, scaphoid, and lunate facets
    - Distal radioulnar joint (DRUJ): Articulation with ulna at sigmoid notch
    - Lister tubercle: Small dorsal prominence; landmark for dorsal approach to wrist; cause of attritional rupture of extensor pollicis longus (EPL) after a distal radius fracture
    - Metaphysis: Thin cortex, vulnerable to bending forces
    - Deforming force: Brachioradialis insertion on radial styloid
    - Normal wrist: Distal radius bears 80% of axial load
- **Clinical evaluation**
    - Pain, swelling, and deformity at the wrist after trauma
    - Open injuries more common in young patients
    - Arm should be examined for concurrent anatomic snuffbox and ulnar-

sided wrist tenderness.

- ▫ Median and ulnar nerve function should be assessed.

- **Radiographic evaluation (posteroanterior, lateral, and oblique views)**

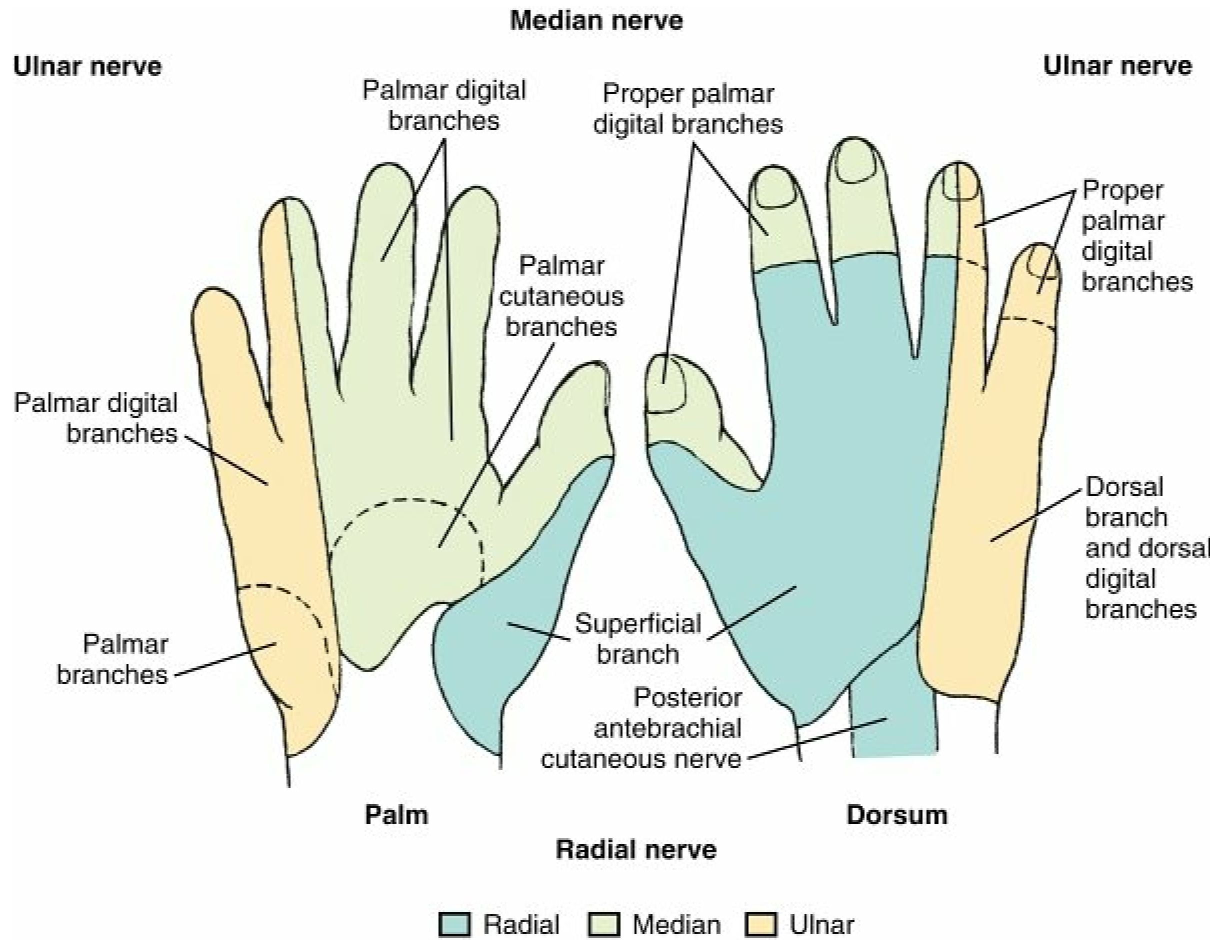


FIG. 7.7 Sensory patterns of the median, ulnar, and radial nerves for the volar *(left)* and dorsal *(right)* aspects of the hand.
From Trumble TE, editor: *Principles of hand surgery and therapy*, Philadelphia, 2000, Saunders.

- ▫ Intra articular involvement (Fig. 7.9): Fracture pattern, gap, and step-off
- ▫ Distal fragment angulation: Apex dorsal (Smith fracture), apex volar (Colles fracture)
- ▫ Radial height, volar tilt, and radial inclination: 11:12:22 rule
  - Radial height: Average 11 mm; less than 5 mm of shortening accepted
  - Radial inclination: Average 22 degrees (Fig. 7.10); less than 5-degree change accepted
  - Volar tilt (lunate fossa inclination): Average 11 degrees; less than 10-degree dorsal angulation accepted
- ▫ Additional considerations
  - Ulnar variance: Neutral (normal), positive, or negative; assessed with forearm in neutral rotation, and compared

with contralateral side (Fig. 7.11)

- DRUJ involvement: True lateral radiograph assessed for DRUJ alignment
- Ligamentous injuries: scapholunate (SL), lunotriquetral (LT), or TFCC

□ Associated fractures: ulnar styloid, distal ulna, carpus

- Chauffeur fracture: Isolated fracture of radial styloid that may be associated with SL ligament disruption
- Radiocarpal dislocation or "inferior arc" injury: Purely ligamentous or associated with styloid fracture (radial and/or ulnar)
  - Highly unstable and difficult to reduce closed
- Other imaging studies: CT for detail of complex intraarticular patterns; MRI for occult fracture, bone contusion, associated soft tissue injury

▪ **Classification**

□ Common eponyms (Colles, Smith, Barton, Hutchinson) predate radiography

□ More than 10 other schemes exist (e.g., AO, Frykman, Fernandez, Melone, Mayo) but largely fail to help with prediction of treatment or prognosis.

▪ **Treatment**

□ Goals: Maintain reduction until union, restore function, prevent symptomatic posttraumatic radiocarpal osteoarthrosis

- Factors: Age, medical condition, activity demands, bone quality, fracture stability, associated injuries

□ Nonoperative: **Immobilization ± closed reduction**

- Indications for immobilization: Extraarticular, minimally displaced fracture; functionally low-demand patient
- Closed reduction indicated in displaced fracture with abnormal radiographic parameters, especially in functionally high-demand patient
  - **Technique of closed reduction: Volar translation of lunate with traction and ulnar deviation.**
    - Dorsal hematoma block with local anesthetic, finger traps
    - Re-creation of deformity, manipulation of distal fragment
    - Sugar-tong plaster splint with three-point mold
    - Aim: To hook volar cortex to try to prevent loss of reduction.
    - MCP and IP joints must be kept free

for motion.

- Loss of reduction correlates with increasing age.
- Postreduction benchmarks (American Academy of Orthopaedic Surgeons guideline)
    - Radial shortening less than 5 mm
    - Dorsal articular tilt less than 5–10 degrees
    - Intraarticular step-off less than 2 mm

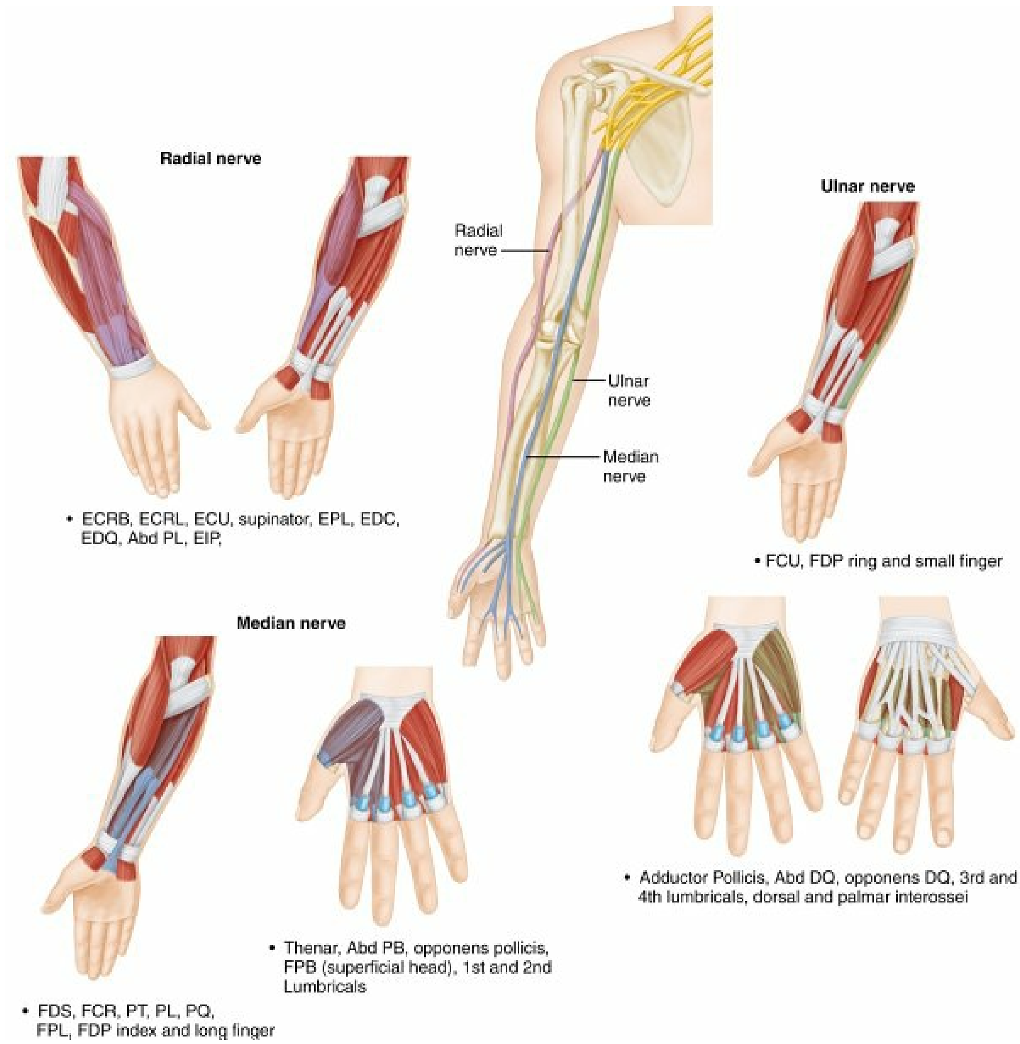


FIG. 7.8 Composite figure demonstrating the innervations of the radial nerve, median nerve, and ulnar nerve in the forearm and hand. *Abd,* Abductor; *DQ,* digiti quinti; *EDQ,* extensor digiti quinti; *PT,* pronator teres.

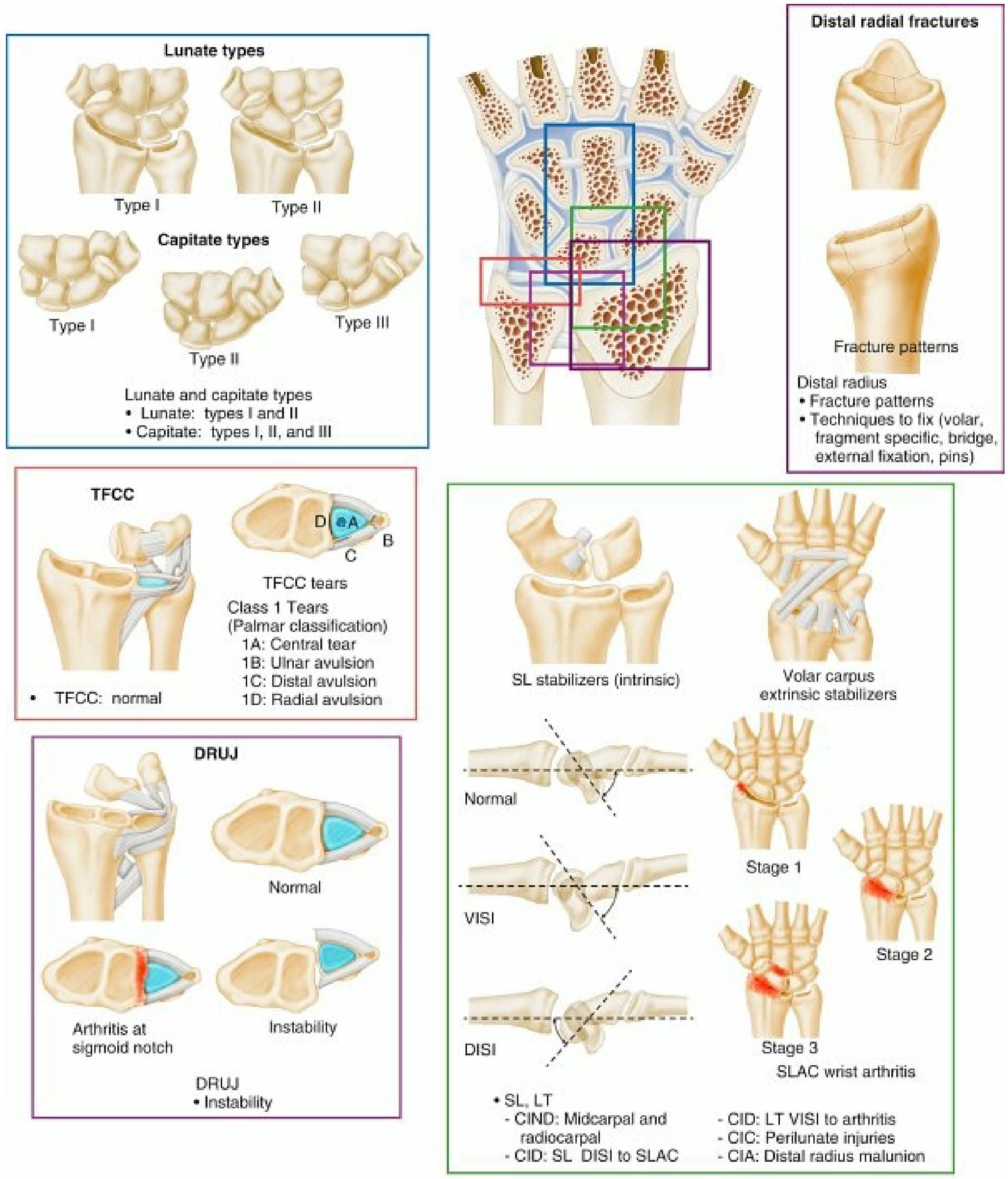
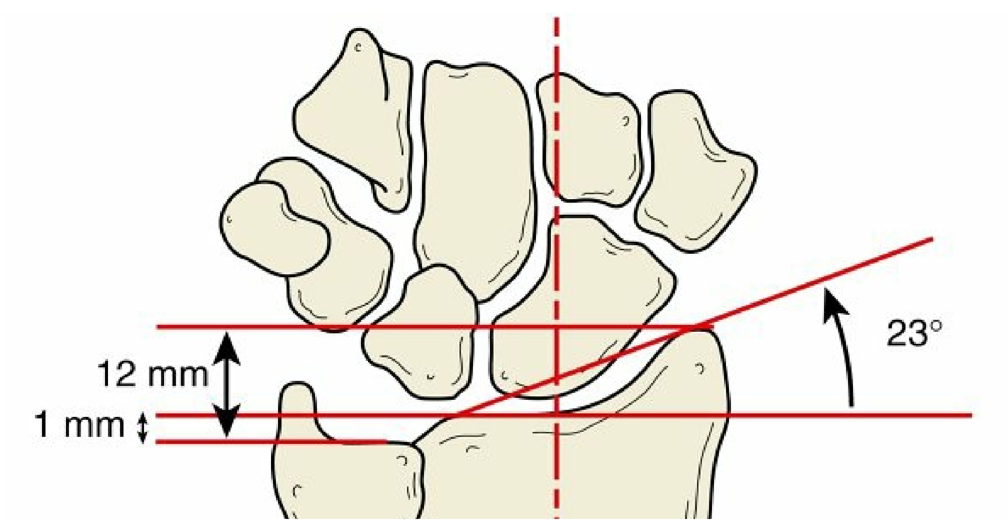


FIG. 7.9 Composite figure outlining various important pathologies in the wrist (described in clockwise order from *top right [purple] box*).

- The distal radius fractures often follow specific fracture types involving the radial, ulnar, volar, and dorsal columns. There are a variety of surgical techniques to fix these fractures according to the fracture pattern.
- The multiple types of carpal instability include carpal instability nondissociative (CIND), carpal instability dissociative (CID), and carpal instability complex (CIC). CID is one of the more commonly faced pathologies, including dorsal intercalated segment instability (DISI) involving the scapholunate (SL) ligament and extrinsic stabilizers, as well as volar intercalated instability (VISI) involving the lunotriquetral (LT) ligament and extrinsic stabilizers. SL pathology can progress to DISI and eventually to different stages of scapholunate advanced collapse (SLAC) arthritis.
- The distal radioulnar joint (DRUJ) has multiple dynamic and static stabilizers. When it is injured, the ulna is able to translate (usually dorsally) with respect to the radius. DRUJ arthritis can happen as a result of trauma (e.g., prior associated fracture), recurrent instability, or either OA or inflammatory arthritis.
- The triangular fibrocartilage complex (TFCC) is one of

the most important DRUJ stabilizers. Multiple tear patterns may be seen; the Palmer classification being one of the most useful to describe them. A TFCC tear has the potential to destabilize the DRUJ.

- There are three types of lunate morphology and two types of capitate morphology. These are important considerations in assessment and treatment of various carpal pathologies. For example, a type 1 (flat) capitate has been shown to be a better indication for proximal row carpectomy than a type 2 (round) or type 3 (V-shaped).



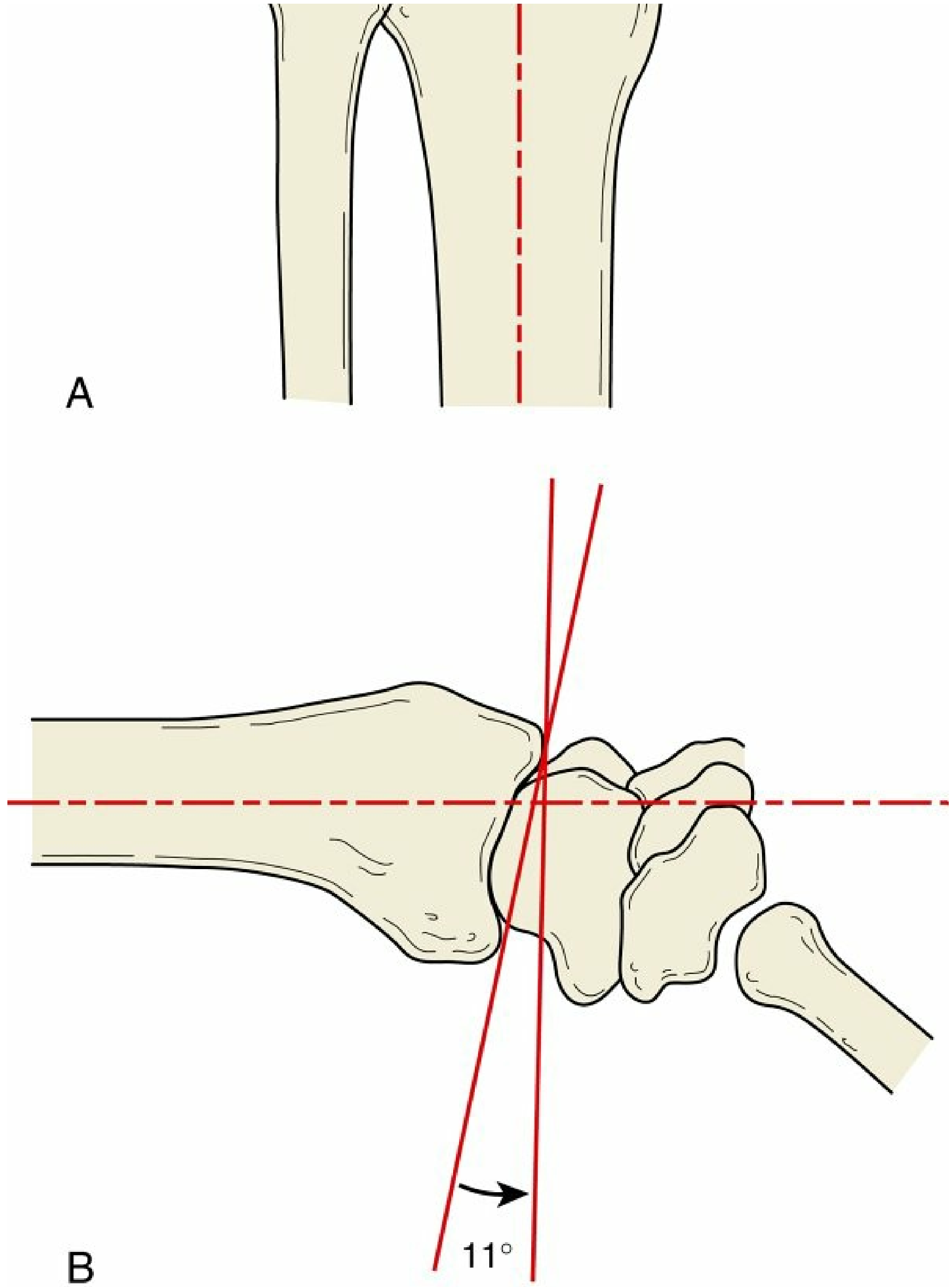


FIG. 7.10 Schematic drawings of the average radial inclination (A) and volar tilt of the distal radius (B).

From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 89.

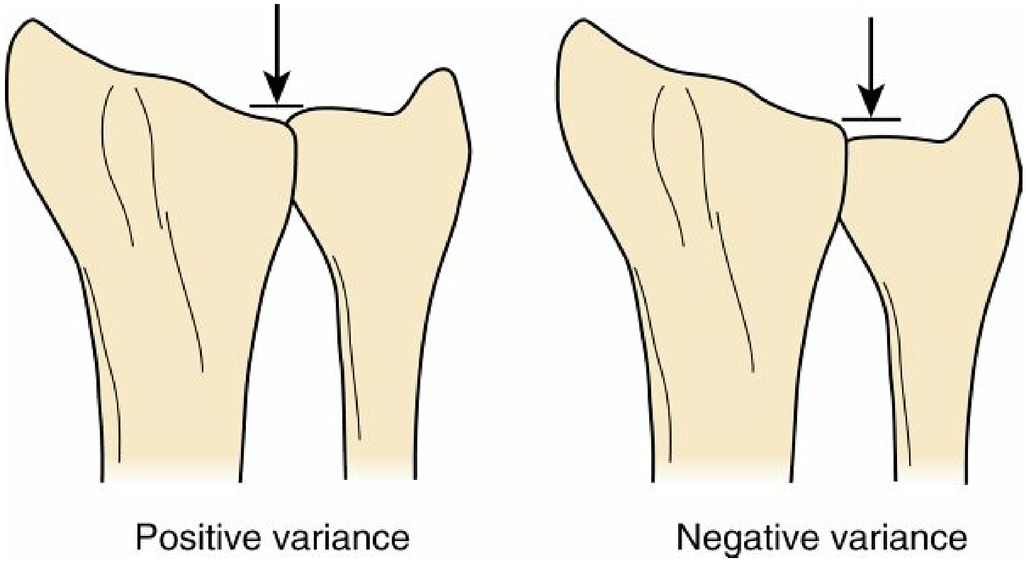
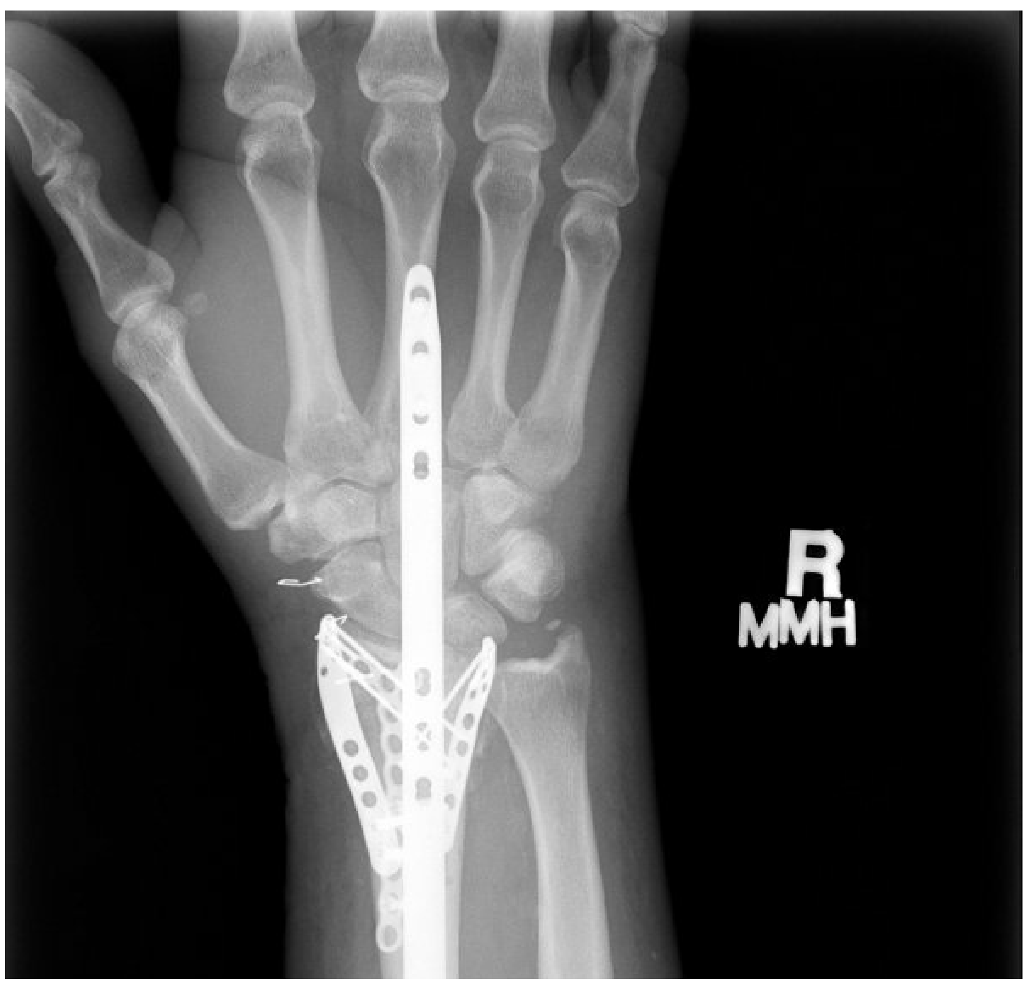


FIG. 7.11 Ulnar variance of the distal radius.
From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 89.

- Immobilization for 6–8 weeks (no evidence to support any particular type)
- Wrist and digit stiffness, muscle atrophy, and disuse osteopenia may result from prolonged immobilization.

□ Operative treatment

- **Closed reduction and percutaneous pinning (CRPP) (see Fig. 7.9)**



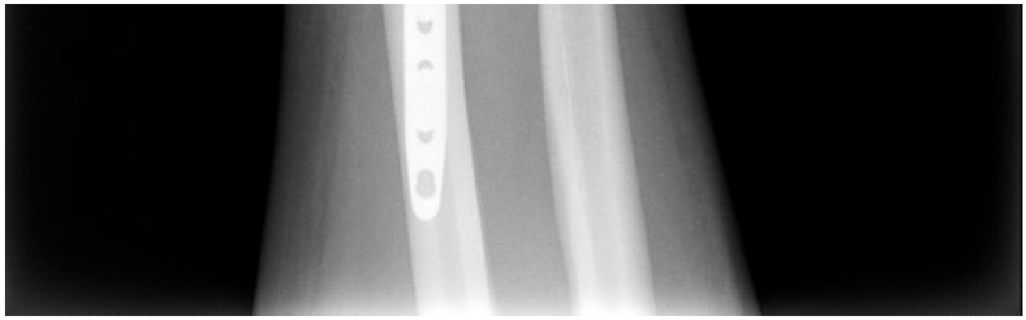


FIG. 7.12 Bridge plate and fragment-specific fixation for highly comminuted distal radius fracture.

- Indications: Extraarticular fracture in younger patients without osteoporosis
    - Is less often used today with the advent of volar plating. Can be used as an isolated treatment or as an adjunct with external fixation.
    - Techniques: Kapandji intrafocal technique or arthroscopically assisted reduction
- **External fixation**
    - Indications: Alone for unstable fractures with soft tissue compromise or in combination with percutaneous pin fixation or internal fixation techniques in highly unstable fractures
        - Articular alignment is difficult to restore.
        - Overdistraction may lead to increased risk of complex regional pain syndrome (CRPS).
- Open reduction with internal fixation (ORIF)
- Patients undergoing ORIF should be monitored for symptomatic hardware that may need to be removed to prevent tendon rupture.
- **Distraction or bridge plating**
    - Indications: Alternative to external fixation in highly comminuted unstable fractures or elderly patients with severe osteoporosis. Allows weight bearing through injured extremity and so a consideration in a multiple-trauma patient.
    - Technique: Secured second or third metacarpal and radial shaft (Fig. 7.12)
        - Can be combined with volar plating
        - Disadvantage: Second procedure to remove plate at 8–12 weeks

- **Dorsal plating**
    - Indications: Dorsally displaced fractures with dorsal bony defects
    - Technique: Approach between third and fourth extensor compartments
        - Enables direct visualization of articular reduction
    - Historical disadvantage: Extensor tendon irritation or rupture from prominent hardware

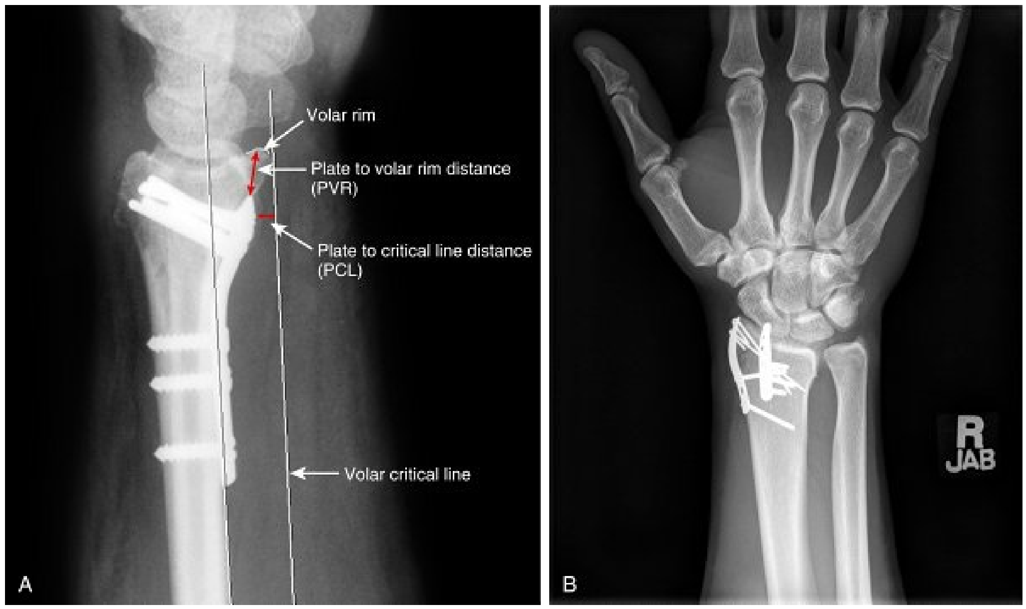


FIG. 7.13 (A) Measurements of plate position and prominence are demonstrated on this facet lateral radiograph. The plate-to–critical line (PCL) distance is measured with negative values for plates dorsal to the critical line and positive values for prominent plates volar to the critical line. The plate-to–volar rim (PVR) distance is measured with positive numbers for plates proximal to the volar rim and negative values for plates distal to the volar rim. (B) This image demonstrates a fragment specific fixation of various columns of the radius, which potentially avoids the concern for plate prominence.
Afrom Kitay Aet al: Volar plate position and flexor tendon rupture following distal radius fracture fixation, *J Hand Surg Am* 38:1091–1096, 2013.

- **Volar plating**
    - Indications (most common): volarly or dorsally displaced fractures, more than 2 mm articular displacement, metaphyseal comminution, combined distal radius and ulna fractures
    - Technique: Henry approach between FCR and radial artery or through floor of FCR tendon sheath
        - Articular reduction not directly visualized; relies on fluoroscopic guidance

        - Fixed-angle and variable-angle plates available
        - Plates placed at or proximal to watershed line (Fig. 7.13)
        - Repair of pronator quadratus: No clinical benefit
        - Can be combined with dorsal bone grafting for dorsal comminution
        - Flexor tendon most commonly injured with a plate placed distal to the watershed line is the FPL, followed by the FDP of the index finger.
        - Extensor tendon most commonly injured with a volar plate is the EPL, from use of a screw that is too long.
- **Fragment-specific techniques**
    - Considerations: Low-profile constructs, technically challenging
    - Indications: May be best suited to certain intraarticular fracture patterns, including those with volar-ulnar ("critical corner") fragment
        - Hook plate may capture volar-ulnar fragment with less chance of flexor tendon irritation than standard volar plate implant.
- **Intramedullary nailing**
    - May have role in stable extraarticular patterns, but minimal data available
- **Arthroscopic reduction assistance**
    - Aids in articular reduction
    - Ensures screws do not penetrate the radiocarpal joint
- **Additional technical considerations**
    - Injectable bone substitutes: Calcium phosphate, coralline hydroxyapatite
        - Possible role in dorsal or metaphyseal comminution
    - Postoperative motion: Evidence does not support any advantage of early over later motion recovery after surgical fixation of distal radius.
- **Ulnar styloid fracture: Concurrent treatment of ulnar styloid fracture is not routinely necessary; it has no additional**

clinical benefit if the DRUJ is stable to clinical examination *after* the distal radius fracture has been stabilized.

- **Painful nonunion/DRUJ instability in small number of cases after radial fracture reduction (<10%)**

□ Complications

- **Acute carpal tunnel syndrome**: Characterized by progressive, evolving paresthesias and disproportionate pain; requires emergent median nerve decompression (carpal tunnel release)
    - Mild, vague, and nonprogressive sensory dysfunction is not indicative of acute carpal tunnel syndrome.
- Ulnar nerve palsy: Possible after high-energy displaced distal radius fracture
- EPL tendon rupture
    - **Late complication due to sheath hematoma, attritional wear, and/or vascular insufficiency near the Lister tubercle**
    - **Presentation: Painless, acute loss of thumb extension; inability to lift thumb off table with palm**

FIG. 7.14 (A) A distal radius malunion. (B) Distal radius corrective osteotomy with correction of carpal malalignment.

- **Treatment: Extensor indicis proprius (EIP)—EPL tendon transfer followed by PL intercalary autograft reconstruction. The EIP is the more ulnar of the two extensor tendons over the index finger MCP joint and has the most distal muscle belly of the fourth extensor compartment tendons at the wrist.**
- Nonunion: Uncommon complication
- Asymptomatic malunion in a functionally low-demand patient does not require treatment

- Ulnocarpal impaction: Can be treated with distal ulna resection (low-demand patient) or ulnar shortening osteotomy (high-demand patient).
    - Corrective radius osteotomy with ORIF and bone grafting may be indicated in functionally high-demand patients to prevent adaptive carpal instability and possible midcarpal arthritis (Fig. 7.14).
- Wrist arthritis: Associated with residual intraarticular step-off, but often does not necessarily correlate with patient-reported symptoms.
- Tendon injury: Reported after volar (flexor and extensor) and dorsal plating (extensor)
    - FPL: Tendon most commonly ruptured after volar plating; potentially due to improper plate placement distal to watershed zone
    - EPL: Extensor tendon most commonly injured; potentially due to drill-bit penetration or dorsally prominent screws
- CRPS: Vitamin C in doses of at least 500 mg/day for 50 days, in patients with normal renal function, may decrease the incidence of CRPS in women older than 50 years who are treated for a distal radius fracture, although this issue is controversial because new evidence disputes early reports.

Carpal Fractures and Instability

- **Anatomy**
    - Eight carpal bones aligned in two rows (see Fig. 7.9)
        - Proximal row: scaphoid, lunate, and triquetrum
            - Flexes with radial deviation, extends with ulnar deviation
        - Distal row: trapezium, trapezoid, capitate, and hamate
        - Pisiform is a sesamoid within the FCU tendon
    - Functional dart-thrower's motion describes combined wrist extension–radial deviation to wrist flexion–ulnar deviation.
        - Occurs through midcarpal joint
        - Proximal row remains relatively immobile
    - Bloody supply: Carpus has a rich vascular supply with multiple anastomoses
        - Scaphoid, lunate, and capitate each have a large area supplied by a single interosseous vessel, making them more

susceptible to osteonecrosis after trauma.

- Scaphoid and capitate have a retrograde blood supply that may result in osteonecrosis of the proximal pole after fracture.

- Innervation: PIN ± AIN may play a role in wrist sensation and proprioception
  - Partial denervation: Excision of PIN ± AIN to relieve pain from wrist arthritis

- **Scaphoid fractures**
  - Most common carpal fractures, accounting for up to 15% of acute wrist injuries
  - Anatomy of scaphoid
    - Approximately 75% covered by articular cartilage
    - Blood supply
      - Main (proximal ¾) supply from dorsal branch of the radial artery enters at dorsal ridge just distal to waist and flows in retrograde fashion toward proximal pole.
      - Distal ¼: Superficial volar branches of radial artery enter at distal tubercle
      - Danger: Tenuous and retrograde vascular supply puts waist and proximal pole fractures at risk for nonunion and posttraumatic osteonecrosis.
  - Diagnosis
    - Mechanism: Forced hyperextension and radial deviation of the wrist
    - Presentation: Swelling, anatomic snuffbox/volar tubercle tenderness, limited wrist and/or thumb motion
    - Radiographs: Standard wrist radiographs; additional scaphoid view—approximately 30 degrees of wrist extension and 20 degrees of ulnar deviation—displays scaphoid in best profile
      - Radiographs initially nondiagnostic in more than 30% of cases

FIG. 7.15 (A) Scaphoid fractures can be simply described as involving the distal pole or tubercle, waist, or proximal pole. (B) Proximal pole fracture. (C) Proximal pole fracture as seen on MRI.
AFrom Trumble TE, editor: *Principles of hand surgery and therapy,* Philadelphia, 2000, Saunders.

    - If normal radiographic findings and high clinical suspicion, arm should be immobilized and physical examination and radiographs should be repeated in 2 weeks, or MRI should be obtained immediately.
- Advanced imaging: Bone scan, ultrasonography, CT, and MRI have all been used for earlier diagnosis.
    - All advanced imaging modalities are better for ruling out rather than ruling in a scaphoid fracture.
    - MRI has highest sensitivity, specificity, and accuracy (all >95%) with high positive and negative predictive values at less than 24 hours.
- Missed fracture: Failure of identification and immobilization for more than 4 weeks after fracture increases nonunion rate almost tenfold.
- Classification
    - Locations (Fig. 7.15)
        - Tubercle, distal pole, waist (most common), proximal pole
        - Distal pole is most common in skeletally immature patients
    - Stability

        - Stable fractures: Transverse pattern, minimal comminution, and limited displacement
        - Unstable fractures: Vertical or oblique patterns, significant comminution, and wide displacement
    - CT: Required for determining displacement and stability
- Treatment
    - Nonoperative
        - Cast immobilization for nondisplaced fractures
        - No difference in the type of cast for union, with similar outcomes seen in long-arm vs. short-arm and standard vs. additional thumb spica component
        - Time to union: Increases as the fracture location becomes more proximal.
            - Consequently, length of cast immobilization should be greater for more proximal fractures.
        - CT is best modality to assess union rates after treatment.
    - Operative
        - **Indications**: proximal pole fracture, **more than 1 mm displacement**, intrascaphoid angle more than 35 degrees (humpback deformity), comminuted or vertical/oblique fracture, and transscaphoid perilunate dislocation
            - Faster time to union and return to work in nondisplaced waist fractures with operative than with nonoperative management
        - Minimally displaced fractures: May be treated with percutaneous internal

fixation using a headless compression screw

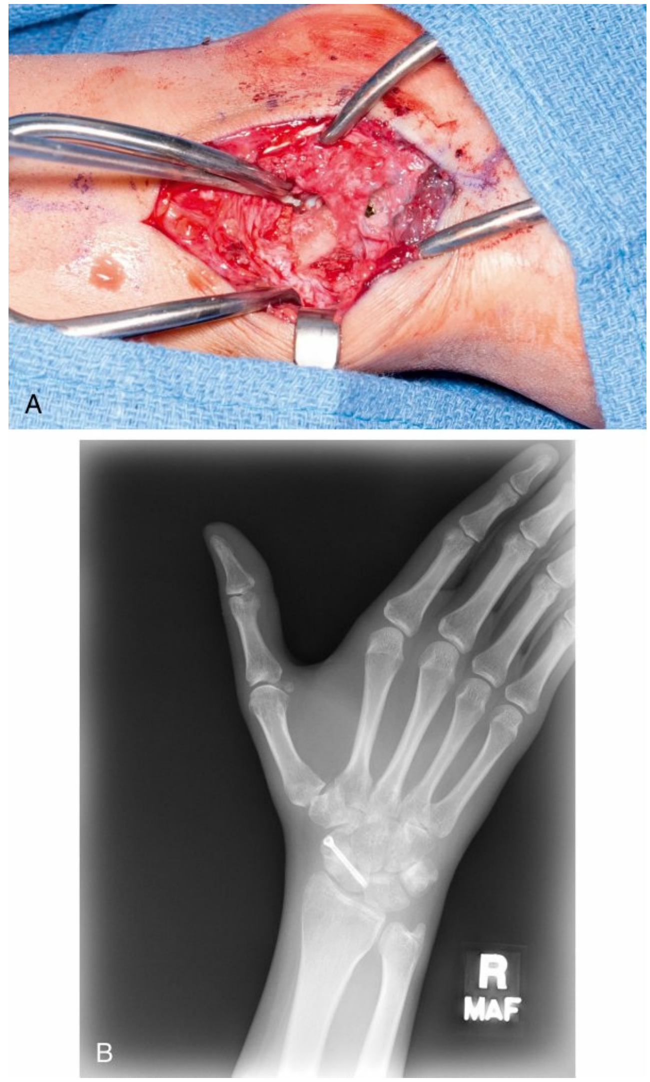


FIG. 7.16 (A) A lilac crest for scaphoid nonunion. (B) Healed scaphoid nonunion.

- Displaced fractures: Formal ORIF via dorsal or volar approach
    - Most critical technical factor: Guide-pin placement should be within the central axes of both the proximal and distal fragments.
    - **Approach: Volar and dorsal approaches have equivalent outcomes. In general, the dorsal approach is used for proximal pole fractures**

and the volar approach for distal pole injuries.

- Outcomes: Union rates of more than 90% expected with surgical treatment
- CT confirmation of union necessary before physical therapy is begun

- Complications
  - **Nonunion: Diagnosed on CT**
    - Symptomatic early-stage scaphoid nonunion may be treated with ORIF and bone grafting (using distal radius or iliac crest) (Fig. 7.16).
    - Vascularized proximal pole: Inlay (Russe) technique used in cases with minimal deformity
      - Best diagnosed with presence of intraoperative punctate bleeding

FIG. 7.17 Proximal row carpectomy.

    - **Humpback deformity: Requires open-wedge interposition structural**

graft to restore scaphoid length and carpal alignment

- **Vascularized bone grafting has a role in nonunion with an avascular proximal pole.**
- Bone most commonly harvested from dorsal aspect of distal radius, based on 1,2 intercompartmental supraretinacular artery (1,2 ICSRA)
- **For correction of both humpback deformity and avascular proximal pole: Free transfer of medial femoral condyle bone graft, supplied by descending medial genicular, and connected end-to-side to radial artery**
- *Scaphoid nonunion advanced collapse* (SNAC) wrist: Untreated, chronic scaphoid nonunion may lead to characteristic progression of posttraumatic osteoarthrosis
    - Stage I—radioscaphoid arthritis
    - Stage II—involvement of the scaphocapitate joint
    - Stage III—involvement of the lunocapitate joint
    - Options for treatment of SNAC wrist include radial styloidectomy, distal scaphoid resection (Malerich procedure), proximal row carpectomy (PRC), scaphoid excision and four-corner (bone) fusion, and total wrist fusion, depending on stage of presentation and surgeon preference (Figs. 7.17 and 7.18).

- **Other carpal bone fractures—small fraction of wrist injuries**
    - Lunate: May be seen with perilunate dislocation

- Treatment: Immobilization or ORIF if displaced

□ Capitate neck: Often occurs in combination with scaphoid fracture or perilunate dislocation

- Treatment: ORIF or intercarpal fusion

□ Triquetrum: Majority are dorsal capsular avulsion fractures (wrist sprains)

- Treatment: Brief period of immobilization; may be associated with an underlying LT ligament injury

FIG. 7.18 Four corner fusion.

FIG. 7.19 The carpal tunnel view demonstrates the hook of the hamate.
From Miller MD, Thompson SR, editors: *DeLee & Drez's orthopaedic sports medicine: principles and practice,* ed 4, Philadelphia, 2015, Elsevier Saunders, p 860.

- ▫ Hook of hamate: Often from blunt trauma to palm, frequently associated with sports (e.g., golf, baseball, hockey, racquet sports)
  - Imaging: Carpal tunnel radiographic view, CT (Figs. 7.19 and 7.20)
  - Treatment: Fragment excision in symptomatic patients in whom trial of cast immobilization fails
  - **Flexor tendon rupture of the ring/small finger may be seen with chronic nonunion.**
  - The examiner should be aware of the bipartite hamate, which may be differentiated from a fracture by its smooth cortical surfaces.
- ▫ Trapezoid or pisiform: Extremely rare
  - Pisiform fractures are treated with cast immobilization.
  - If symptomatic nonunion occurs, pisiform excision can be performed.

▪ **Carpal instability**

- ▫ Characterized by wrist pain, loss of motion, weakness (see Fig. 7.9)
- ▫ Lack of treatment may lead to degenerative arthritis and disability.

- □ Spectrum of injury: Occult (predynamic) to dynamic to static
    - Static instability: Seen on standard radiographs
    - Dynamic instability: Requires either stress radiographs or live fluoroscopy
- □ *Carpal instability dissociative* (CID): Instability between individual carpal bones of single carpal row, such as dorsal intercalated segmental instability (DISI) with an SL ligament injury and volar intercalated segmental instability (VISI) with an LT ligament injury (Figs. 7.21 and 7.22).
- □ *Carpal instability nondissociative* (CIND): Instability between carpal rows, such as midcarpal or radiocarpal instability.
- □ *Carpal instability adaptive (CIA):* Carpal instability resulting from a malunited distal radius fracture.
- □ *Carpal instability complex (CIC):* Perilunate dislocations combine CID and CIND.
- □ Specific injuries
    - DISI: Most common form of carpal instability; lunate and triquetrum tilt dorsally (see Fig. 7.9)
        - Etiology: SL ligament disruption
            - Dorsal fibers are stronger than volar fibers.
            - DISI develops after secondary injury to stabilizing dorsal and/or volar extrinsic ligaments, volar scaphotrapeziotrapezoid (STT) ligaments
        - Mechanism: Scaphoid hyperflexion and lunate hyperextension
            - May be traumatic or may result from inflammatory or crystalline arthropathy
        - Physical examination: Dorsal wrist pain with loading, diminished grip strength
            - Watson shift test: Reproduction of pain/palpable clunk with scaphoid shift test (dorsally directed pressure over volar scaphoid tubercle while wrist is brought from ulnar to radial deviation subluxates or dislocates scaphoid over dorsal ridge of distal radius that, when released, causes scaphoid to reduce with painful clunk)

- Bilateral nonpainful clunks constitute a negative test result.
- Diagnosis
  - Radiographs: Cortical ring sign showing flexion of the scaphoid, increased scapholunate angle (>70 degrees), or widened scapholunate interval (>3 mm).
    - Pencil test or bilateral clenched-fist (AP grip) comparison views: Dynamic DISI with relatively widened scapholunate interval on affected side (stress radiographs)
  - MRI: Best but not perfect for detection of SL ligament injury
  - Wrist arthroscopy: Gold standard to diagnose any wrist ligament injury (including SL)
    - Geissler classification (Table 7.2)
- Treatment: Depends on stage of instability
  - Partial ligament injuries (predynamic or dynamic instability): Nonoperative treatment or arthroscopic débridement.

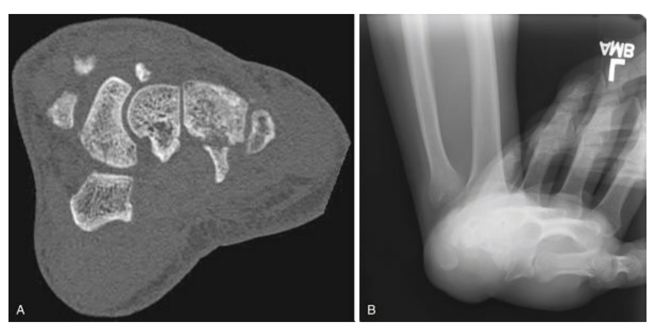


FIG. 7.20 (A) CT scan showing hook of hamate fracture. (B) Carpal tunnel radiographic view demonstrates excision of hook of hamate.

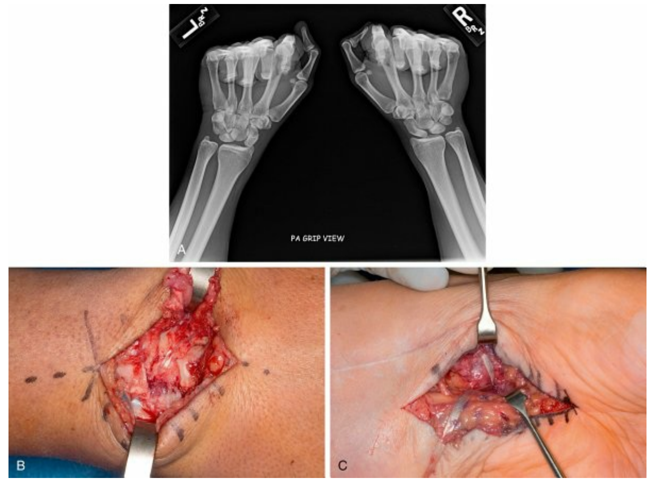


FIG. 7.21 (A) An SL diastasis on the left side (compare with right side). (B) Dorsal SL reconstruction. (C) Volar SL reconstruction.

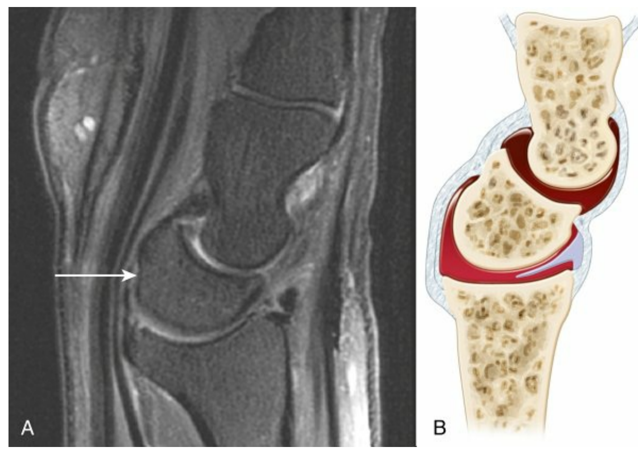


FIG. 7.22 Dorsal intercalary segmental instability. (A) The DISI posture of the lunate as seen on sagittal plane MRI in a patient with scapholunate dissociation. *Arrow* points to the abnormally extended lunate. (B) Artist's rendition of the DISI pattern.
From Miller MD, Thompson SR, editors: *DeLee & Drez's orthopaedic sports medicine: principles and practice*, ed 4, Philadelphia, 2015, Elsevier Saunders, p 831.

Table 7.2

Geissler Arthroscopic Classification of Scapholunate Ligament Disruption

Grade	Description
I	Attenuation or hemorrhage of interosseous ligament as seen from radiocarpal space. No incongruity of carpal alignment in midcarpal space.
II	Attenuation or hemorrhage of interosseous ligament as seen from radiocarpal space. There may be a slight gap (less than width of probe) between carpal bones in midcarpal space.
III	Incongruity or step-off of carpal alignment as seen from both radiocarpal and midcarpal spaces. Probe may be passed through gap between carpal bones.
IV	Incongruity or step-off of carpal alignment as seen from both radiocarpal and midcarpal spaces. There is gross instability with manipulation. A 2.7-mm arthroscope may be passed through the gap between carpal bones ("drive-through sign").

From Miller MD, Thompson SR, editors: *DeLee & Drez's orthopaedic sports medicine: principles and practice*, ed 4, Philadelphia, 2015, Elsevier Saunders, p 839.

- For acute SL ligament rupture: Rarely amenable to primary repair alone
- After delayed diagnosis of SL ligament rupture: Open reduction of scapholunate interval and K-wire pinning with or without dorsal capsulodesis or tendon autograft reconstruction
    - Various tendon (e.g., Brunelli) and bone-retinaculum-bone grafts have also been attempted for SL reconstruction.
    - Limited clinical data on reduction-association of scaphoid and lunate

        - (RASL) procedure or other forms of implants to span SL joint
- Scapholunate advanced collapse (SLAC): Chronic untreated static SL instability
    - Fig. 7.23 illustrates the three stages.
    - Radiolunate joint is often spared.
    - **Treatment: Depends on condition of articular surfaces and competency of the radioscaphocapitate ligament.**
        - Options include radial styloidectomy, PRC, scaphoid excision with four-corner arthrodesis, isolated capitolunate arthrodesis, and total wrist arthrodesis.
        - Partial wrist denervation: Excision of the terminal branch of the PIN ± AIN is often done in conjunction with these procedures but is also an option on its own.
- VISI: Second most common form of carpal instability; lunate and scaphoid tilt volarly (see Fig. 7.9)
    - Disruption of LT interosseous ligament
        - Volar fibers are stronger than dorsal fibers.
    - Static instability: Accompanying injury of the dorsal extrinsic ligaments (dorsal radiocarpal and intercarpal ligaments)
    - Physical examination
        - Ulnar-sided wrist pain
        - Lunotriquetral shear or shuck test
    - Diagnosis
        - Radiographic findings: Break in Gilula arc on posteroanterior view and scapholunate angle decreased to less than 30 degrees on lateral view
        - MRI may show pathology of LT ligament.
        - Wrist arthroscopy: Gold standard
    - Treatment
        - Direct volar lunotriquetral ligament repair
        - FCU tendon augmentation

- Lunotriquetral arthrodesis
- Ulnar shortening osteotomy for patients with concurrent ulnocarpal impaction syndrome

- Midcarpal carpal instability nondissociative (CIND)
  - Clunking wrist that may or may not be painful
  - Many patients have generalized ligamentous laxity.
  - History of trauma often absent
  - Sudden shift of proximal carpal row with active ulnar deviation

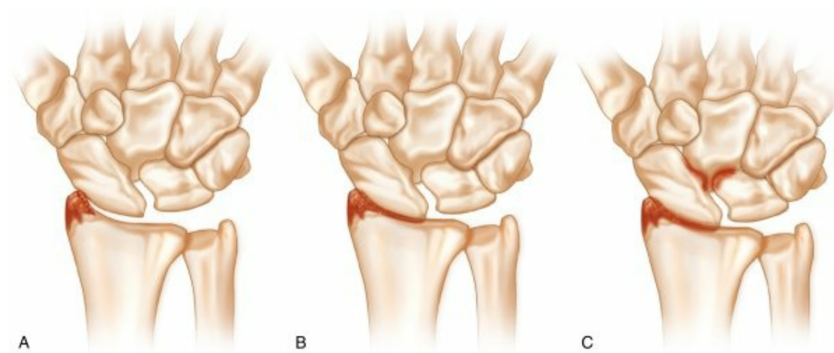


FIG. 7.23 Progression of scapholunate advanced collapse. (A and B) Progressive degenerative changes at the radioscaphoid joint. (C) With advancing carpal collapse, the capitate may migrate proximally, resulting in midcarpal arthritis and disruption of the radiographic Gilula lines.

  - Nonoperative management, including hand therapy and proprioceptive training, should be maximized.
  - Midcarpal fusion preferred over soft tissue reconstructions in patients in whom non-operative treatment fails, because the latter repair may stretch out.

- Radiocarpal dislocation (CIND)
  - Rare, high-energy injury
  - "Inferior arc" injury
  - May be associated with intracarpal injury, acute carpal tunnel syndrome, possible compartment syndrome, other major musculoskeletal and/or organ injuries
  - May be purely ligamentous or include radial and/or ulnar styloid fractures

- Ulnar translocation of the carpus signifies global ligamentous disruption.
  - The affected ligaments are:
    - **Volar extrinsic ligaments (in order, radial to ulnar):** Radioscaphocapitate, long radiolunate, short radiolunate, and radioscapholunate (also termed *ligament of Testut*—vestigial neurovascular contents)
    - Ulnocarpal ligaments: Ulnolunate, ulnotriquetral, and ulnocapitate
  - ORIF of radial styloid fractures may reduce ulnar translocation of the carpus by restoring radioscaphocapitate ligament stability.
    - May also require direct ligamentous repair and/or external fixation or bridge plate to neutralize forces
    - Associated intracarpal injuries treated simultaneously

- Carpal instability adaptive from distal radius malunion
  - May result from deformities with more than 30 degrees of dorsal angulation in the sagittal plane
  - Concern for midcarpal pain/arthritis
  - Treated with corrective osteotomy of the distal radius
- Perilunate dislocations (carpal instability complex)
  - Potentially devastating injuries resulting from forced dorsiflexion, ulnar deviation, and intercarpal supination
  - Approximately 25% of cases may be missed in the emergency department due to poor radiographs and lack of awareness. Key is to analyze the three

Gilula lines on an AP plain radiograph.

- Mayfield described four stages of perilunar disruption of ligamentous constraints, proceeding in counterclockwise direction
  - Stage I: Scapholunate disruption
  - Stage II: Capitolunate disruption
  - Stage III:
    - Lunotriquetral disruption
    - Dorsal midcarpal dislocation
    - Capitate appears dorsal to lunate on lateral view
  - Stage IV:
    - Circumferential disruption
      - Volar lunate dislocation: Osteonecrosis of the lunate avoided because of attached volar extrinsic (short radiolunate) ligament that maintains blood supply (Fig. 7.24)
- Lesser-arc injuries: Purely ligamentous
- Greater-arc injuries: Carpal fracture (transscaphoid most common)
- Treatment: Prompt attempt at closed reduction, especially in setting of acute carpal tunnel syndrome
      - Stable closed reduction may allow for delayed definitive surgical management, but there is no role for closed treatment alone.
  - Irreducible injuries necessitate urgent operative intervention.
    - ORIF may require dorsal

and/or volar approach.
- Combination of ligamentous repair, fracture fixation, dorsal capsulodesis, and K-wire pinning of proximal row and midcarpal joint (Fig. 7.25)
- Carpal tunnel release for associated acute carpal tunnel syndrome
- Cast immobilization for 2–3 months

- Late diagnosis leads to consistently poor outcomes
  - Methods of treating delayed and chronic perilunate dislocations are controversial.

FIG. 7.24 Posteroanterior *(left)* and lateral *(right)* radiographs of a perilunate dislocation. Notice the difficulty of assessing the dislocation on the posteroanterior view alone. On the lateral radiograph, the lunate is seen to be completely dislocated.
From Miller MD, Thompson SR, editors: *DeLee & Drez's orthopaedic sports medicine: principles and practice,* ed 4, Philadelphia, 2015, Elsevier Saunders, p 829.

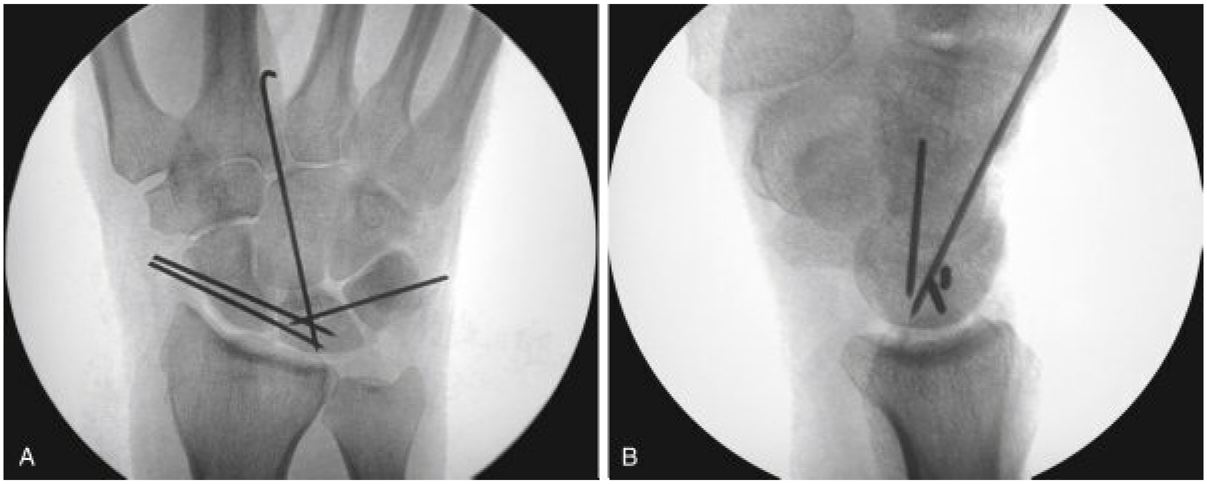


FIG. 7.25 Posteroanterior (A) and lateral (B) plain radiographs demonstrating the appropriate position of intercarpal pins after reduction and ligamentous stabilization of a perilunate dislocation. From Miller MD, Thompson SR, editors: *DeLee & Drez's orthopaedic sports medicine: principles and practice,* ed 4, Philadelphia, 2015, Elsevier Saunders, p 855.

Metacarpal and Phalangeal Injuries

- **Introduction**
  - Vast majority treated nonoperatively with splint or taping for less than 4 weeks
    - Intrinsic-plus splint
      - Wrist in 15–30 degrees of extension
      - MCP joints in 70–90 degrees of flexion to guard against stiffness secondary to the cam effect keeping collateral ligaments on stretch
      - Interphalangeal joints in neutral
    - Surgical intervention: Open injuries, intraarticular fractures, irreducible fractures, digit malrotation (scissoring), shortening, and multiple associated fractures
      - Digit rotation: Assessed statically with wrist tenodesis and dynamically as patient initiates making a fist
        - All fingertips should point toward volar scaphoid tubercle; should be compared with contralateral side.
    - Goals: Stable reduction, edema control, and early ROM.
- **Fractures and dislocations**
  - **Metacarpal head fracture**
    - Most commonly occurs in the index or middle finger
    - Some condylar injuries represent ligamentous avulsions
    - Surgical treatment
      - More than 1 mm of articular step-off: ORIF

        - Open fight bites: Early surgical débridement and assessment of extensor mechanism injury
        - Severe open or comminuted fractures (e.g., gunshot wounds): Spanning external fixation.
        - Severe comminuted closed fractures: Arthroplasty or arthrodesis (especially index MCP)
    - Joint stiffness: most common complication with both nonoperative and operative treatment.
- □ **Metacarpal neck fracture**
    - Weakest portion of metacarpal
    - Most frequently involves the ring and small fingers
    - Boxer's fracture: Metacarpal neck fracture of the small finger
    - Deforming forces: Intrinsic muscles lead to apex dorsal angulation.
    - Examiner should check for malrotation, pseudoclawing, and MCP joint extensor lag.
    - Nonoperative treatment: Most cases can be treated with closed reduction (dorsal pressure or Jahss maneuver) and 3–4 weeks of immobilization.
    - Acceptable angulation of each metacarpal neck
        - Index/long: less than 15–20 degrees
        - Ring: less than 30–40 degrees
        - Small: less than 60–70 degrees (controversial)
        - Greater compensation from more mobile fourth and fifth carpometacarpal (CMC) joints
    - Irreducible fractures: CRPP (antegrade, retrograde, or transverse)
- □ **Metacarpal shaft fracture**
    - Transverse, oblique, or spiral
    - Higher risk of malrotation: 5 degrees of malrotation results in 1.5 cm of digital overlap.
    - Acceptable angulation/shortening of each metacarpal shaft
        - Index/long: less than 10 degrees
        - Ring/small: less than 30 degrees
        - **All: less than 5 mm of shortening is acceptable without significant functional deficit.**
            - **Every 2 mm of metacarpal shortening leads to 7 degrees of extensor lag.**
    - Irreducible displaced fractures: CRPP or ORIF
        - Intramedullary pinning: Antegrade or retrograde
        - Lag screw fixation: Fracture length twice the bone diameter
        - Dorsal plates: Prominent dorsal plates irritate or

injure extensor tendons.

- Multiple metacarpal shaft fractures are unstable injuries that often necessitate surgical intervention.

□ **Metacarpal base fracture and CMC joint dislocation**

- Stable, minimally displaced fractures of metacarpal base are treated nonoperatively.
- Ring and small CMC joint fracture-dislocations often result from higher-energy mechanisms.
  - Radiographs: Pronated 30-degree oblique view
  - CT: For complex injuries
- Small-finger CMC joint fracture-dislocation is termed a reverse or baby Bennett fracture.
  - Extensor carpi ulnaris (ECU) tendon is major deforming force.
  - Accompanying distal row carpal fractures may be seen, especially of the hamate and capitate, which can signify high-energy mechanism.
  - Closed reduction may be attempted, but these are unstable injuries that often require surgical stabilization via CRPP or ORIF. Over the fourth and fifth CMC joints, care must be taken not to injure the dorsal sensory branch of the ulnar nerve during open approaches.
- Delayed treatment, painful malunion, or posttraumatic osteoarthrosis may require arthrodesis.

□ **Thumb metacarpal fracture**

- Most common pattern is extraarticular basilar fracture.
  - Acceptable angulation: Up to 30 degrees, secondary to compensatory CMC joint motion
  - Excessive angulation: MCP joint hyperextension, requiring CRPP or ORIF
  - Mnemonic for reduction maneuver is TAPE: *t*raction, *a*bduction, *p*ronation, and *e*xtension of thumb metacarpal (©Kakar).

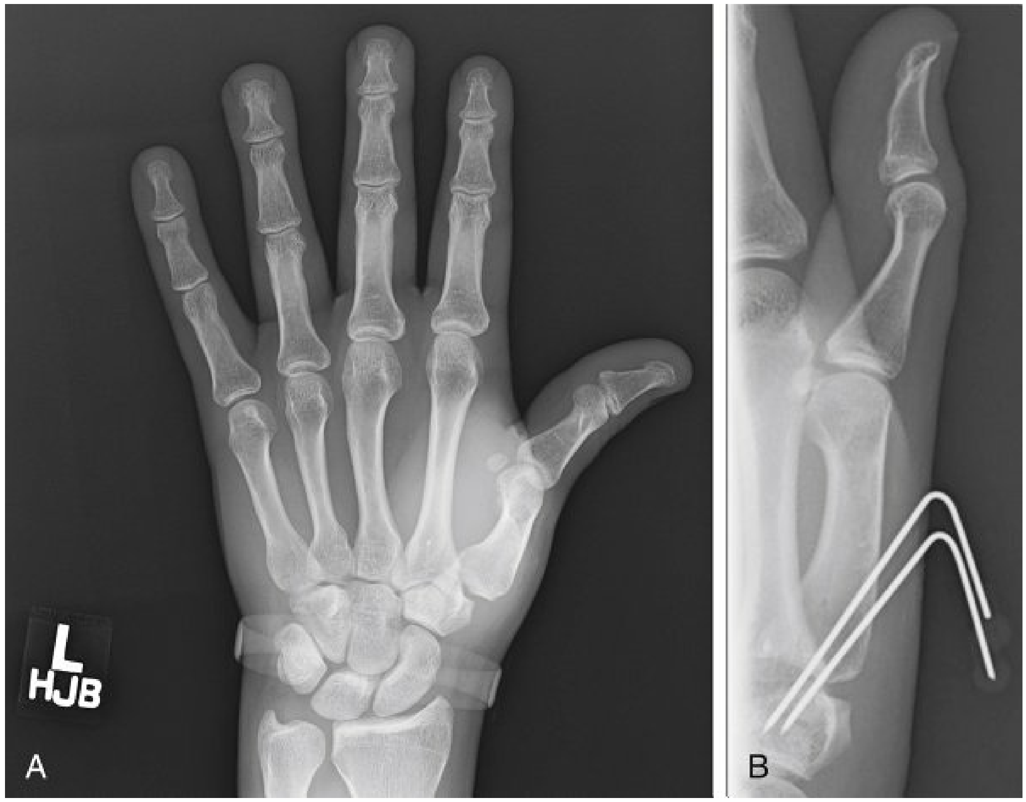


FIG. 7.26 (A) Bennett fracture of the left thumb. (B) Closed reduction and percutaneous pinning of thumb.

- Bennett fracture: Intraarticular fracture-dislocation (Fig. 7.26)
    - Deforming forces: Abductor pollicis longus (APL) and thumb extensors cause proximal, dorsal, and radial displacement of the metacarpal shaft.
        - APL causes supination and adduction of the metacarpal shaft.
        - Anterior oblique or "beak" ligament keeps the volar-ulnar base fragment reduced to the trapezium.
    - Treatment: CRPP or ORIF based on the size of fragment
        - Reduction: Traction, palmar abduction, and pronation
        - Goal: More than 1–2 mm of articular step-off
- Rolando fracture: Comminuted intraarticular fracture (T or Y shape) (Fig. 7.27)
    - CRPP, ORIF, and external fixation: All options, depending on degree of comminution and surgeon experience

□ Thumb MCP ligamentous injuries

- Injuries: Acute (skier's thumb) or chronic (gamekeeper's thumb) injury to the ulnar collateral ligament (UCL) of the thumb via supination of the proximal phalanx around intact

RCL

- UCL function is critical for strong, effective pinch.

- Mechanism of injury: Forceful thumb hyperextension and/or hyperabduction
- Spectrum of injury: Dorsal-to-volar, involving proper UCL, accessory UCL, and volar plate. Ligament injury tends to occur at its insertion at the base of the proximal phalanx.
- Radiographs: Obtained prior to stress examination to rule out bony avulsion injury.

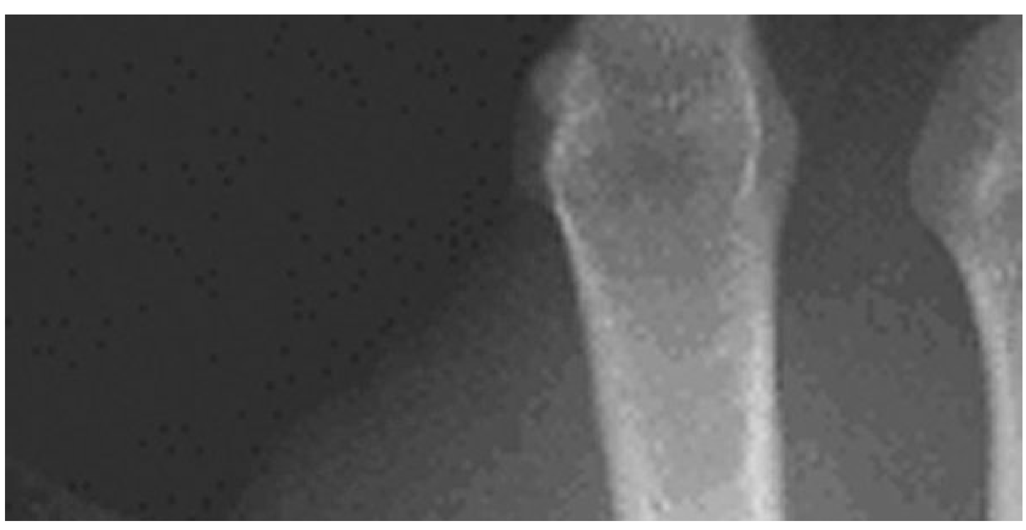
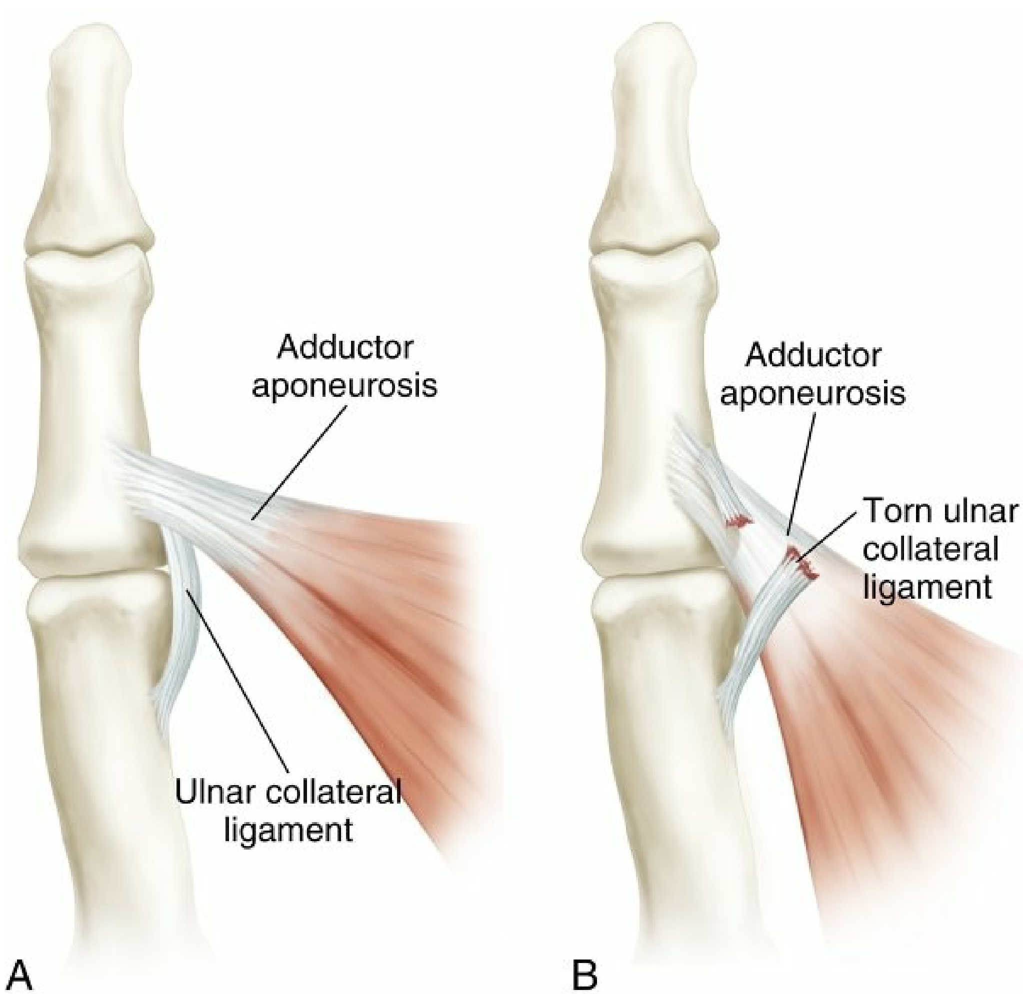


FIG. 7.27 Radiograph of a Rolando fracture, which is a comminuted injury of, in this case, the first metacarpal base.
From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 66.

- MCP stress test (in the absence of fracture): MCP joint is stressed with radial deviation both in neutral and in 30 degrees of flexion.
  - Instability in 30 degrees of flexion: Proper UCL and/or dorsal capsule injury
  - Instability in neutral: Accessory UCL and/or volar plate injury
  - Threshold: More than 35 degrees of opening or more than 20 degrees of difference from opening of uninjured thumb
- Complete vs. partial tears: Difficult to differentiate by physical examination alone
  - Diagnosis: Stress radiographs and/or MRI

- Partial injuries: Treated with thumb spica cast immobilization for 4–6 weeks.
- Stener lesion: Occurs in 85% of complete injuries when the adductor pollicis aponeurosis is interposed between the avulsed UCL and its insertion site on the base of the proximal phalanx (Fig. 7.28)
    - Treatment: Surgical reattachment of ligament through drill holes, suture anchor, or interference screw.
- Large displaced avulsion fracture of the base of the proximal phalanx: Requires ORIF



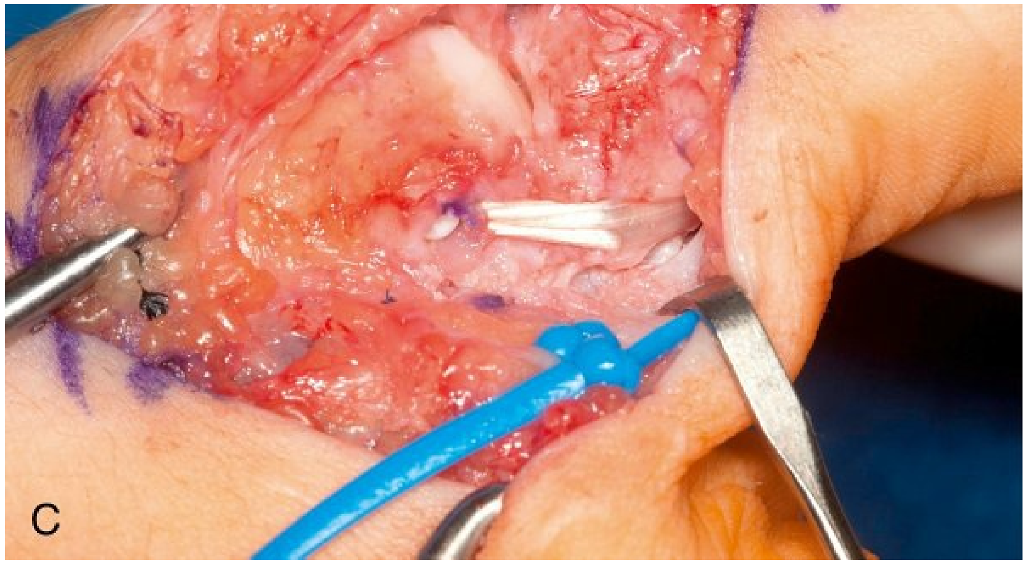


FIG. 7.28 (A–C) Stener lesion. The adductor aponeurosis separates the two ends of the ulnar collateral ligament, and the aponeurosis must be incised to repair the ligament.
From Morrison WB, Sanders TG: *Problem solving in musculoskeletal imaging,* Philadelphia, 2008, Elsevier.

- Chronic UCL injuries: Ligament reconstruction with either adjacent joint capsule or tendon graft, ± pinning of joint.
  - Posttraumatic osteoarthrosis: MCP arthrodesis
- Radial collateral ligament (RCL) injury: RCL instability is due to overpull of adductor, which causes proximal phalanx to pronate around intact RCL. It is much more rare than the UCL tears, but has a similar evaluation and treatment approach.
- Isolated injuries to the thumb MCP radial collateral ligament: After a forced flexion-ulnar deviation mechanism
  - Nonoperative treatment in most cases
  - Surgery: For high-grade or complete tears associated with volar MCP subluxation. Ligament injury tends to occur at its origin at the metacarpal.

□ MCP joint dislocation

- Classified as simple (reducible) or complex (irreducible)
- Dorsal dislocations are most common
  - Pathognomonic diagnosis: Skin dimpling in distal palm
  - **Kaplan's lesion: Irreducible dorsal dislocation with volar plate interposed between base of proximal phalanx and metacarpal head**
    - Index, small fingers most frequently involved
    - Nonoperative treatment: Closed reduction to reduce P1 perched on

metacarpal

- Technique: Direct pressure is applied over P1 with wrist in flexion to relax extrinsic flexors
- Longitudinal traction and MCP hyperextension should be avoided because they may cause volar plate to get caught in joint.

- Complex dislocation: P1 and metacarpal are in bayonet position, and interposition of volar plate and/or sesamoids likely
  - Usually irreducible by closed means
  - Treatment: Open reduction through dorsal or volar approach
    - Volar approach risks iatrogenic neurovascular injury because displacement brings the digital nerve closer to the skin.
    - A1 pulley is divided to loosen noose around metacarpal head, and volar plate extracted.

□ Boxer’s knuckle

- Most common hand injury in both amateur and professional fighters
- The extensor hood of the MCP joint is ruptured, leading to increased risk of chondral injury and osteoarthrosis of the joint.
- Presentation: Swelling, reduced range of motion (ROM), and occasional extensor lag
- Treatment: Direct repair of the extensor hood

□ Injuries to P1 and P2 phalanges

- P1 fractures deform with apex volar angulation.
  - Proximal fragment flexion (interossei)
  - Distal fragment extension (central slip)
- P2 fractures deform with apex dorsal or volar angulation.
  - Proximal to FDS insertion: Apex dorsal
  - Distal to FDS insertion: Apex volar
- Nonoperative (most): Less than 10 degrees of angulation and no rotational deformity
  - Three weeks of immobilization followed by ROM

exercises
- Radiographic union lags behind clinical union by several weeks
- Surgery: Irreducible or unstable fracture patterns
    - Crossed Kirschner wires
    - Eaton-Belsky pinning through metacarpal head
    - Minifragment fixation (lag screws ± plate)
    - External fixation: Highly comminuted intraarticular fractures, gross contamination, and/or segmental bone loss

□ PIP joint dislocation

- Dorsal dislocation most common
    - Injury to volar plate and at least one collateral ligament
    - Simple dislocation: Middle phalanx in contact with condyles of proximal phalanx
        - Treatment: Reduction with longitudinal traction
    - Complex dislocation: Base of middle phalanx no longer in contact with condyle of proximal phalanx, leading to a bayonet appearance
        - Volar plate blocks reduction by longitudinal traction.
        - Reduction maneuver: Hyperextension of middle phalanx followed by a volar-directed pressure
        - **After reduction: Short-term buddy taping**
        - Persistent instability: Rare, treated with dorsal block splinting
        - Persistent swelling and soreness for months is common with stiffness or a flexion contracture.
    - Irreducible complex dislocations: Open reduction via a dorsal approach and incision between the central slip and lateral band
- Volar dislocation
- Rare closed injury to central slip and at least one collateral ligament
- Treatment: Closed reduction with flexion followed by

assessment of active extension

- Stable injuries without excessive extensor lag: Temporary splinting
- Significant extensor lag following reduction: Central slip repair followed by 6 weeks of immobilization in full extension of the PIP joint but with encouragement of ROM of the DIP joint

- Boutonnière deformity: Inadequate treatment due to retraction of the central slip and volar translation of the lateral band secondary to triangular ligament injury
- Rotatory dislocation
  - One of the phalangeal condyles is buttonholed between central slip and lateral band
  - Unlike other PIP dislocations, this often requires open reduction

□ PIP joint fracture-dislocation

- Dorsal dislocation accompanied by fracture at P2 base (Fig. 7.29)
- Hastings classification based on amount of P2 articular surface involved (Table 7.3)
- Treatment
  - Dorsal block splinting, dorsal block pinning, ORIF, or hemihamate reconstruction
  - More than 30% of involvement of the base of the proximal phalanx tends to lead to persistent dorsal subluxation of the PIP joint; surgical reconstructions such as volar plate arthroplasty and hemihamate transfer aim at restoring the volar buttress to dorsal displacement.
  - Maintenance of adequate joint reduction is most important factor for favorable long-term outcome.
  - Chronic PIP fracture-dislocations without severe posttraumatic osteoarthrosis: Hemihamate reconstruction or volar plate arthroplasty, depending on functional demands of the patient.

FIG. 7.29 (A) An apex volar fracture of the proximal phalanx. (B) An AP radiograph of dynamic traction device to treat PIP joint fracture-dislocation. (C) A lateral radiograph showing dynamic traction device and dorsal block pin. Note the concentric reduction of the joint. (D) ORIF metacarpal fracture.

Table 7.3

Classification of PIP Joint Fracture-Dislocations (Hastings)

Type	Amount of P2 Articular Surface Involved (%)	Treatment
I—stable	<30	Dorsally based extension block splint
II—tenuous	30–50	If reducible in flexion, dorsally based extension block splint or dorsal blocking K-wire
III—unstable	>50	ORIF, hemihamate autograft, or volar plate arthroplasty

- PIP posttraumatic arthritis: Silicone arthroplasty or arthrodesis
- Highly comminuted pilon fractures are best handled with dynamic distraction external fixation for simple ligamentotaxis and early ROM.

- DIP dislocation and distal phalanx fractures
  - Reducible DIP dislocation: Closed reduction and immobilization in slight flexion with a dorsal splint for 2 weeks
  - Irreducible DIP dislocation: Caused by interposition of the volar plate
    - Treatment: Open reduction and extraction of the volar plate
  - Stable tuft fracture (common): No specific treatment apart from temporary splinting
  - Open injuries: Irrigation and débridement, reduction, nail bed repair (if necessary), antibiotics, tetanus prophylaxis, and splinting
  - Unstable displaced fractures of the distal phalanx: Percutaneous pinning to support the nail bed repair
  - Common associated injuries: Soft tissue and/or nail bed disruption
  - Highly comminuted injuries with significant soft tissue loss: Revision amputation (shortening and closure)
  - Seymour fracture: A transverse physeal injury that may become displaced and require extraction of interposed nail matrix to prevent malunion. This is considered an open fracture.
  - For further details see the section Nail and Fingertip Injuries.

Tendon Injuries and Overuse Syndromes

- **Extensor tendon injury**
  - Description and treatment are based on zones of injury (Fig. 7.30)
  - Most commonly injured digit is long finger
  - Partial lacerations less than 50% of tendon width: Do not require direct repair if patient can extend finger against resistance
    - Treatment: Early protected motion to prevent tendon adhesions
  - Complete (or partial >50% width) lacerations: Direct suture repair
    - Postoperative rehabilitation: Based on zone of injury
  - Specific injuries
    - **Zone I injury (mallet finger)**
      - Location: Terminal extensor tendon at or distal to DIP joint
      - Mechanism: Sudden forced flexion of the extended fingertip

- Presentation: Patient cannot actively extend at DIP joint, and finger remains in flexed posture.
- Bony mallet: Bony avulsion injury from dorsal base of P3 (bony mallet)
- Nonoperative treatment: If detected less than 12 weeks of injury
    - DIP joint extension splinting for 6 weeks, followed by part-time splinting for an additional 4–6 weeks
    - No proven best type of splint
- Hyperextension should be avoided because it can cause skin necrosis.
- Maintenance of PIP joint motion often overlooked
- Nondisplaced bony mallet finger: Extension splinting until fracture union
- Displaced bony mallet finger: Controversial surgical indication
    - Treatment options: CRPP through DIP joint or extension block pinning if there is joint subluxation on the lateral radiograph or >50% articular surface
- Chronic mallet finger (>12 weeks after injury)
    - Closed treatment: If joint supple, congruent, and without arthritic changes
    - Dynamic splinting + serial casting: Contracted joint
    - Operative treatment: Tenodermodesis, Fowler tenotomy
- Prolonged DIP flexion: Associated with swan neck deformity from dorsal subluxation of lateral bands and corresponding PIP joint hyperextension
    - Supple swan neck deformities may be treated with
        - Fowler central slip tenotomy (maximum deformity 35 degrees), which allows the extensor apparatus to slide proximally, thereby increasing its

effective pull at the DIP joint.

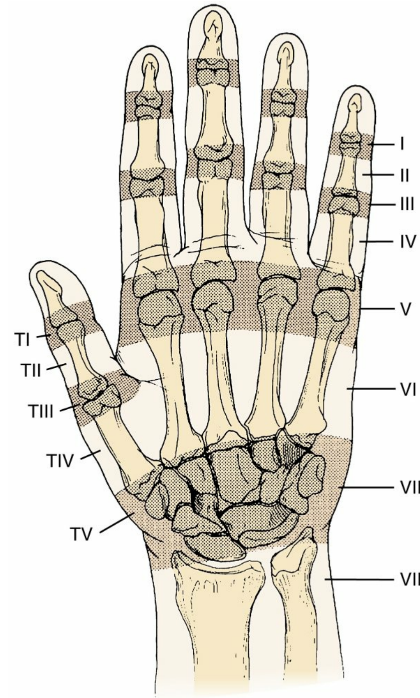


FIG. 7.30 Zones of the extensor tendon system. *T,* Thumb. From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 203.

- Boutonnière deformity is prevented by not injuring the triangular ligament, thereby keeping the lateral bands dorsal of the midline in the sagittal plane.
- Spiral oblique retinacular ligament (SORL) reconstruction

- DIP joint arthrosis: DIP arthrodesis.

- **Zone II injury**
    - Location: Middle phalanx of digit or over proximal phalanx of thumb
    - Mechanism: Dorsal laceration or crush component
    - Partial disruptions (<50%): Local wound care and

early mobilization
- Lacerations more than 50%: Direct surgical repair
- Controversial: Temporary pinning across terminal joint after direct repair

- **Zone III injury (boutonnière)**
  - Location: PIP joint of digit (central slip) or MCP joint of thumb
  - Open injuries: Directly repaired if possible
    - Loss of tendon substance: Free tendon graft or extensor mechanism turndown flap
  - Elson test: Examiner performs by flexing the patient's PIP joint 90 degrees over the edge of a table and asking patient to extend the PIP joint against resistance.
    - Central slip intact: The DIP joint will remain supple as the power of extension is focused at the central slip insertion with the lateral bands remaining lax.
    - Central slip rupture: The DIP joint will be rigid as the power of extension is diverted to the lateral band rather than the central slip.

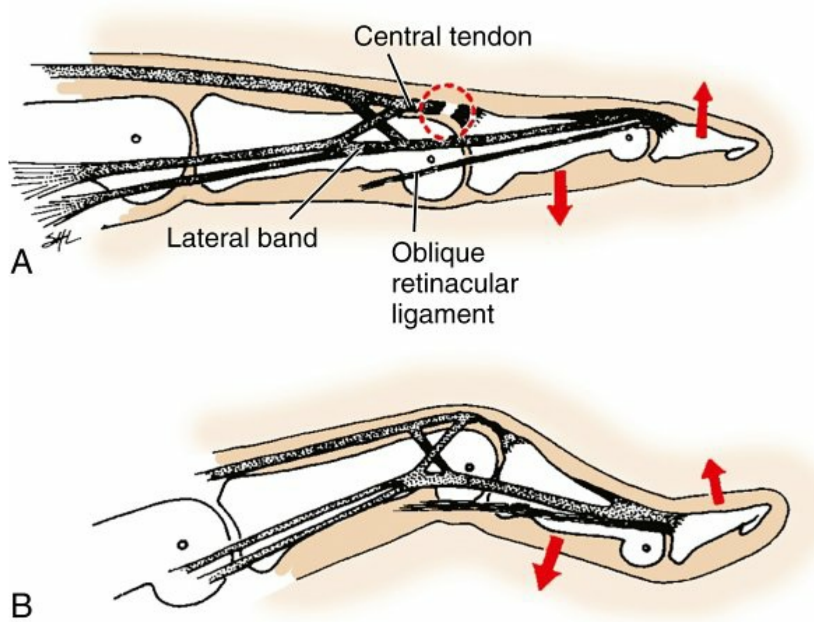


FIG. 7.31 Pathomechanics of the boutonnière deformity. (A) Attenuation of the central slip results in unopposed flexion at the PIP joint. (B) With PIP joint flexion, the lateral bands drift volar to the axis of rotation at the PIP joint. The lateral bands stay in the volar position owing to loss of dorsal support from the attenuated triangular ligament and contracture of the transverse retinacular ligament.

From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 175.

- Acute boutonnière deformity: Results from central slip disruption and volar subluxation of the lateral bands, resulting in DIP hyperextension (Fig. 7.31)
- Closed injury: Full-time PIP extension splinting for at least 6 weeks, followed by part-time splinting for an additional 4–6 weeks.
    - DIP flexion maintained to balance extensor mechanism by encouraging the lateral bands to drift dorsal of the midline in the sagittal plane.
- Chronic (untreated) boutonnière deformity
    - May require dynamic splinting or serial casting to achieve maximal passive motion first
    - Terminal extensor tenotomy, PIP volar plate release
    - Central slip reconstruction techniques: Tendon graft, extensor turndown, lateral band mobilization with transverse retinacular ligament release

- PIP joint arthrosis: PIP arthrodesis
- Zone IV injury
  - Location: Proximal phalanx of digit or over the metacarpal of thumb
  - Treatment: Similar to that for injuries in zone II
  - Common complication: Adhesion formation leading to loss of digital flexion
    - Prevention of adhesion formation: Early protected ROM and dynamic splinting
    - Failure of nonoperative management may require extensor tenolysis.
- Zone V injury
  - Location: MCP joint of digit or over CMC joint of thumb
  - Treatment (most): Early mobilization and dynamic splinting
  - Fight bite: Surgical débridement of the MCP joint with loose or delayed wound closure
    - Most common organism: *Eikenella corrodens*
    - Extensor lag and loss of flexion are common.
  - Sagittal band rupture (flea-flicker injury): From forced extension of flexed digit
    - Long finger most commonly injured
    - Rupture of the stronger radial fibers may lead to extensor tendon ulnar subluxation/dislocation.
    - Finger will be held in flexed position at MCP joint with no active extension.
    - Passive extension of the MCP joint is possible, and the patient can then usually maintain the finger in an extended position.
    - Treatment
      - Acute injuries: 4–6 weeks of extension splinting of the MCP joint (one of the only exceptions to splinting the MCP joints in flexion).

- Failure of nonoperative management or missed injuries: Repair or reconstruction of the sagittal band
- Zone VI injury
  - Location: Metacarpal and represents most frequently injured zone
  - Associated injuries: Lacerations of superficial veins and nerves
  - Laceration more than 50% tendon: Direct surgical repair
  - Early protected motion advocated postoperatively
    - Dynamic splinting may offer better short-term ROM and strength, without increased complications, than static splinting.
  - Good prognosis is good in the absence of concurrent bony injury.
- Zone VII and VIII injuries
  - Location: Level of the wrist joint (VII) and distal forearm at the musculotendinous junction (VIII)
  - Lacerations at wrist level are usually associated with extensor retinaculum disruption, and postoperative adhesions are common.
  - Treatment
    - The retinaculum should be repaired to prevent tendon bowstringing.
    - Static immobilization with the wrist held in extension and the MCP joints partially flexed for the first 3 weeks, followed by protected motion
    - The results of surgical repair in these zones are not as good as those in zones IV, V, and VI.

▪ **Flexor tendon injury**

□ Overview

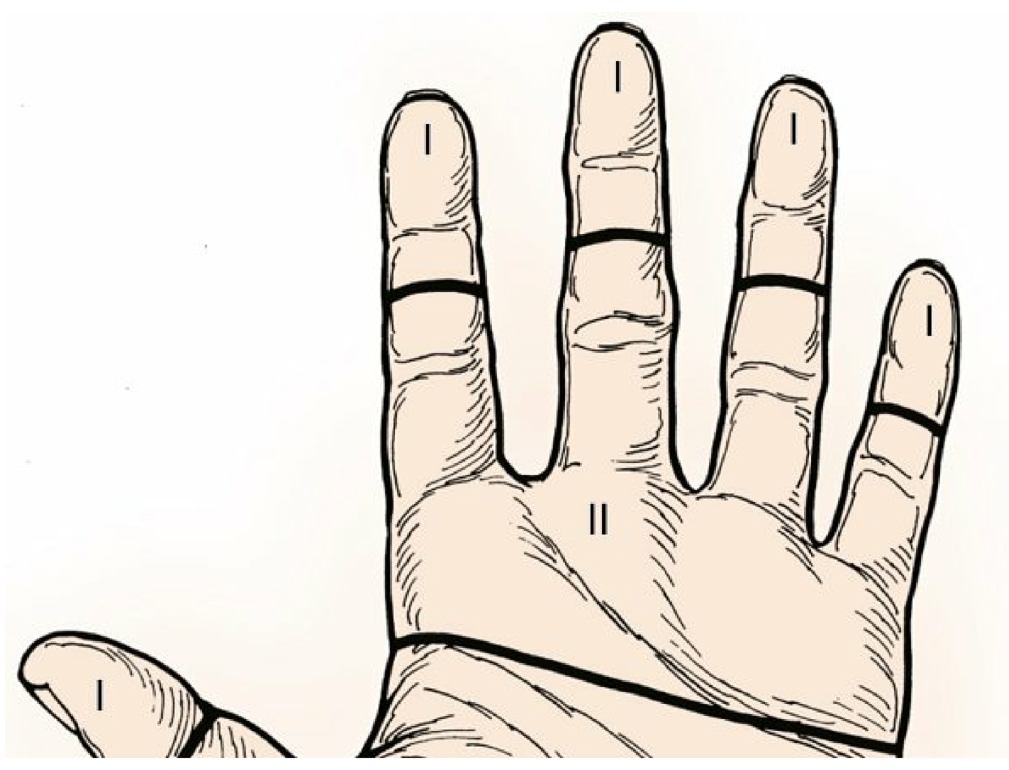
- Concomitant neurovascular injury is common when associated with lacerations.
- Physical examination: Examiner should note the resting posture of the hand and check the tenodesis effect with passive wrist flexion and extension.
  - Each digit should be tested in isolation for active

DIP (FDP function) and PIP flexion (FDS function).

- Treatment
    - **Partial lacerations may be associated with gap formation or triggering with nonoperative treatment**
    - **Triggering treatment: Trimming tendon ends or performing epitendinous repair**
    - **Lacerations more than 60% tendon width: Simultaneous core and epitendinous repair within 3 weeks (ideally <10 days of injury)**

□ Basic surgical techniques of flexor tendon repair

- Strength of repair proportional to number of suture strands that cross repair site (core sutures)



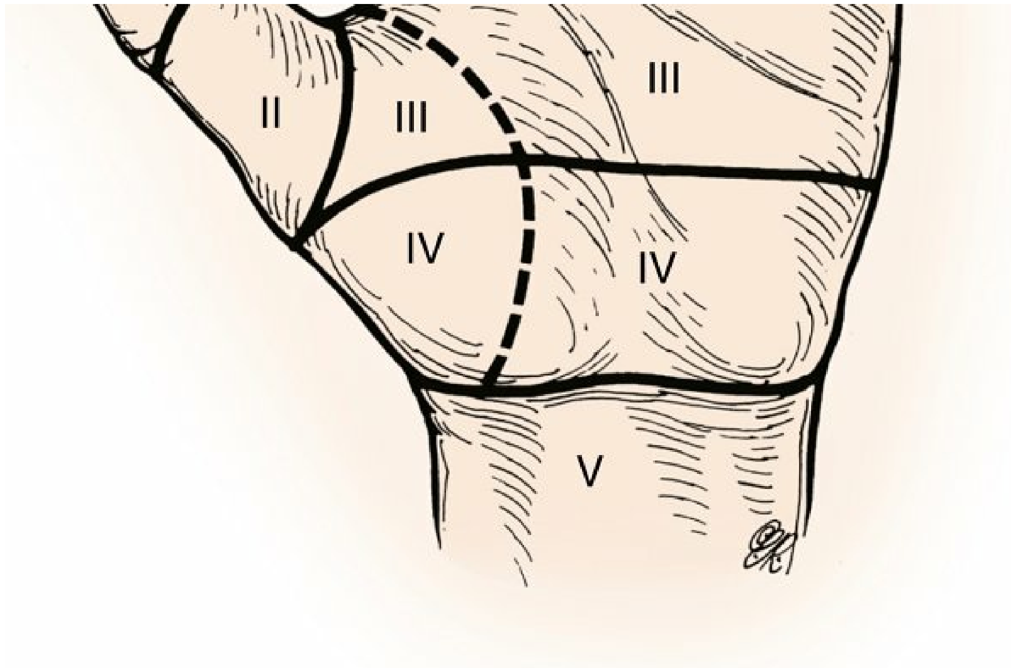


FIG. 7.32 Zones of the flexor tendon system.

- 6–8 strands have superior strength and stiffness
- High-caliber (e.g., 5-0 instead of 6-0) suture material decreases gap formation and increases strength and stiffness.
- A locking-loop configuration decreases gap formation.
- Epitendinous repair decreases gap size and increases overall strength by 10%–50%.
- *Purchase,* defined as the longitudinal distance from cut tendon end to transverse component of the core suture, should be 0.7–1.2 cm.
- Dorsally placed core sutures are stronger.
- Repair of the flexor tendon sheath has no effect on flexor tendon repair.
- Atraumatic, minimal-touch technique minimizes adhesions.
- A2 (most important) and A4 pulleys (oblique pulley in thumb) must be preserved to prevent bowstringing.
- Risk of tendon rupture greatest 3 weeks after repair; failure typically occurs at suture knots.
- **Wide awake local anesthesia no tourniquet [WALANT] (uses lidocaine *with* epinephrine) allows one to perform flexor tendon repair with the patient wide awake to allow testing of the integrity of the repair.**
- Early protected ROM is thought to increase tendon excursion, decrease adhesion formation, and increase repair strength.
- Postoperative use of an active flexion protocol requires a minimum four-strand repair with epitendinous suture.
- Young children cannot comply with protected motion

protocols so require cast immobilization for 4 weeks.

- Tendon healing factors
  - Intrinsic healing is directed by tendon fibroblasts (tenocytes)
  - Extrinsic healing potential is limited
    - Only small contribution from repair cells within tendon sheath or from vascular invasion
  - Tendon healing is strongly influenced by biomechanical stimuli, and early mobilization has been shown to decrease adhesion formation and increase the strength of repair tissue.

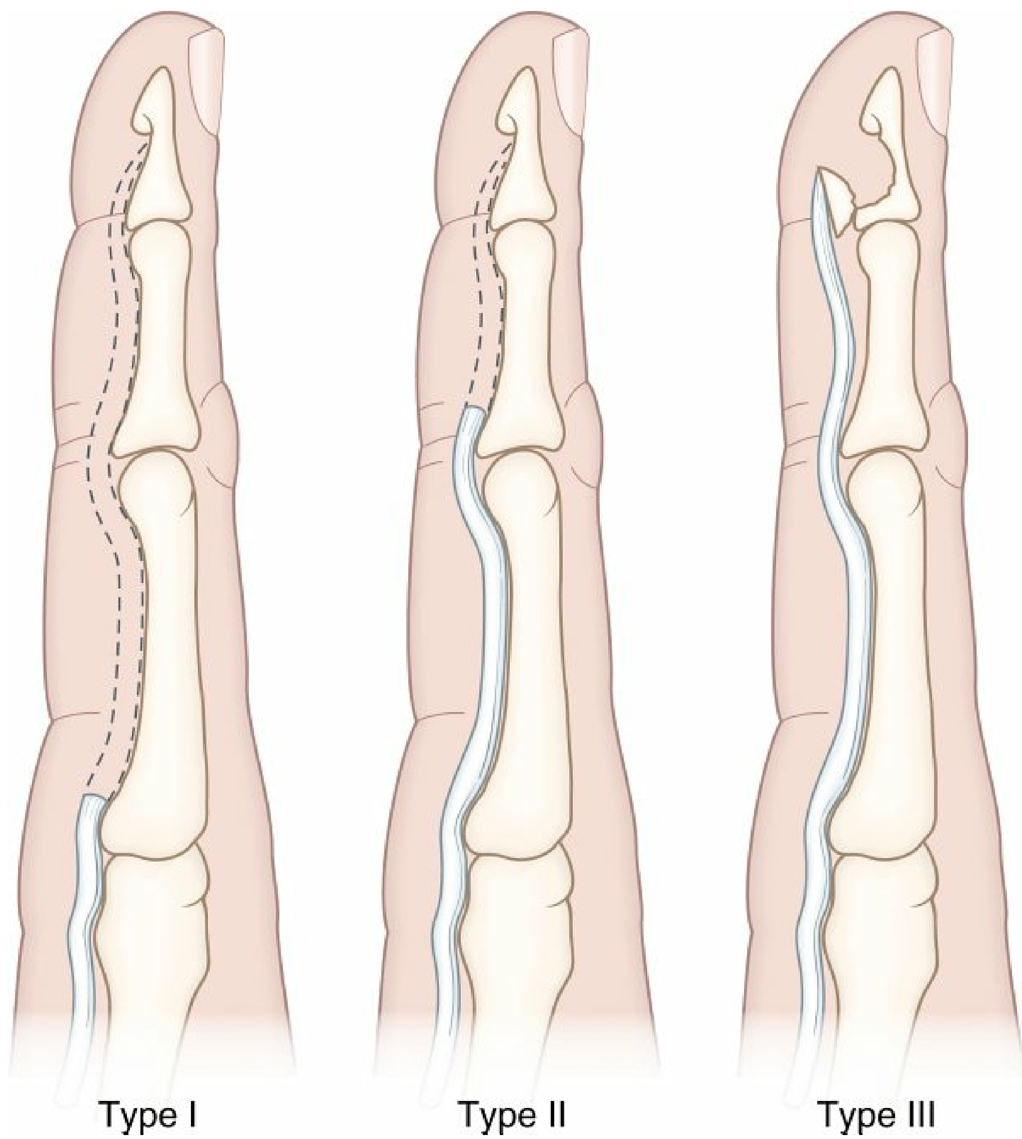


FIG. 7.33 Classification of profundus tendon avulsions.
From Tang JB, editor: *Tendon surgery of the hand,* Philadelphia, 2012, Elsevier Saunders, p 220.

- No definitive evidence of growth factor or stem cell augmentation of healing

- Treatment according to Verdan zones (Fig. 7.32)
  - Zone I injury (rugger jersey finger)
    - Location: FDP avulsion distal to the FDS insertion

- Tendons involved: FDP only
- Mechanism: Forced extension of the DIP joint during grasping
- The ring finger is involved in 75% of cases.
- Classification: Leddy and Packer (Fig. 7.33)
    - Type I: FDP is retracted to the palm; requires direct repair within 7–10 days.
    - Type II: May be directly repaired up to 6 weeks later because the intact vincula prevent FDP retraction proximal to the PIP joint
    - Type III: Associated with small bony avulsion fragment with minimal retraction as the fragment is caught upon the pulley; may be successfully repaired up to 6 weeks after injury
    - Type IV: FDP is avulsed off bony fragment and as such can retract proximally and requires expeditious repair (rare subtype).
- Key point: Profundus advancement of 1 cm or more carries a risk of DIP joint flexion contracture or quadrigia.
    - Quadrigia: FDP tendons (middle, ring, small) have a common muscle belly, so distal advancement of one tendon compromises flexion of the adjacent digits, because the advanced FDP tendon has greater tension in comparison with the laxity of the adjacent FDP tendons. As such, when the advanced FDP tendon contracts, the efficiency of contraction of the adjacent FDPs is decreased, resulting in decreased DIP joint motion of the adjacent digits.
- Full PIP flexion in chronic injuries: Treated with observation or DIP arthrodesis in a functional position
- Intact FDS function should never be sacrificed to permit reconstruction of an injured FDP tendon.
- **Two-stage flexor tendon reconstruction with**

silicone rod can be considered in young motivated patients, although the results can be unpredictable.

- Zone II ("no man's land") injury
    - Location: Between the FDS insertion and the distal palmar crease within flexor tendon sheath
    - Tendons involved: Both the FDS and FDP may be injured.
    - Key point: Tendon lacerations may be at a different level from that of the skin laceration, depending on the position of the finger when the laceration occurred.
    - Treatment: Direct repair of both tendons with a core and epitendinous suture technique followed by an early mobilization protocol
    - Outcomes: Historically poor owing to the high rate of adhesion formation at the pulleys and associated digital neurovascular injuries
        - Although advances in postoperative rehabilitation have improved the clinical outcomes, up to 50% of patients require subsequent tenolysis to enhance active motion at least 3 months after repair.
- Zone III injury
    - Location: Occurs between the distal palmar crease and the distal end of the carpal tunnel
    - Tendons involved: Both FDP and FDS can be injured.
    - Treatment: In comparison with results of zone II injuries, those of direct repair are much better owing to a lack of the pulley system and hence fewer adhesions.
    - Key point: Lumbrical muscles originate from the radial aspect of FDP tendons in zone III.
- Zone IV injury
    - Location: Within the carpal tunnel
- Zone V injury
    - Location: Between proximal carpal tunnel and musculotendinous junction
    - Treatment: Direct repair in this zone has a favorable prognosis.
    - Outcomes: Results may be compromised by

coexisting nerve injury.

- □ FPL injury
  - Zone I injuries: Distal to IP joint
  - Zone II injuries: Between IP and MCP joints
  - Zone III injuries: Deep to thenar muscles
  - Postoperative rehabilitation
    - Two most common rehabilitation protocols are those of Kleinert and Duran.
      - Kleinert protocol: Dynamic splinting, allowing for active digit extension and passive digit flexion
      - Duran protocol: Other hand used to perform passive digital flexion exercises
        - Requires strict patient compliance
      - Both protocols: Avoidance of active flexion for 6 weeks
      - Newer advancements: Components of early active digital flexion added to reduce adhesion formation and increase tendon excursion
    - These protocols require stronger repair methods (i.e., use of a minimum of four core sutures).
- □ Flexor tendon reconstruction
  - Indication: Failed primary repair or chronic, untreated injuries
  - Requirements: Supple skin, a sensate digit, adequate vascularity, and full passive ROM of adjacent joints
  - The majority of cases require two-stage reconstruction.
    - Stage I: Implantation of a temporary silicone (Hunter) rod that is secured distally but allowed to glide proximally to recreate a “tunnel” for the new tendon to glide through
      - A2 and A4 pulleys preserved or reconstructed
    - Stage II: Performed more than 3 months later, once full passive ROM has been attained and a sheath has formed around the silicone rod.
      - Rod is removed and tendon autograft is passed through the sheath
      - Grafts
        - Extrasynovial (e.g.,

palmaris longus or plantaris): Act as scaffold to allow tenocytes infiltration and collagen deposition
        - Intrasynovial (e.g., FDS): Retain their gliding surface and heal intrinsically
    - Postoperative rehabilitation: Despite the need for an intensive program, subsequent tenolysis is often required (>50%).

- **Stenosing tenosynovitis (trigger finger)**
    - Demographics
        - Women older than 50 years of age
        - Middle and ring finger involvement most common in adults
    - Comorbidities: Associated with diabetes and inflammatory arthropathy
    - Etiology: Possibly associated with repetitive grasping activities
    - Histology: Fibrocartilaginous metaplasia (pulley and/or FDS tendon)
    - Presentation
        - Pain/tenderness in the distal palm, progressing to mechanical catching/locking, and may become fixed (Green classification [Table 7.4])
        - Common complaint of referred pain at the dorsal MCP/PIP area
        - Concomitant trigger finger/carpal tunnel syndrome in 40%–60% of patients
    - Thumb: Newer evidence has found fourth pulley (variable annular pulley) in 75% of patients, which may contribute to stenosis.
    - Nonoperative treatment: Corticosteroid injection into flexor tendon sheath
        - Injection: "Curative" in about 60% of patients initially
        - Diabetic patients generally less responsive to injection
        - No difference between soluble and insoluble preparations
    - Surgical treatment (with failure of nonoperative treatment): Surgical release of A1 pulley (open or percutaneous), with resection of ulnar FDS slip when necessary, if there is recurrent triggering after the A1 pulley has been released
        - In patients with rheumatoid arthritis (RA), preference is to excise a slip of the FDS tendon rather than to release the A1 pulley, because these patients are at risk for ulnar drift at the

MCP joint and with release of the A1 pulley, there is a chance that this drift can be exacerbated.

- Radial digital nerve at risk of iatrogenic injury during thumb trigger finger release, given its superficial location
- Minor complications (relatively high): Wound dehiscence, scar tenderness, decreased ROM

Table 7.4

Classification of Trigger Finger (Green)

Grade	Description
I	Pain and tenderness at the A1 pulley
II	Catching of finger
III	Locking of finger; passively correctable
IV	Fixed, locked finger

- **Pediatric trigger digits**
  - □ Trigger thumb
    - Notta node: Pathologic nodular tendon thickening (not seen in adults)
    - Presentation: Mechanical catching or fixed flexion deformity of IP joint in early childhood
    - More accurately deemed developmental than congenital
    - Treatment: Observation initially
    - 2–4 years of age: annular pulley release to prevent IP joint contracture
    - Radial digital nerve at risk during release
  - □ Trigger finger
    - Etiology: Anatomic anomaly in most cases (in contrast to adults)

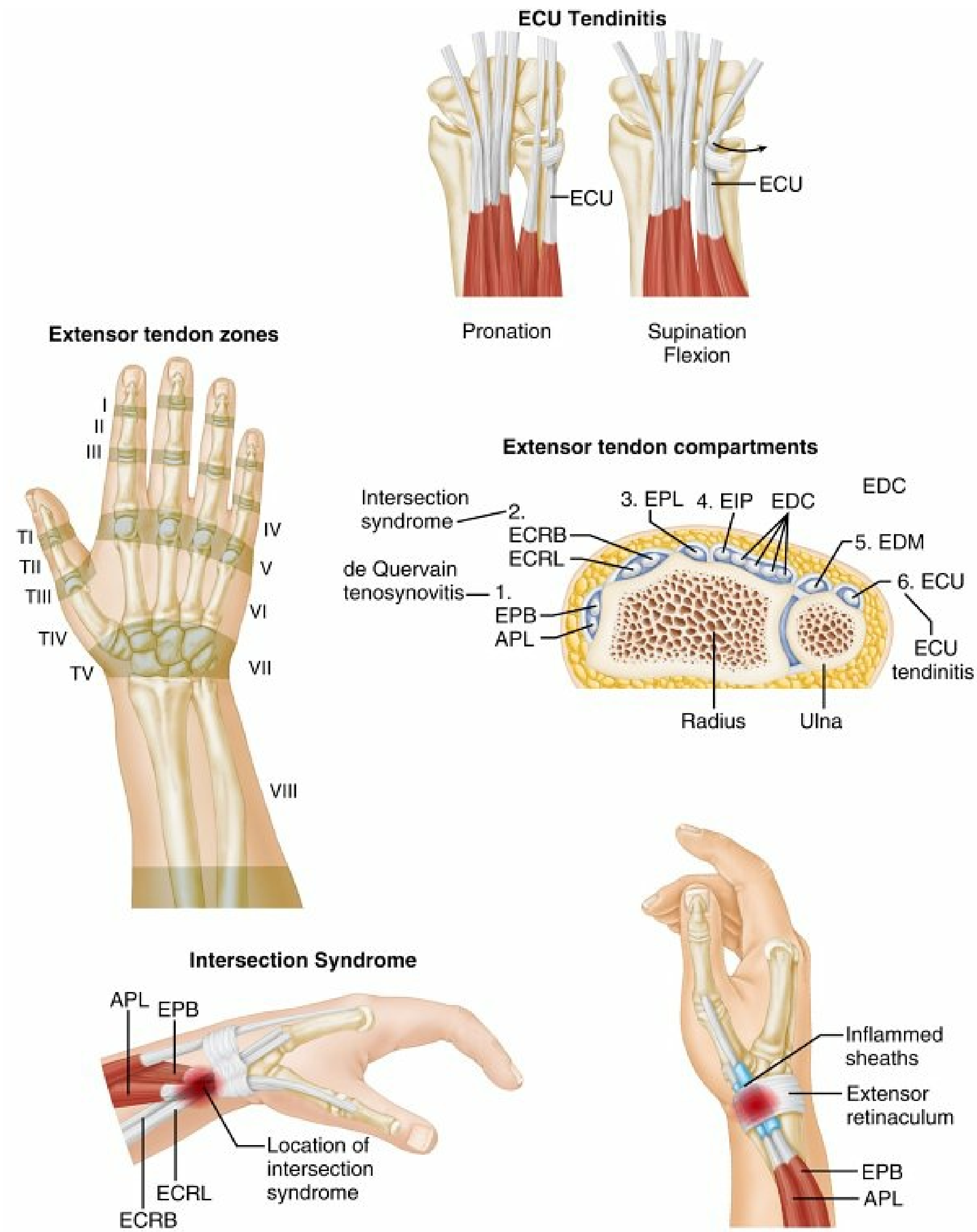


FIG. 7.34 There are eight extensor tendon zones, all important to consider when deciding how to repair associated injuries. There are six dorsal extensor compartments, each with its own specific types of pathologies. For example, the sixth dorsal compartment contains the ECU, which can develop either instability or tendinitis because of the high stress placed on the tendon with the wrist in supination. The first and second extensor compartments are involved in intersection syndrome, whereas the first dorsal compartment containing the EPB and the abductor pollicis longus APL are involved in de Quervain tenosynovitis.

- Treatment: Case-by-case basis, guided by intraoperative findings
    - **A1 pulley release may not resolve triggering; additional A3 release or resection of ulnar FDS slip may be required.**

- **de Quervain tenosynovitis (** Fig. 7.34 **)**
    - Attritional and degenerative condition affecting the first extensor

compartment (APL/ extensor pollicis brevis [EPB])

- □ Demographics: Middle-aged women
  - Other high-risk groups: New mothers, golfers, and racquet-sport athletes
- □ Presentation: Dorsoradial wrist tenderness, swelling, crepitus
- □ Finkelstein test and/or Eichhoff maneuver: Places first extensor compartment tendons under maximum tension and exacerbates symptoms
- □ Nonoperative treatment: Rest, activity modification, thumb spica splinting/bracing, NSAIDs, and corticosteroid injections into the first dorsal extensor compartment
  - Corticosteroid injections successful in more than 80% of patients; risk of skin hypopigmentation, fat atrophy, and tendon rupture (if multiple intratendinous injections)
- □ Surgical treatment (with failure of nonoperative treatment): Release of the first extensor compartment
  - Dorsal retinaculum is released to prevent volar tendon subluxation.
  - Key point: Anatomic variations are frequently encountered in recalcitrant cases.
    - Examples: Multiple slips of APL, EPB in its own separate compartment
  - Outcomes generally excellent
  - Complications: Iatrogenic injury to the SBRN, tendon subluxation, CRPS, and recurrence (incomplete release)

▪ **Intersection syndrome (see Fig. 7.34)**

- □ Tenosynovitis and/or bursitis occurring at the junction between the first and second extensor compartments, where APL and EPB tendons cross ECRL and ECRB
- □ Demographics: Rowers, weight lifters, football lineman, martial artists, golfers
- □ Presentation: Tenderness, swelling, and crepitus are localized to an area approximately 4–5 cm proximal to the radiocarpal joint.
- □ Nonoperative treatment: Ice, splinting, NSAIDs, corticosteroid injection into the second extensor compartment
- □ Surgical treatment (with failure of nonoperative treatment): Release of the second extensor compartment and débridement of inflamed bursa

▪ **Acute calcific tendinitis**

- □ Overuse syndrome from repetitive resisted wrist flexion
- □ Most frequently involves FCU but may also involve FCR
- □ Presentation: Acute onset of wrist pain, swelling, and discoloration that mimics infection or crystalline arthropathy in severity
- □ Radiographs: Fluffy calcium deposits

- ☐ Nonoperative treatment: Short course of oral steroids or high-dose NSAIDs, ice, and immobilization usually effective

▪ **ECU tendinitis and subluxation (see Fig. 7.34)**

- ☐ All extensor tendons about the wrist run along the radius *except* the ECU tendon, which is held tightly within a groove in the distal ulna, tethered by a fibroosseous sheath.
- ☐ Etiology: Overuse tendinopathy (e.g., racquet-sport athletes); worse in supination
- ☐ MRI findings: Thickening (hypertrophy), partial longitudinal tears, or increased signal intensity within tendon and/or sheath
- ☐ Nonoperative treatment: Rest, activity modification, splinting, NSAIDs, and corticosteroid injections
- ☐ Traumatic subluxation of ECU tendon: Forceful hypersupination and wrist ulnar deviation
  - Physical examination: Painful audible snap or visible dislocation may be induced with reproduction of this mechanism.
  - Acute subluxation: Long-arm cast immobilization (or Muenster splint) with the wrist held in pronation and slight radial deviation
  - Chronic subluxation: Either direct repair or reconstruction of the overlying extensor retinaculum ± ulnar groove deepening
  - Concomitant TFCC tears in ≈50% of cases

Distal Radioulnar Joint, Triangular Fibrocartilage Complex, and Wrist Arthroscopy

▪ **Anatomy**

- ☐ Radius rotates around a fixed ulna at the DRUJ.
- ☐ Stability of the DRUJ comprises numerous structures (mnemonic: RUPERT)
  - Distal **r**adius: 20% stability
  - Soft tissues: 80% stability
    - **U**lnocarpal ligaments
    - Deep head of **p**ronator quadratus
    - **E**CU tendon
    - **R**adioulnar ligaments, including the dorsal oblique bundle
    - **T**FCC (foveal attachment more important for stability than styloid attachment)
- ☐ *Ulnar variance:* The distance (mm) between the distal aspect of the ulnar head and the articular surface of the distal radius (Fig. 7.35)

• Determined on PA radiograph of wrist in neutral supination/pronation

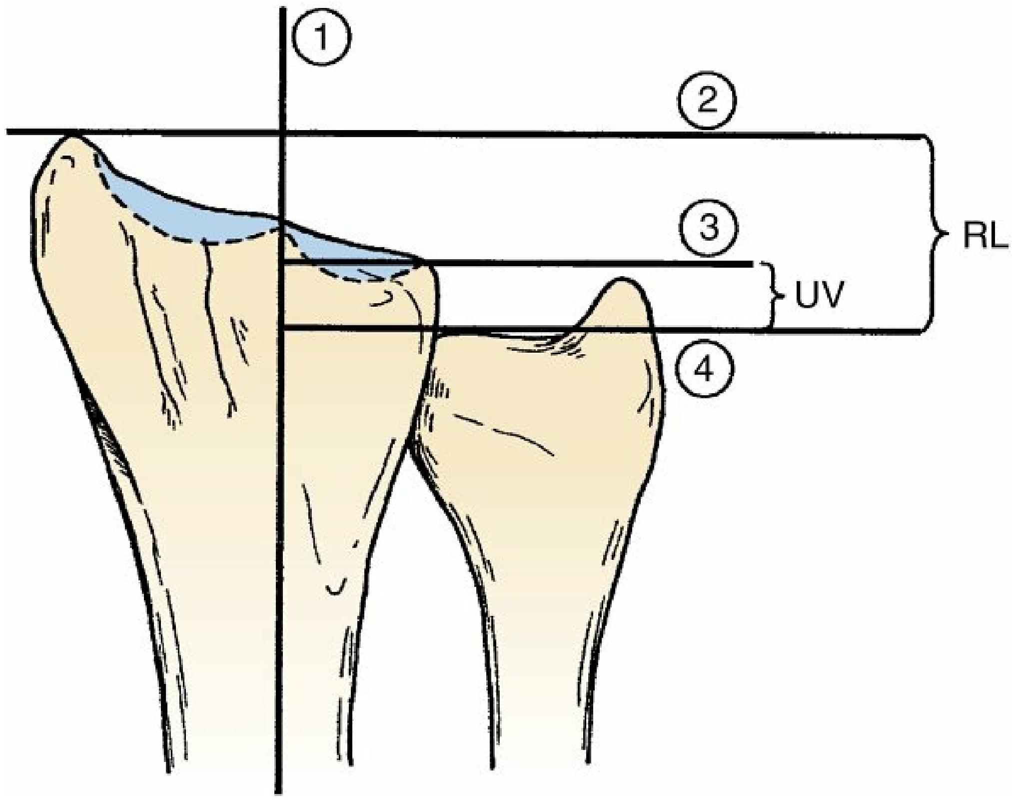


FIG. 7.35 The relative length *(RL)* of the radius and ulna can be determined by measuring the distance from the tip of the radial styloid *(line 2)* drawn perpendicular to the long axis of the radius *(line 1)* and the distal end of the ulnar articular surface *(line 4)*. The ulnar variance *(UV)* is the distance between *line 4* and *line 3,* the dense cortical line along the ulnar border of the distal radius articular surface.
From Trumble TE: Distal radioulnar joint and triangular fibrocartilage complex. In Trumble TE, editor: *Principles of hand surgery and therapy,* Philadelphia, 2000, Saunders.

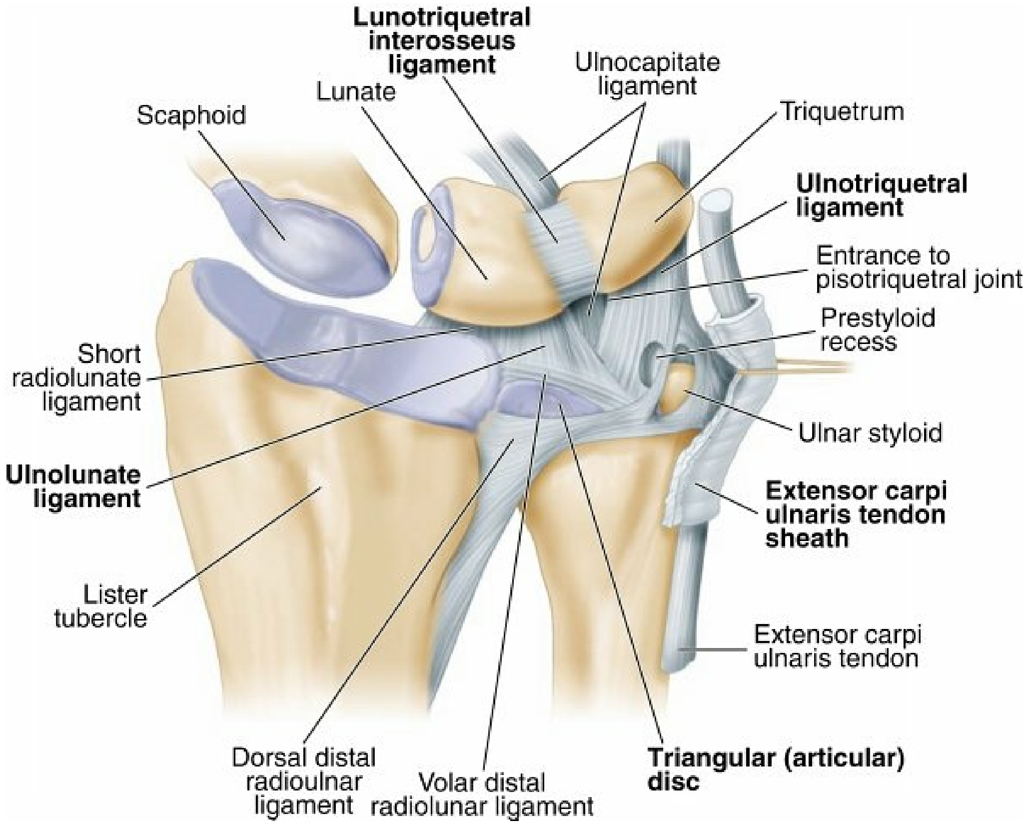


FIG. 7.36 Anatomy of the triangular fibrocartilage complex.
From Cooney WP et al: *The wrist: diagnosis and operative treatment,* St Louis, 1998, Mosby.

Table 7.5

Class 1 (Traumatic) TFCC Injuries

Subclass	Characteristics	Treatment
1A	Central perforation or tear	Resection of an unstable flap back to a stable rim
1B	Ulnar avulsion with or without ulnar styloid fracture	Repair of the rim to its origin at the ulnar styloid
1C	Distal avulsion (origins of UL and UT ligaments)	Advancement of the distal volar rim to the triquetrum (bone anchor)
1D	Radial avulsion (involving the dorsal and/or volar radioulnar ligaments)	Direct repair to the radius to preserve the TFCC contribution to DRUJ stability

Table 7.6

Class 2 (Degenerative) TFCC Tears (Ulnocarpal Impaction Syndrome)

Class	Characteristics
2A	TFCC wear (thinning)
2B	2A + lunate and/or ulnar chondromalacia
2C	TFCC perforation + lunate and/or ulnar chondromalacia
2D	2C + lunotriquetral ligament disruption
2E	2D + ulnocarpal and DRUJ arthritis

- Forearm rotation: Positive ulnar variance in pronation and negative ulnar variance in supination
- □ TFCC function: Stabilizes the DRUJ and transmits 20% of axial load at the wrist (neutral ulnar variance)
- □ Components of the TFCC: The dorsal and volar radioulnar ligaments, the articular disc, a meniscus homologue, ECU, and ulnolunate and ulnotriquetral ligaments
- Neutral variance: 80% compressive loads through radius and 20% through ulna
- +2 mm variance: 60% through radius and 40% through ulna
- □ Vascularity: Periphery of TFCC is well-vascularized, whereas the radial central portion is avascular (Fig. 7.36).
- □ TFCC is composed of superficial and deep limbs.
  - Ligamentum subcruentum: Deep fibers inserting into the distal ulna fovea

▪ **TFCC tears**

- □ Palmer classification: Traumatic (class 1) or degenerative (class 2) (see Fig. 7.9)
  - Subtypes: Based on the specific location within TFCC (Tables 7.5 and 7.6)
  - Class and location of the tear have important implications for treatment
- □ MRI: Controversial, but newer innovations suggest value in detection and localization of TFCC pathology
- □ Arthroscopy is the gold standard for detection of TFCC tears.
  - Arthroscopic trampoline test is performed to assess TFCC resiliency by balloting central portion with small probe (Hermansdorfer and Kleinman).
  - Arthroscopic hook test can be used to demonstrate peripheral detachment of the TFCC (Ruch).
  - Arthroscopic suction test (Greene and Kakar) can show laxity of the TFCC when peripherally scarred in or foveal

detachment when the DRUJ is clinically unstable.

- Class 1 (acute traumatic) TFCC injuries
  - All cases initially managed with immobilization and NSAIDs.
  - Surgical treatment (with failure of nonoperative treatment): Wrist arthroscopic and/or open repair
    - Class 1A (central): Inherently stable; treated with débridement if persistently symptomatic because this area of the TFCC is devoid of vascularity and unable to heal.
      - Key point: A 2-mm peripheral rim should be maintained.
    - Class 1B (peripheral): Amenable to arthroscopic or open repair, because the rim is well vascularized (akin to meniscus within the knee)
      - Key point: Concurrent fractures of ulnar styloid with persistent instability are either excised or fixed.
    - Class 1C (rare): Amenable to arthroscopic or open repair
    - Class ID: Frequently associated with distal radius fractures and often respond to reduction of radius
    - Outcomes: Repair of a traumatic TFCC tear within 3 months of injury allows a patient to regain 80% of wrist ROM and grip strength.
- Class 2 (degenerative) TFCC injuries
  - Associated with positive ulnar variance, increased ulnocarpal loading, and ulnocarpal impaction syndrome from abutment of the ulnar head into the proximal carpal row
  - Presentation: Chronic ulnar-sided wrist pain that increases with forearm rotation and grip
    - Specific test: Presence or absence of pain with loading of wrist in extension and ulnar deviation
  - MRI: In addition to TFCC pathology, there may be increased T2-weighted signal in proximal ulnar corner of lunate and/or ulnar head at point of chronic impaction
  - Nonoperative treatment is mainstay of initial treatment
  - Surgical treatment: Goal is reduction of ulnocarpal loading
    - Ulnar shortening osteotomy: If there is no DRUJ arthrosis
    - Wafer resection: Alternative to osteotomy or for presence of DRUJ arthrosis; removes some of the

abutting surface of the ulnar head within the ulnocarpal joint
      - Coexisting TFCC pathology: Arthroscopic or open débridement

- **DRUJ instability and posttraumatic OA**
  - Instability (see Fig. 7.9)
    - Acute dislocation of DRUJ can occur alone or in combination with ulnar styloid (base), radial shaft (Galeazzi), or Essex-Lopresti injury.
    - Isolated dislocations: Treated with closed reduction and immobilization
      - Closed reduction may be impeded by interposition of the ECU tendon.
    - Concurrent distal ulna fractures and TFCC tears: Open or arthroscopic treatment
    - Galeazzi injury: ORIF of the radial shaft is followed by assessment of DRUJ stability.
      - Unstable DRUJ: TFCC repair and/or temporary radioulnar pinning proximal to the joint, with the forearm immobilized in neutral
    - Chronic DRUJ instability from distal radius malunion, ulnar styloid nonunion, or large TFCC/ligamentous disruptions
      - Diagnosis: Sequential CT scans of arm in neutral forearm rotation, full supination, and full pronation are compared with scans of the other arm.
        - More than 50% translation is abnormal
      - Treatment: TFCC repair or ligament reconstruction (Berger-Adams) with a palmaris tendon autograft
        - Distal radius malunion necessitates corrective osteotomy and treatment of positive ulnar variance.
  - Posttraumatic DRUJ OA
    - Nonoperative management as initial treatment should be maximized.
    - Surgical options
      - Distal ulna resection (Darrach procedure):
        - Functionally low-demand, elderly patients
        - Complication: Painful proximal ulna stump instability and convergence of

the radius upon the ulna

- Hemiresection or interposition arthroplasty: Maintains the ulnar insertion of the TFCC and prevents radioulnar impingement by soft tissue (ECU tendon or capsular flap) interposition
- Sauvé-Kapandji procedure: DRUJ arthrodesis with creation of a proximal pseudarthrosis at the ulnar neck
- Ulnar head or total joint implant arthroplasty (Fig. 7.37)
  - Maintains the relationship between the radius and the ulnar
  - Results show good pain relief at the risk of ulnar head instability, aseptic loosening, and no appreciable change in pronosupination in comparison with preoperative values.
- One-bone forearm: Through elimination of forearm rotation, procedure represents the ultimate salvage operation for persistent pain/complications by fusing the proximal ulnar to the distal radius shaft

▪ **Wrist arthroscopy**

□ Indicated for the diagnosis of wrist pain
□ Indications: TFCC tears, osteochondral injuries, loose bodies, intercarpal ligament injuries, ganglions, intraarticular distal radius fractures, and scaphoid fractures
□ Equipment: Traction tower, 1.9- or 2.7-mm, 30-degree arthroscope
□ Arthroscopic portals (Fig. 7.38)
□ Diagnostic arthroscopy: Radiocarpal → ulnocarpal → midcarpal joint inspection
□ Most common complication: Injury to superficial sensory nerves (branches of superficial sensory radial, dorsal sensory ulnar, lateral antebrachial cutaneous)

Nail and Fingertip Injuries

▪ **Introduction**

□ Fingertip injuries are the most common hand injuries seen in the emergency department
□ Long finger is most commonly involved digit
□ These injuries may be broadly classified as those with and those without soft tissue loss
□ Crush injuries without extensive soft tissue loss may result in nail plate avulsions, nail matrix lacerations, and distal phalanx (tuft) fractures
□ Distal phalanx fractures are typically reduced when the nail bed is repaired, but large displaced fragments may require percutaneous pinning.

▪ **Nail structure (** Fig. 7.39)

□ Nail plate: Composed of keratin; originates from germinal matrix proximal to nail fold

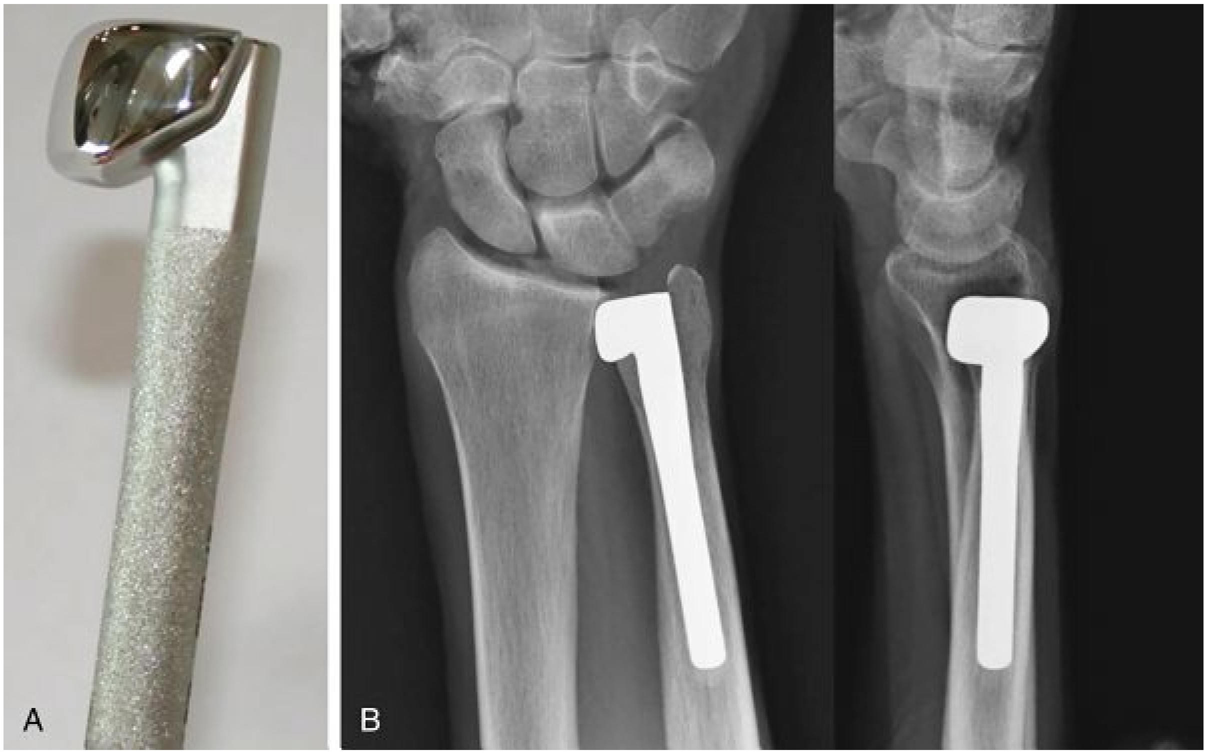


FIG. 7.37 (A) Partial ulnar head replacement. (B) Posteroanterior and lateral radiographs of an arm with partial ulnar head replacement.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 556.

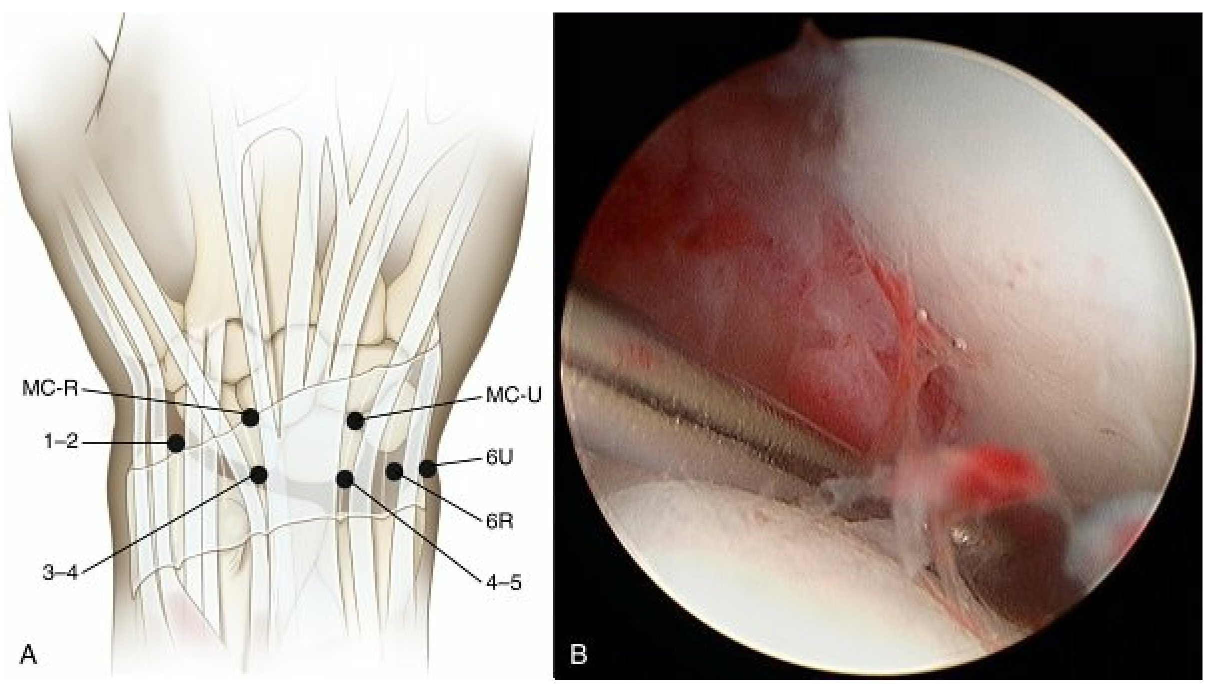


FIG. 7.38 (A) Arthroscopic wrist portals. Numbers indicate wrist extensor compartments and associated portals. *MC-R,* Midcarpal radial; *MC-U,* midcarpal ulnar; *R,* radial; *U,* ulnar. (B) Wrist arthroscopic view showing gross separation between the scaphoid and lunate.
A from Miller MD et al, editors: *Orthopaedic surgical approaches,* Philadelphia, 2008, Elsevier.

    - Sterile matrix: Directly beneath nail plate; contributes keratin to increase plate thickness
    - Lunula (white crescent-shaped): Proximal nail plate at junction of sterile and germinal matrices
    - Hyponychium: Between distal nail bed and skin of fingertip; barrier to microorganisms
    - Eponychium (cuticle): At distal margin of proximal nail fold
    - Paronychium: Forms lateral margins
- **Nail bed injury**
    - Small subungual hematoma (<50% of nail area): Treated without nail plate removal
        - Nail plate should be perforated with a sterile needle (trephination)
    - Large subungual hematoma (>50% of nail area): Requires nail plate removal for repair of underlying nail matrix lacerations
        - Acute repair offers best results
        - Key point: Tetanus prophylaxis and antibiotic coverage
        - Technical tips: digital block, clamped Penrose drain (temporary finger tourniquet), and nail plate soaked in povidone-iodine
            - Sterile and/or germinal matrix lacerations are repaired with 6-0 or smaller absorbable suture under loupe magnification or with cyanoacrylate tissue adhesive (Dermabond).

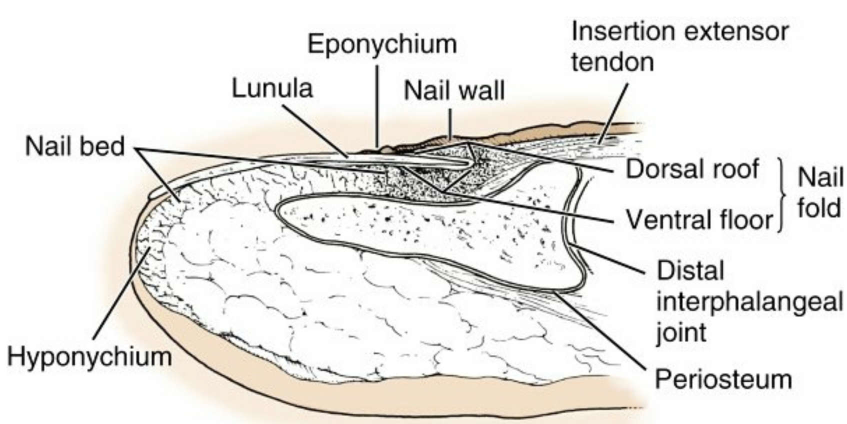


FIG. 7.39 Sagittal depiction of nail bed anatomy.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 333.

            - The eponychial fold is then splinted open with the povidone-iodine–soaked nail plate, a piece of aluminum foil, or some nonadherent gauze to create room for the new nail plate to grow from germinal matrix.

- Key point: A single-institution randomized controlled trial demonstrated faster healing with cyanoacrylate tissue adhesive (Dermabond) than with suture repair
  - Severe nail matrix loss: Split-thickness matrix graft from an adjacent injured finger or transfer of the nail matrix from the second toe
  - Complications
    - Nail plate deformities (e.g., nail ridging): Very common after crush injuries but may be prevented by a flat nail bed repair
    - Hook nail: Results from a tight nail bed repair, distal advancement of the matrix, or loss of underlying bony support
    - Fingertip hypersensitivity: High incidence of fingertip hypersensitivity and/or cold intolerance for up to 1 year
  - Nail growth: ≈0.1 mm/day; complete growth of a new nail plate takes 3–6 months, depending on patient's age
- **Fingertip injuries with tissue loss**
  - Principles of treatment: Preservation of digit length, maintenance of sensate fingertip pulp, prevention of joint contracture, and pain-free use of digit
  - The characterization of the injury is critical and guides treatment
    - Fingertip injuries without exposed bone
      - Allowed to heal by second intention if less than 1 cm^2 of the tip or pulp is involved
      - If required, full-thickness skin grafts (FTSGs) are preferred for the fingertip because they provide better durability, less contraction, and superior sensibility than composite or split-thickness skin grafts (STSGs)
    - **Fingertip injuries with exposed bone**
      - Characterized by the orientation of tissue loss (Fig. 7.40)
        - **Volar oblique injury**
          - Cross-finger flap
            - Dorsal skin and subcutaneous tissue elevated superficial to the paratenon from adjacent digit to create a bed for the injured fingertip
            - Donor site: Covered

with an STSG.

   - The flap is split during a separate procedure 2–3 weeks later (Fig. 7.41).

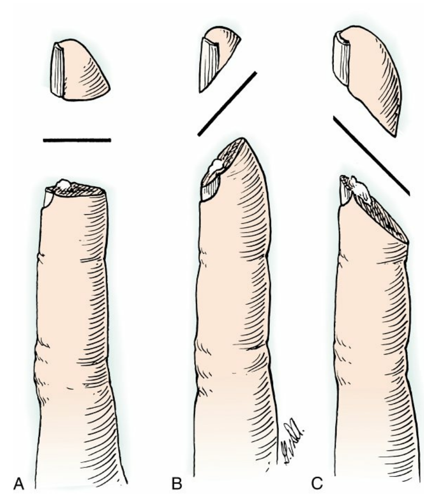


FIG. 7.40 Orientation of fingertip amputations. (A) Transverse. (B) Dorsal oblique. (C) Volar oblique.
Modified from Lister GD: The theory of the transposition flap and its practical application in the hand, *Clin Plast Surg* 8:115-128, 1981.

- Thenar flap
   - Indication: Volar oblique injuries to the index or long digits
   - Flap lifted parallel to the proximal thumb crease; split after 2–3 weeks
   - Complications: Donor site tenderness and PIP contracture (especially in older patients)
- Homodigital island flap
   - Raised on digital

artery of involved finger and may maintain sensory innervation to the fingertip
- Heterodigital island flap
    - Raised on ulnar aspect of the long or ring finger and typically tunneled in the palm to provide coverage to the thumb
- Other possible donor sites
    - Distant flaps in the chest, abdomen, and groin
        - Often they may be cumbersome and too bulky for the fingertip

- **Transverse or dorsal oblique digit injury**
    - V-Y advancement
        - Indication: Preserve length and cover transverse or dorsal oblique fingertip injuries
        - A wide volar flap is lifted off the distal phalanx, with a tapered base created at the level of the DIP flexion crease.
        - Flap is advanced over the fingertip toward the dorsal side, with a

tension-free closure.

- Kutler popularized two separate smaller V-Y advancements from the lateral aspects of the digit to cover transverse fingertip injuries

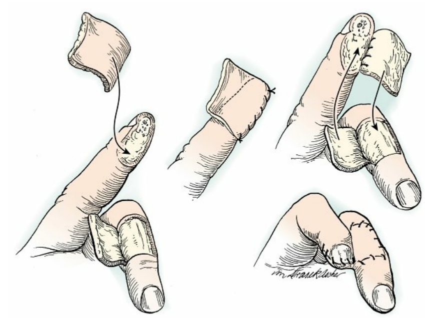


FIG. 7.41 Cross-finger flap.
From the Christine Kleinert Institute for Hand and Microsurgery, Inc., with permission.

- Reverse cross-finger flap
    - **Indicated for loss of tenosynovium and dorsal exposure of bone**
    - **Volar skin and subcutaneous tissue elevated superficial to the paratenon from adjacent digit to create a bed for the injured dorsal finger**
- Alternative: Bone shortening and conversion to a volar coverage option
    - Shortening and closing an injury that leads to proximal migration

of the FDP from its insertion at the base of the distal phalanx may result in a lumbrical-plus finger.

- FDP tendon retracts and creates tension on the extensor mechanism through the lumbrical that originates off the FDP tendon, causing paradoxical IP joint extension with active digit flexion.
- Treated with release of the radial lateral band

- Transverse or volar oblique thumb injury
  - Moberg advancement flap
    - Entire volar surface of thumb is advanced with its neurovascular bundles (Fig. 7.42).
    - Complications: Flap necrosis and thumb IP joint flexion contracture
- **Dorsal thumb injury**
  - First dorsal metacarpal artery “kite” flap or heterodigital island flap
- Pediatric distal fingertip amputation

- Composite flaps (reattachment of amputated tissue without vascular repair) for distal fingertip amputations may be attempted in patients younger than 6 years, but patients' parents must acknowledge possibility of failure

- Lumbrical-plus: Shortening injury that acutely violates the FDP insertion

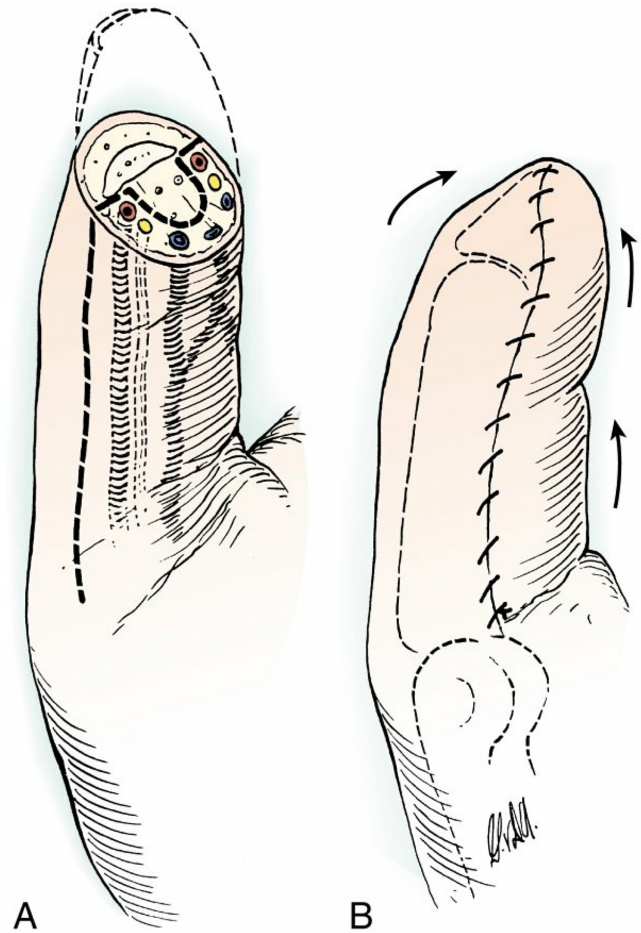


FIG. 7.42 Moberg advancement flap. (A) Most useful for amputations distal to the thumb IP joint, the flap consists of the entire volar skin of the thumb and its neurovascular bundles. (B) Flexion of the IP joint assists in coverage of the soft tissue defect by the advancement flap.

Modified from Lister GD: The theory of the transposition flap and its practical application in the hand, *Clin Plast Surg* 8:115-128, 1981.

- FDP tendon retracts, leading to paradoxic proximal IP joint extension through intact lumbrical origin on the FDP and insertion into the extensor hood with active finger flexion.
  - Treatment: Release of the radial lateral band

Soft Tissue Coverage and Microsurgery

- **Upper extremity wounds**
  - Introduction
    - Management begins with thorough assessment of wound, including size, location, involvement of deep structures, and presence of contamination.
    - Standard of care: Early débridement and administration of antibiotics guided by the degree of contamination, extent of involvement, and associated injuries
    - Complex wounds often require serial surgical débridements of nonviable tissue
    - Definitive coverage procedure requires a clean wound bed.
    - Infection rates increase dramatically if coverage is delayed more than 1 week after injury.
  - Reconstructive ladder
    - Goals of soft tissue reconstruction
      - Provide coverage of deep structures (e.g., bone, cartilage, tendons, nerves, blood vessels)
      - Create a barrier to microorganisms, restore dynamic function of the limb, and prevent joint contracture
      - Achieve cosmetic appearance (secondary priority)
    - Options for soft tissue closure/reconstruction
      - Primary closure
      - Second intention healing
      - Skin grafting
      - Flaps
        - Pedicled
        - Free
    - Decision making guided by wound characteristics and patient factors
      - Primary closure: Not indicated unless contamination is minimal and closure is possible within 6 hours of injury
      - Second intention healing: wound granulation, epithelialization, and contraction
        - Indication: No exposure of deep neurovascular, tendinous or bony structures
        - Key point: Healing is promoted by regular dressing changes or vacuum-assisted closure (VAC) devices
          - Function of VAC devices: Dissipate

interstitial edema, reduce bacterial counts, and stimulate cell division by mechanical stretching of cells

- ▫ Specific methods of soft tissue coverage
  - **Skin grafts**
    - Autografts: either STSGs or FTSGs
      - Both types require a clean wound bed without exposed bone or tendon
      - Early failure of skin grafts occurs from shear stress and hematoma formation.
      - STSGs
        - Indication: Dorsal hand wounds
        - Meshed grafts: Greater surface area and often associated with a better "take" because of a lower incidence of hematoma formation and infection
        - Donor site: Anterolateral thigh common; reepithelialization occurs in 2–3 weeks
      - FTSGs
        - Indication: Volar hand and fingertip wounds
        - Healing sequence: Plasma imbibition, inosculation, revascularization
        - Advantages: Are more durable, contract less, and provide better sensibility
        - Less contraction with higher total percentage of dermis grafted, early grafting, and pressure

application during remodeling phase
- Donor sites: Proximal forearm, medial arm, and hypothenar aspect of the hand
- Allografts or collagen matrices: Temporary measures to prepare a wound bed for later autografting
  - Newer studies have shown promising role for allografts or collagen matrices as definitive techniques

- **Flaps**
  - Flap definition: Unit of tissue supported by blood vessels and moved from a donor site to a recipient site to cover a defect
    - This unit may be one tissue type or a composite of several tissue types (e.g., skin, fascia, muscle, tendon, nerve, or bone)
  - Vascularized tissue: Promotes healing and lowers the secondary infection rate
  - Indications: Exposed bone (stripped of periosteum), tendon (stripped of paratenon), cartilage, or an orthopaedic implant
  - Flaps may be classified by their vascular supply, tissue type, donor site, and method of transfer
    - Flap classification by blood supply
      - Axial-pattern flap
        - Single named arteriovenous pedicle
        - More predictable blood supply
        - Greater resistance to infection
        - Raised on its pedicle and transferred locally, or pedicle can be divided and

transferred to a distant site as a free flap. Examples include a radial artery forearm flap (radial artery), latissimus dorsi flap (thoracodorsal artery).

- Random-pattern flaps
    - No single named arteriovenous pedicle
    - Depend on microcirculation
    - Examples are cross-finger and thenar flaps
- Flap classification by tissue type
    - Single
        - Fascia
            - Lateral arm
        - Muscle
            - Latissimus, gastrocnemius
        - Bone
            - Medial femoral condyle
    - Composite
        - Cutaneous flaps include skin and subcutaneous tissue.
            - Thenar flap
        - Fasciocutaneous flaps include fascia with overlying skin and subcutaneous tissue.
            - Radial forearm flap (Fig. 7.43)
        - Musculocutaneous flaps include

muscle with the overlying skin, subcutaneous tissue, and fascia.
    - Gracilis
- Osteocutaneous flap composed of a portion of bone with overlying soft tissue
    - Fibular, iliac crest
- Innervated flaps preserve the nerve supply with the tissue unit.
    - Motor or sensory nerves may be preserved, depending on their anatomic location and the choice of flap to be transferred.

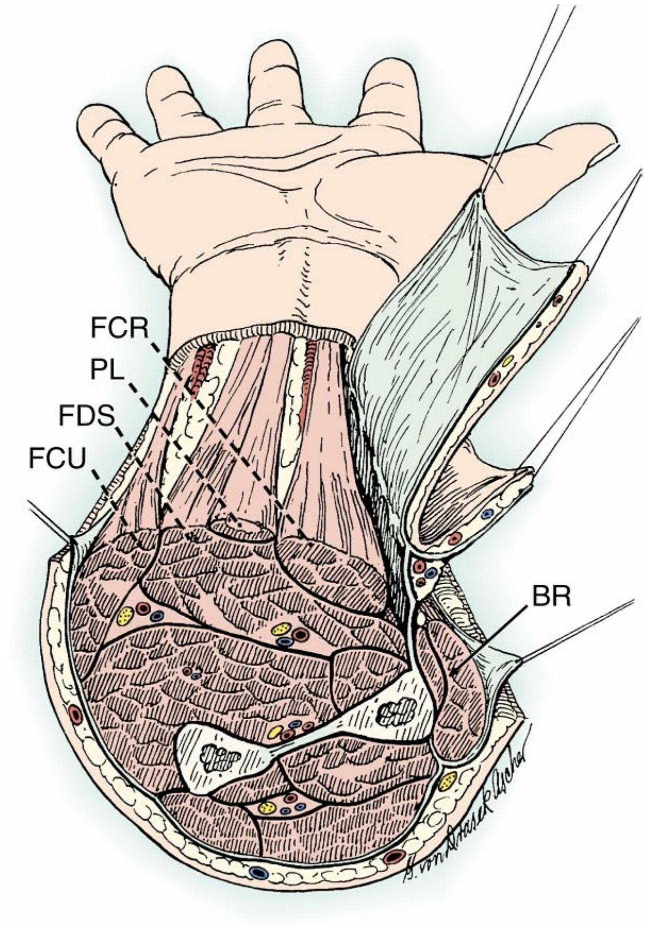


FIG. 7.43 Radial forearm flap. Incision of fascia lifts the entire flap off the underlying forearm muscles. *BR,* Brachioradialis.
From the Christine Kleinert Institute for Hand and Microsurgery, Inc., with permission.

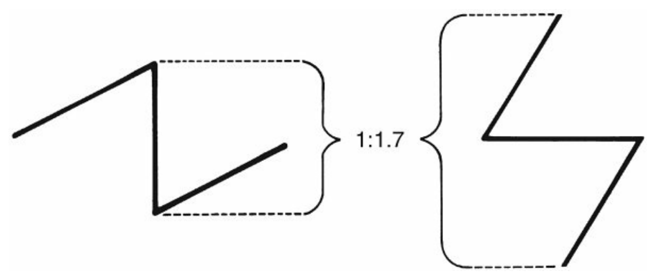


FIG. 7.44 Standard 60-degree Z-plasty.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 1668.

- Flap classification by donor site
  - Local flap: Provided by tissue adjacent to or near the defect
    - Transposition flaps are geometric in design and may be either axial or

random pattern with regard to blood supply

  - Example: Z-plasty
  - Limbs should always be equal, but the flap cut angles may vary to change the amount of desired lengthening—30 degrees for 25% lengthening, 45 degrees for 50%, and 60 degrees for 75% (Fig. 7.44).

- Rotation flaps are not geometric and are universally random pattern with regard to blood supply.
  - Rotated flap should be no longer than the width of its base, to avoid exceeding capacity of the microcirculation to maintain tissue viability.
- Advancement flaps such as V-Y and Moberg types proceed in straight line to fill defect.
- Axial flag flaps are

based on a digital artery.
      - Homodigital
      - Heterodigital
    - Fillet flap, taken from an amputated digit, is occasionally salvaged for initial coverage of a mangled hand.
  - Distant flap
    - Used when local flaps are either inadequate or unavailable for soft tissue coverage
    - Example: A degloved or burned hand may be placed in a raised pocket of tissue in the abdomen or groin
    - Several weeks later, the flap is divided and the donor site either skin-grafted or allowed to heal by second intention.
    - Alternative: The defect site may be dissected away from the distant pocket of skin, with the donor site primarily closed and an STSG over the defect site.
- Flap classification by method of transfer
  - Flap reconstruction may

be performed in one or two stages (e.g., abdominal or groin pocket flap)

- In most instances, the donor tissue remains attached to the native vasculature.
- Alternative: Free flap (free tissue transfer) is a distant axial-pattern flap raised on a named arteriovenous pedicle.
    - Free flap is then divided and reanastomosed to donor vessels near the defect but away from the zone of injury.
    - Most frequently used donors for use in the upper extremity
        - Gracilis (medial femoral circumflex artery)
        - Latissimus dorsi (thoracodorsal artery)
        - Serratus anterior (serratus branch of subscapular artery)
        - Anterolateral thigh (descending branch of lateral femoral

circumflex artery)
    - Lateral arm (posterior branch of radial collateral artery)
- Patients are typically monitored postoperatively in intensive care unit
    - Room kept warm for vasodilation
    - Vasoconstrictive agents (e.g., nicotine, caffeine) restricted
    - Hypotension must be avoided, and the patient kept well hydrated.
- Complications
    - Main cause of free-flap failure: Inadequate arterial blood flow
    - Persistent vasospasm may lead to thrombosis at the anastomosis.
    - Seroma or hematoma formation may

lead to flap failure.

- **Traumatic upper extremity amputation**
  - Indications and contraindications
    - Primary indications for attempting replantation
      - Thumb
      - Multiple digits
      - Wrist level or proximal
      - Any amputation in child
    - Relative indication: Amputation level distal to the FDS insertion (zone I)
    - Primary contraindications to replantation
      - Single digit amputation, especially index
      - Crushed or mangled amputated parts, **arterial ribbon sign**
      - Prolonged ischemia
      - Segmental amputations
      - **Level of amputation within zone II flexor tendon sheath, because of pain and stiffness**
    - Poor candidates for replantation: patients with multisystem traumatic injuries and those with multiple medical comorbidities or disabling psychiatric conditions
  - Care of the amputated part
    - Wrapped in moist gauze (normal saline or lactated Ringer's solution) and placed within a sealed plastic bag in an ice-water bath.
    - Replantation is not recommended for (controversial):
      - Warm ischemia time is more than 6 hours for an amputation level proximal to the carpus or more than 12 hours for an amputated digit
      - Cold ischemia time of more than 12 hours for an amputation level proximal to the carpus or more than 24 hours for an amputated digit
  - Operative sequence of replantation (mnemonic: BEFAVNS)
    - Bone stabilization, usually with shortening
    - Extensor tendon repair
    - Flexor tendon(s) repair
    - Arterial reanastomosis
    - Venous reanastomosis
    - Nerve repair
    - Skin approximation (loose)
    - If multiple digits, priority sequence is thumb > long > ring > small > index

        - Thumb provides 40% of hand function.
- Structure-by-structure technique faster and yields higher viability rate than finger-by-finger technique.
- Use of venous couplers may result in shorter operative times and less vasospastic collapse of the anastomosis.
- Postoperative care
    - Warm environment (≈80°F)
    - Adequate hydration
    - Pain relief to prevent sympathetic surge and vasoconstriction
    - Aspirin
    - Dextran/heparin controversial
    - Thorazine acts as both vasodilator and anxiolytic (especially good for children)
    - Prohibition of nicotine, caffeine, other vasoconstricting agents
- Replantation monitoring
    - Most reliable method is close observation of color, capillary refill, and tissue turgor.
    - Monitoring techniques: Measurement of oxygen saturation by pulse oximetry and of skin surface temperature
        - A drop in temperature of more than 2°C in 1 hour and a temperature of less than 30°C both indicate decreased digital perfusion.
        - Invasive alternative: Placement of implantable venous Doppler probe
    - Length of monitoring: 4–5 days
- Complications
    - Early (<12 hours) replantation failure: Due to arterial thrombosis from persistent vasospasm
        - Diagnosis: Pale skin color, decrease or absence of capillary refill, loss of ultrasound-measurable signal

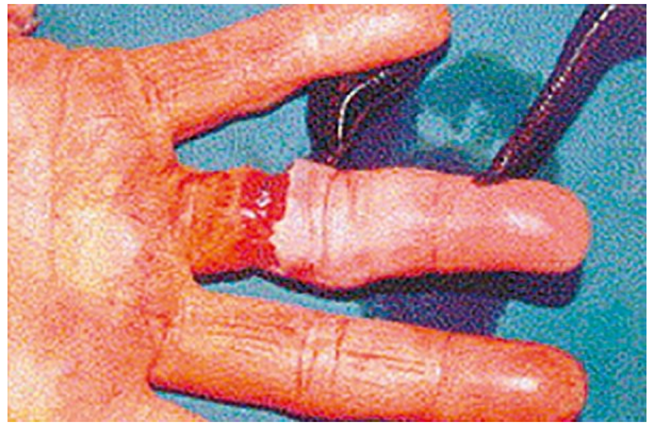


FIG. 7.45 Class IIC ring avulsion injury of the ring finger, with venous insufficiency treated by leech therapy.
From Tuncali D et al: The value of medical leeches in the treatment of class IIC ring avulsion injuries: report of two cases, *J Hand Surg Am* 29:943–946, 2004.

- Initial treatment: Release of constricting bandages, placement of extremity in dependent position, administration of heparin, stellate ganglion block
- If initial measures fail: Exploration and attempt at reanastomosis

- Late (>12 hours) replantation failure: Due to venous congestion or thrombosis
    - Diagnosis: Rubrous skin color, **increased** capillary refill, tissue engorgement
    - Arterial inflow may subsequently diminish.
    - Initial treatment: Removal of dressings and elevation of extremity
        - Heparin-soaked pledgets
        - Medicinal leeches (*Hirudo medicinalis*): Produce the anticoagulant hirudin, yield 8–12 hours of sustained bleeding (Fig. 7.45)
            - May be required for up to 5–7 days
            - *Aeromonas hydrophila* infection

risk: Prophylactic antibiotics (e.g., ceftriaxone or ciprofloxacin) during leech therapy

        - Revision of venous anastomosis is last resort.
    - Late complications: Tendon adhesions, bone nonunion, and neuroma formation
        - Tenolysis is the most commonly performed secondary procedure following successful replantation.
- Results
    - Factor most predictive of digit survival after replantation: Mechanism of injury (clean cut better than crush or avulsion)
    - Next most important factor: (Probably) ischemia time
        - Clean transverse amputations with cold ischemia time less than 8 hours survive replantation in more than 90% of cases
            - After 8 hours, the success rate drops to approximately 75%.
    - Replanted digits typically regain 50% of total active motion and static two-point discrimination of approximately 10 mm.
    - Long-term cold intolerance is almost universal, regardless of whether amputated digit is replanted or revised.

□ Forearm and arm replantation

- Key Point: Arterial inflow is established before skeletal stabilization (with use of shunts if necessary) to minimize ischemia time.
- Postreplantation fasciotomies performed to prevent reperfusion-induced compartment syndrome
    - Muscle necrosis leads to myoglobinuria and life-threatening renal failure.
- Elevated postoperative serum potassium value may be prognostic of replantation failure.
- Late complications: Infection, Volkmann ischemic

contracture, insignificant functional recovery

- □ Hand allotransplantation
  - Occurring around the world with more frequency, including in United States, at specialized centers with abundant resources
  - Bilateral transplantations have been performed with good survivorship, including several above-elbow procedures.
  - Newer immunosuppressive protocols are less toxic and may lead to less long-term recipient morbidity.
    - Long-term risk of continued immunosuppression is malignancy.

- **Ring avulsion injuries**
  - □ Forceful avulsion of overlying soft tissues from skeletal structures
  - □ Classified by Urbaniak
    - Class I: Circulation adequate; digit salvage with standard soft tissue treatment
    - Class II: Circulation compromised and inadequate; revascularization recommended if no accompanying severe bone or tendon injury
    - Class III: Complete degloving; treated with completion amputation
- **Thumb reconstruction**
  - Traumatic thumb loss devastating to overall hand function (thumb accounts for 40% of hand function)
  - For amputation through middle to proximal third of proximal phalanx
    - First web space deepening
    - Metacarpal lengthening with dynamic distraction external fixator
      - Average 3-cm gain
    - For more proximal amputation level
      - Index finger pollicization
      - Great or second toe transfer by microvascular reconstruction

Vascular Disorders

- **Anatomy**
  - □ Vascular supply to the hand: Radial and ulnar arteries
    - The ulnar artery is the main contributor to the superficial palmar arch.
    - The radial artery is the main contributor to the deep palmar

arch and the thumb via the princeps pollicis artery.

- A complete palmar arch, present in more than 80% of hands, provides arterial branches to all five digits; if either the radial or ulnar artery is injured proximally, remaining digital perfusion through the uninjured artery and the complete arch is sufficient.
  - With an incomplete palmar arch (≈20% of hands), perfusion may be significantly compromised if the dominant artery is injured
    - Allen test: Detects the presence of an incomplete arch (see under Evaluation of Vascular Dysfunction).
- Persistent median artery: Present in up to 15% of patients
  - Associated with high median nerve division or bifid nerve

▪ **Evaluation of vascular dysfunction**

- Allen test
  - Both radial and ulnar arteries are compressed at the distal forearm, and patient is asked to squeeze and release hand several times.
  - In sequential tests, one artery is released while the other remains compressed.
  - Positive result: Absence of arterial filling of the digits upon release of the compressed artery; demonstrates an incomplete palmar arch
  - May also be performed with aid of Doppler probe
- Cold stimulation test
  - May demonstrate autonomic vascular dysfunction
  - Hand is submersed in iced water for 20 seconds and then removed; skin temperature is measured before and after submersion.
  - In patients with arterial disease, return to preexposure temperature requires more than 20 minutes; in normal subjects, temperature returns in ≈10 minutes.
- Digital-brachial index
  - Comparison of blood pressure between arm and digit
  - Value less than 0.7 is abnormal for a digit.
- Color duplex ultrasonography
  - Excellent noninvasive study to help detect many forms of vessel pathology, with rates of sensitivity and specificity similar to those in arteriography (with experienced operators)
- Photoplethysmography (pulse volume recording)
  - Demonstrates arterial insufficiency when there is loss of the dicrotic notch or a decreased rate of rise in the systolic peak

- Three-phase bone scan
  - May be useful adjunctive test in certain clinical scenarios (e.g., frostbite)
  - Phase I images, taken 2 minutes after radiotracer injection, provide information similar to that from arteriography.
    - Arterial occlusion, arteriovenous malformations, and vascular tumors can be detected during this phase
  - Phase II (soft tissue) images, taken after 5–10 minutes, may show decreased perfusion in patients with vasospastic disorders.
  - Delayed or phase III (skeletal) images, obtained 2–3 hours after injection, are not particularly helpful in vascular disorders.
- Arteriography
  - Gold standard for elucidating the nature and extent of thrombotic and embolic diseases of the hand vasculature
  - Provides a road map for surgical intervention

- **Occlusive vascular disease**
  - Etiologies: Blunt or penetrating arterial trauma, atherosclerosis, aneurysm formation, emboli, and a variety of systemic diseases
  - Often manifests as unilateral claudication (ischemic pain), paresthesias, and/or cold intolerance
  - Ulcerations and gangrene are late findings of unrecognized vascular compromise
  - Hypothenar hammer syndrome
    - Most common posttraumatic vascular occlusive condition of the upper extremity

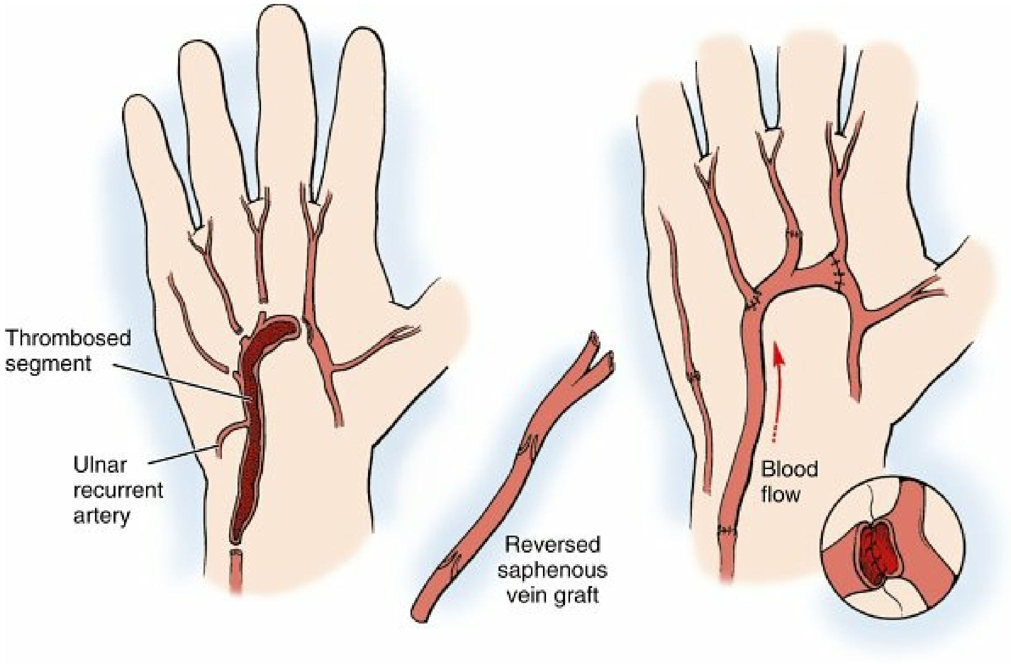


FIG. 7.46 Complex reversed interposition vein grafts may be necessary to reconstruct extensive occlusive disease in the hand.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 2224.

- Etiology: Thrombosis or aneurysm formation of the distal ulnar artery occurs from blunt trauma to the hypothenar eminence (in roofers, carpenters, etc.)
- Presentation: Localized tenderness, cold intolerance, ischemic pain of the ulnar digits, and accompanying compression neuropathy of the ulnar nerve in Guyon canal
- **Diagnosis: Noninvasive vascular studies or arteriography: Patients with digital-brachial index less than 0.7 should undergo reconstruction.**
- **Treatment: Resection and ligation of the thrombosed ulnar artery or reconstruction with a reversed interposition vein graft or arterial conduit for better patency rate (** Fig. 7.46 **)**

□ **Small-vessel occlusive disease**

- Associated with connective tissue diseases: scleroderma, SLE, RA, Sjögren syndrome, and dermatomyositis
- Buerger disease: Small-vessel arteritis, predominantly in males and heavy smokers
- These conditions are often progressive despite treatments such as calcium channel blockers and periarterial sympathectomy

□ **Embolic disease**

- Majority of upper extremity emboli are of cardiac origin, with a smaller subset from the subclavian system in cases of vascular thoracic outlet syndrome
- Emergency embolectomy is performed when feasible and

followed by anticoagulation
    - Smaller vessels are treated with thrombolytic agents such as TPA, streptokinase, or urokinase if the diagnosis is made within 36 hours of occlusion
    - Warfarin is prescribed for 3–6 months

- **Vasospastic disease**
  - Periodic digital ischemia may be induced by cold temperature or other sympathetic stimuli (e.g., pain, emotional stress)
  - Presentation: Digits initially turn white from vasospasm and cessation of flow, then blue from cyanosis and venous stasis, and finally red from rebound hyperemia
    - Last stage often accompanied by dysesthesia

Box 7.1 Causes of Secondary Vasospastic Disorder

- Connective tissue disease: scleroderma (incidence of Raynaud disease, 80%–90%), SLE (incidence, 18%–26%), dermatomyositis (incidence, 30%), RA (incidence, 11%)
- Occlusive arterial disease
- Neurovascular compression: thoracic outlet syndrome
- Hematologic abnormalities: cryoproteinemia, polycythemia, paraproteinemia
- Occupational trauma: percussion and vibratory tool workers
- Drugs and toxins: sympathomimetics, ergot compounds, β-adrenergic blockers
- CNS disease: syringomyelia, poliomyelitis, tumors/infarcts
- Miscellaneous: reflex sympathetic dystrophy, malignant disease

  - Raynaud phenomenon: Vasospastic disease with a known underlying cause (Box 7.1; Table 7.7)
    - Some degree of vascular occlusive disease is always present, giving a combined clinical picture
    - Symptoms are usually asymmetric, and peripheral pulses are often absent
    - Trophic changes may occur
  - Treatment is focused on the underlying disease.n Raynaud disease: Vasospastic disease with no underlying cause (see Table 7.7).
    - Most commonly affected group is premenopausal women
    - Symptoms: Usually bilateral; peripheral pulses often present
    - Nonoperative treatment: Calcium channel blockers (transient relief) and biofeedback techniques
      - **Botulinum toxin injection near the neurovascular bundle can improve digital perfusion**
    - Surgical treatment: Digital sympathectomy is considered in

severe cases.

- Smoking cessation and avoidance of cold exposure are imperative in both Raynaud phenomenon and Raynaud disease.

Table 7.7

Raynaud Disease versus Raynaud Phenomenon

Characteristic	Disease	Phenomenon
History		
Triphasic color change	Yes	Yes
Patient age >40 years	No	Yes
Progression rapid	No	Yes
Underlying disease	No	Yes
Female predominance	Frequent	Occasional
Physical Examination		
Trophic findings (ulcer, gangrene)	Infrequent	Frequent
Abnormal Allen test result	No	Common
Asymmetric findings	Infrequent	Frequent
Laboratory Testing		
Blood chemistry	Normal	Frequently abnormal
Microangiology	Normal	Frequently abnormal
Angiography	Normal	Frequently abnormal

Modified from Green DP et al, editors: *Green's operative hand surgery*, ed 5, Philadelphia, 2005, Churchill Livingstone, p 2304.

- **Acute compartment syndrome**
- Surgical emergency resulting from increased pressure within a closed anatomic space and leading to reduced capillary blood flow below the threshold for local tissue perfusion and oxygen delivery
- Prolonged ischemia secondary to a missed or delayed diagnosis may result in irreversible muscle or nerve damage within a compartment.
- Three forearm compartments
    - Mobile wad of three (brachioradialis, ECRL, and ECRB)
    - Dorsal
    - Volar (superficial and deep muscles; deep muscles—FPL, FDP, pronator quadratus PQ—incur highest pressure)
- Ten hand compartments
    - Thenar

- Hypothenar
- Adductor pollicis
- Four dorsal interosseous
- Three volar interosseous

□ Diagnosis: Compartment syndrome is a clinical diagnosis; a high index of suspicion is critical after crush injuries and limb reperfusion.
□ In children the most common cause is a supracondylar humerus fracture.
□ Compartment pressures should be measured in all equivocal cases and in unresponsive patients.
□ Compartment monitoring: Imperative after animal bites, high-energy trauma, and burn injuries
□ Physical examination: Increased pain with passive stretch of the affected compartment is most sensitive finding.
□ Late findings: Paresthesias, pallor, pulselessness, and paralysis
□ Treatment: Emergent fasciotomy of all affected compartments

- Forearm fasciotomies require 2 or 3 skin incisions over the three compartments.
- Hand fasciotomies may be accomplished through 5 skin incisions.
    - Two dorsal incisions to release five interossei and the adductor pollicis
    - Separate incisions over thenar and hypothenar musculature (Fig. 7.47)

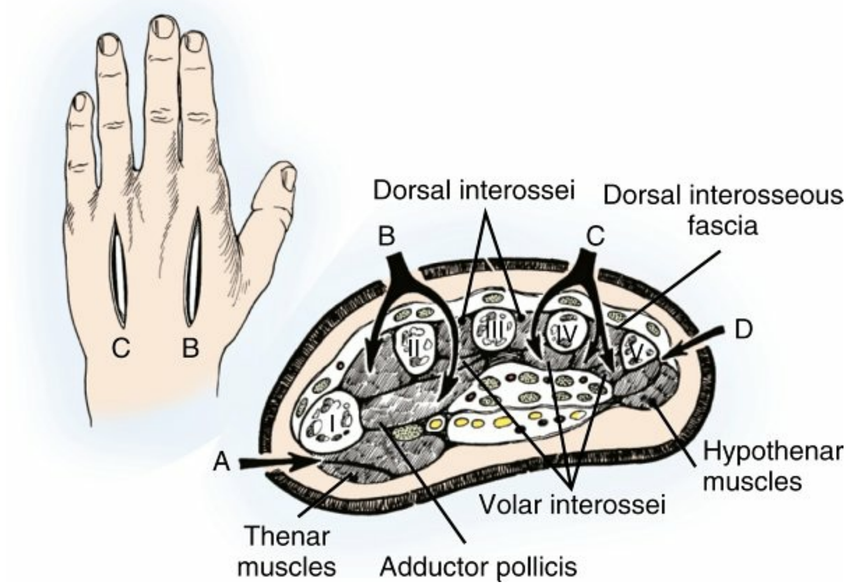


FIG. 7.47 Both dorsal and volar interosseous compartments and the adductor compartment to the thumb can be released through two longitudinal incisions over the second and third metacarpals (*B* and *C*). The thenar and hypothenar compartments are opened through separate incisions (*A* and *D*).
From Green DP et al, editors: *Green's operative hand surgery,* ed 5, Philadelphia, 2005, Churchill Livingstone, p 1993.

- Transverse carpal ligament release often done in same setting to decompress the median nerve at the carpal tunnel.
- Delayed wound closure and/or skin grafting recommended
- Most important prognostic factor: Time between onset and surgical intervention

□ Long-term sequelae of unrecognized and untreated acute compartment syndrome include muscle fibrosis and Volkmann ischemic contracture.

- Volkmann ischemic contracture
  - Classic sequela of untreated acute compartment syndrome, developing from advanced myonecrosis and muscle fibrosis in the forearm
  - FDP and FPL muscles most vulnerable
  - Mild, moderate, and severe forms have been described
    - Mild form: Mild DIP flexion contractures, with preserved strength and sensibility
    - Moderate/severe forms: Progressively worsening contractures and sensorimotor deficits
  - Chronic pain and significant hand dysfunction are common

- Intrinsic-minus or claw hand deformity: Consequence of the severe form
- Treatment
  - Muscle slides, contracture releases, and tendon transfers help improve function, with limited goals in the severe form.
  - Nerve decompression: In patients with chronic neuropathic pain, especially when muscle fibrosis causes extrinsic compression on intrinsically compromised peripheral nerves
  - Free innervated gracilis muscle transfer: Selected severe cases

- **Frostbite**
  - Damage to tissue from prolonged exposure to subfreezing temperatures
  - Etiology: Ice crystals form within extracellular fluid, leading to intracellular dehydration and cell death.
    - Increased wind chill, skin contact with metal or ice, and alcohol intoxication exacerbate cases of frostbite.

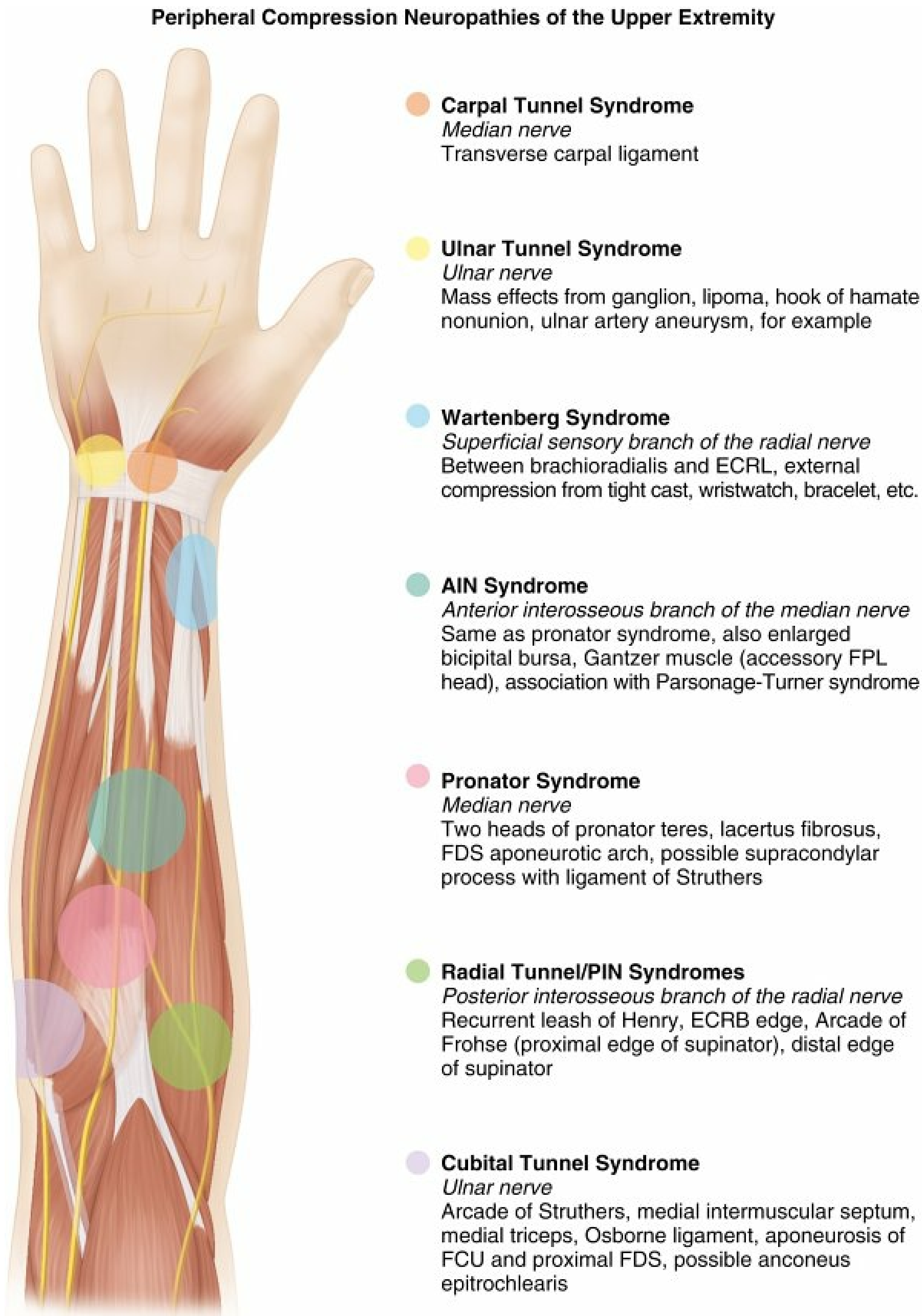


FIG. 7.48 Composite image displaying common upper extremity peripheral compression neuropathies.

- Initial treatment: Resuscitative measures, then rapid rewarming of the affected body part in a water bath kept at 40°–42°C
- IV analgesics or conscious sedation is usually necessary for pain.
- Repeated freeze/thaw cycles should be avoided.
- Local wound management: Topical aloe vera, limb elevation, and splinting administered soon after the injury.
- **Surgical débridement and amputation: Usually delayed until unequivocal tissue demarcation occurs (1–3 months)**
- Urgent escharotomy: Required for constrictive circumferential digital involvement
- Limited débridement of nonhemorrhagic blisters can be performed acutely.
- Bone scan or angiography helps evaluate severity of injury.
    - IV TPA recommended if no digital blood flow exists.
- Complications: Chronic cold intolerance, neuropathy, articular cartilage degradation
- Late persistent vasospastic disease: Calcium channel blockers or surgical sympathectomy
- Children: Prone to premature growth plate closure

Compression Neuropathy

- **Introduction**
  - Chronic condition that may involve any peripheral nerve within the upper extremity with sensory, motor, or mixed manifestations (Fig. 7.48)
  - Sequence of sensory losses: light touch → pressure and vibration → pain and temperature
  - Paresthesias: From early microvascular compression and neural ischemia
    - Intraneural edema increases over time and exacerbates microvascular compression.
    - Pressure and vibratory thresholds are increased.
  - Continued compression leads to structural changes such as demyelination, fibrosis, and axonal loss.
  - Prolonged compression: Weakness or paralysis of the motor nerve, abnormal two-point discrimination
  - Presentation: Night-time symptoms, dropping of objects, clumsiness, or weakness.
  - Changes in skin color, temperature, texture, and moisture result from sympathetic nervous system dysfunction
  - Differential diagnosis (Box 7.2)
    - Parsonage-Turner syndrome
      - Characterized by viral illness and shoulder pain prior to nerve symptoms
      - Self-limiting inflammatory brachial neuritis or plexopathy
    - Diabetes, thyroid disease, inflammatory arthropathy, vitamin deficiency
  - Physical examination
    - Individual muscle strength (grades 0 [none] to 5 [maximal]), pinch strength, and grip strength in cases of long-standing compression
    - Neurosensory testing performed in context of both dermatomal and peripheral nerve distributions
      - Semmes-Weinstein monofilaments measure the cutaneous pressure threshold, a function of large nerve fibers (first to be affected in compression neuropathy).
        - Sensing the 2.83 monofilament is normal.

- Two-point discrimination (performed with patient's eyes closed)

Box 7.2 Nerve Compression Associations

Systemic
- Diabetes
- Alcoholism
- Renal failure
- Raynaud

Inflammatory
- Rheumatoid arthritis
- Infection
- Gout
- Tenosynovitis

Fluid Imbalance
- Pregnancy
- Obesity

Anatomic
- Synovial fibrosis
- Lumbrical encroachment
- Anomalous tendon
- Persistent median artery

Mass
- Ganglion
- Lipoma
- Hematoma

    - Inability to perceive a difference between points more than 6 mm apart is considered abnormal and constitutes a late finding in compression neuropathy.

- □ Electrodiagnostic testing
  - Sensory and motor nerve function tested by EMG (tests muscle innervation) and nerve conduction study (NCS; tests conduction along the nerve).
    - Operator dependent but may provide the only objective evidence of neuropathic condition
    - Most helpful in localizing point of compromise and distinguishing between several differential diagnoses in equivocal cases
    - High false-negative rate, especially in early disease

- NCS measures nerve conduction velocity, distal latency, and amplitude.
  - Demyelination decreases conduction velocity (sensory fibers before motor fibers) and increases distal latency.
  - Axonal loss decreases sensory and/or motor potential amplitude.
- EMG measures electrical activity of muscle during voluntary contraction.
  - With muscle denervation, EMG abnormalities include fibrillations, positive sharp waves, and fasciculations.

□ Compression neuropathy is characterized by phases of disease (Table 7.8).

□ Treatment decisions guided by history, physical findings, and results of sensory threshold and electrodiagnostic testing

□ Double-crush phenomenon
- Normal axonal function depends on factors synthesized in the nerve cell body.
- Blockage of axonal transport at one point makes the entire axon more susceptible to compression elsewhere.
- Cervical radiculopathy or proximal nerve entrapment may coexist with distal nerve compression in double-crush phenomenon.
- Outcome of surgical decompression may be disappointing unless all points of compression are addressed.
- Logical approach is to start with less complex distal releases.

▪ **Median nerve**

□ **Carpal tunnel syndrome (CTS) (Fig. 7.49)**
- Most common compressive neuropathy in the upper extremity
  - ≈500,000 cases per year in United States
- Anatomy of the carpal tunnel
  - Volar boundary (roof): Transverse carpal ligament (TCL)
    - Attaches to scaphoid tubercle/trapezium radially and to pisiform/hook of hamate ulnarly
  - Dorsal boundary (floor): Proximal carpal row and extrinsic volar carpal ligaments

Table 7.8

Compression Neuropathy

Phase	Symptoms	NCS Findings	EMG Findings	Pathology	Treatme
Early	Intermittent	Normal or increased sensory latency	Normal	Edema	Nonope
Intermediate	Constant	+	±	Edema	Surgery
Late	Sensory and motor deficit	+	+	Fibrosis and axonal loss	Surgery prec outc

Plus, Positive; plus/minus, equivocal.

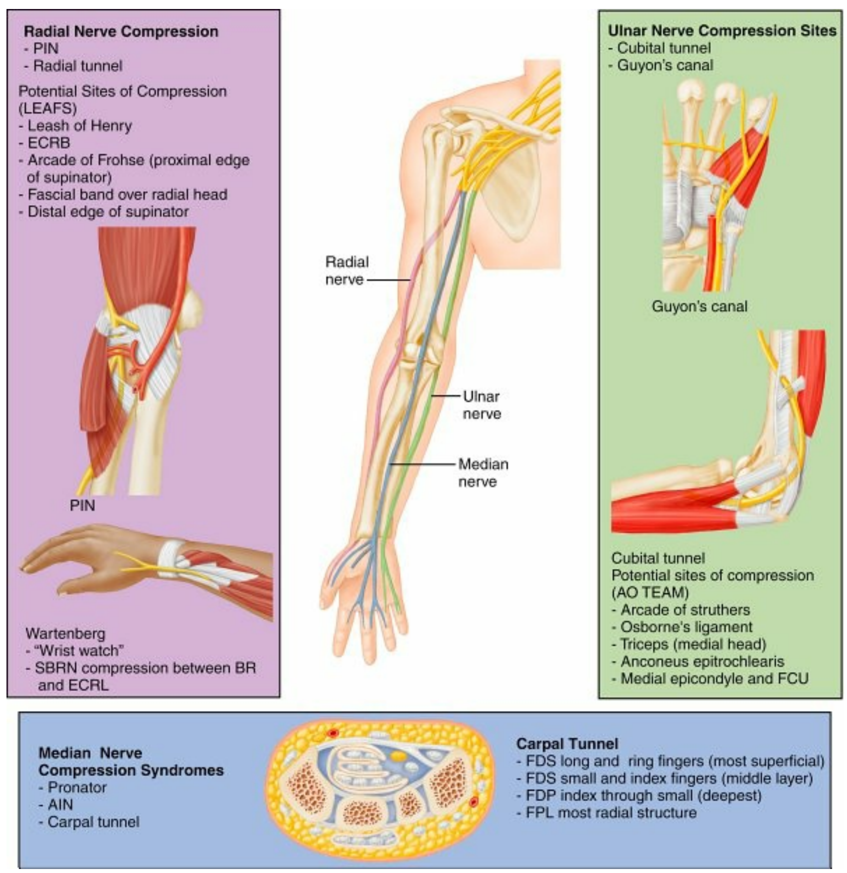


FIG. 7.49 Composite figure showing multiple types of nerve compression syndromes. The radial nerve is involved in posterior interosseous nerve (PIN), radial tunnel, and Wartenberg syndromes. The median nerve is involved in the pronator, anterior interosseous nerve (AIN), and carpal tunnel syndromes. The ulnar nerve is involved in the cubital tunnel and Guyon canal syndromes. Various points of compression and associated anatomy are illustrated in the figure.

- Contents: Median nerve, FPL, four FDS tendons, and four FDP tendons
    - Normal pressure ≈2.5 mm Hg
    - Pressure more than 20 mm Hg: Epineural blood flow decreases; nerve becomes edematous.
    - Pressure more than 30 mm Hg: Nerve conduction decreases.

- Forms of CTS
  - Idiopathic form; most common in adults
    - Mucopolysaccharidosis is the most common cause in children
  - May also be anatomic variation
    - Persistent median artery, small carpal canal, anomalous muscles, extrinsic mass effect
  - Risk factors: obesity, pregnancy, diabetes, thyroid disease, chronic renal failure, inflammatory arthropathy, storage diseases, vitamin deficiency, alcoholism, advanced age, vibratory exposure at work
    - Direct relationship between repetitive work activities (e.g., keyboarding) and CTS has never been established.
  - Acute CTS occurs in the setting of high-energy trauma (e.g., perilunate dislocation, hemorrhage, infection).
    - Evolving paresthesias and pain with increasing intensity
    - Treatment: Emergent decompression
- Diagnosis (clinical)
  - Presentation: Paresthesias and pain (often at night) in volar aspect of radial 3½ digits (thumb, index, long, and radial half of ring)
    - Late findings: Weakness, loss of fine motor control, abnormal two-point discrimination
    - Most sensitive provocative test: Carpal tunnel compression test (Durkan test) with wrist in neutral position
    - Other provocative tests: Tinel test over the median nerve; Phalen test

produces symptoms with wrist flexion.
    - Large sensory fibers (light touch, vibration) are affected before small fibers (pain and temperature).
        - Semmes-Weinstein monofilament testing is sensitive for diagnosing early CTS
    - Thenar atrophy may be present in severe denervation
- CTS-6 diagnostic tool (Graham, 2008)
    - There is an 80% probability of CTS if patient has all 6 features:
        - Symptoms along digits innervated by median nerve
        - Night-time symptoms
        - Thenar atrophy or weakness
        - Presence of Tinel sign over median nerve
        - Positive Phalen test result
        - Loss of two-point discrimination
- Electrodiagnostic tests are not necessary for the diagnosis of CTS but may help confirm diagnosis in equivocal cases
    - Distal sensory latencies of more than 3.5 ms or motor latencies of more than 4.5 ms are abnormal.
    - Decreased conduction velocity and decreased peak amplitude are less specific.
    - EMG may show increased insertional activity, positive sharp waves, fibrillation, and/or abductor pollicis brevis fasciculation.
    - **More severe findings on EMG are associated with worse treatment outcomes.**
- Differential diagnosis: cervical radiculopathy,

brachial plexopathy, thoracic outlet syndrome, pronator syndrome, ulnar neuropathy with Martin-Gruber anastomoses, peripheral neuropathy

- Treatment
  - Nonoperative treatment: activity modification, night splints to keep wrist in neutral extension and decrease pressure within carpal tunnel, NSAIDs
    - **Single corticosteroid injection yields transient relief in approximately 80% of patients after 6 weeks, but only 20% are symptom free by 1 year.**
    - Failure to improve after corticosteroid injection is poor prognostic sign; surgery less successful in these cases.
  - Surgical treatment: open, mini-open, or endoscopic release of the TCL
    - No additional benefit gained from internal median nerve neurolysis or flexor tenosynovectomy
    - No need for preoperative antibiotics
    - Nerves at risk
      - If incision and approach are too ulnar: Ulnar neurovascular structures within Guyon canal
      - If incision and approach are too radial: Recurrent motor branch of the median nerve (Fig. 7.50)
        - Three main variations of the recurrent motor branch
          - Extraligamentou — approximately 50%
          - Subligamentou

—
approximately 30%

- Transligamento — approximately 20%

- Endoscopic carpal tunnel release: Outcomes similar to those of open release, with potentially less early scar tenderness, better short-term grip/pinch strength, and shorter return to work
  - Long-term outcomes of endoscopic and open release procedures are equivalent
  - Endoscopic release is associated with a surgeon learning curve; higher rate of major complications (nerve injury or incomplete TCL division) may be seen early in surgeon experience.
  - Open carpal tunnel release
    - Pinch strength returns to preoperative level in 6 weeks, and grip strength in 3 months.
    - Pillar pain adjacent to incision for 3–4 months after open carpal tunnel release is common.
    - Persistent symptoms after release: May be

- secondary to incomplete release of the TCL, a missed double-crush phenomenon, concomitant peripheral neuropathy, space-occupying lesion, or wrong diagnosis
- Worsening symptoms after surgery may indicate iatrogenic nerve injury.
- Higher severity of preoperative symptoms negatively impacts the degree of symptom relief after carpal tunnel release.
- Depression and poor coping mechanisms shown to predict patient dissatisfaction
- Pain catastrophizing also prolongs return to work.
- Chronic compression in elderly patients
  - Full sensory and motor function rarely recovered
  - Relief of painful nocturnal paresthesias more consistent
  - Improvements in activities of daily living, work performance, and overall hand function
  - Over 90% of patients satisfied with outcome
- Revision carpal tunnel release: Outcome depends on identification and treatment of the underlying cause of the failure.
  - Hypothenar or fat pad graft may be employed in revision cases (pedicle off ulnar artery).

□ **Pronator syndrome**

- Compression of the median nerve in the arm/forearm
- Potential sites of compression (Fig. 7.51) (mnemonic: SLAPS [©Kakar])
  - **S**upracondylar process: Anterior distal humerus

seen on lateral radiograph, in ~1% of the population
    - Ligament of **S**truthers: Courses between the supracondylar process and medial epicondyle
    - Bicipital aponeurosis (**l**acertus fibrosis)
    - FDS **a**poneurotic arch
    - Between the two heads of **p**ronator teres muscle
- Pronator syndrome differentiated from CTS by proximal volar forearm pain and sensory disturbances in distribution of palmar cutaneous branch of the median nerve over the thenar region, which comes off the median nerve proximal to the carpal tunnel
    - Patients with CTS have normal sensation over the thenar eminence
    - Patients with pronator syndrome have decreased sensation over the thenar region
- Provocative tests: Resisted elbow flexion with forearm supinated (bicipital aponeurosis), resisted forearm pronation with elbow *extended* (pronator teres), and resisted long finger PIP joint flexion (FDS)
- Electrodiagnostic test results often inconclusive
- Nonoperative treatment: Activity modification, splints, NSAIDs

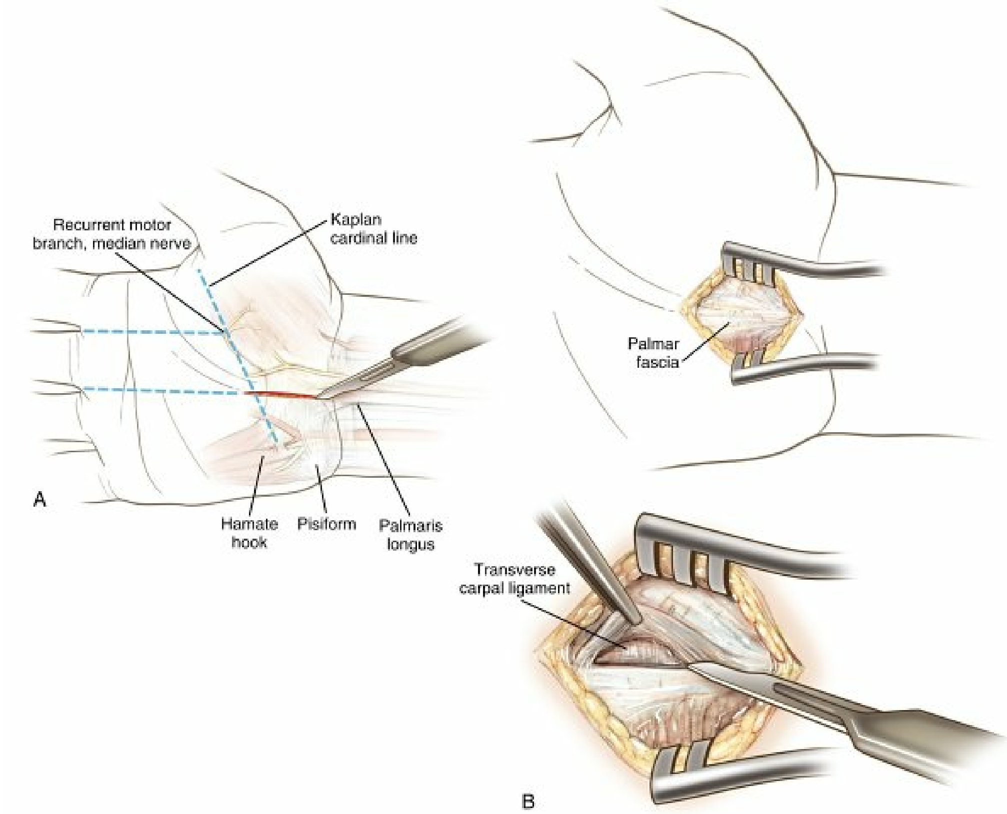


FIG. 7.50 (A) Landmarks for surgical approach to carpal tunnel release. (B) Exposure of the palmar fascia and transverse carpal ligament.
From Miller MD et al: *Orthopaedic surgical approaches,* Philadelphia, 2008, Saunders.

- Surgical treatment (with failure of nonoperative management): Release of all potential sites of compression
    - Success rate approximately 80% in most series
- Pronator syndrome is often associated with medial epicondylitis and tends to improve with its treatment

□ **AIN syndrome**

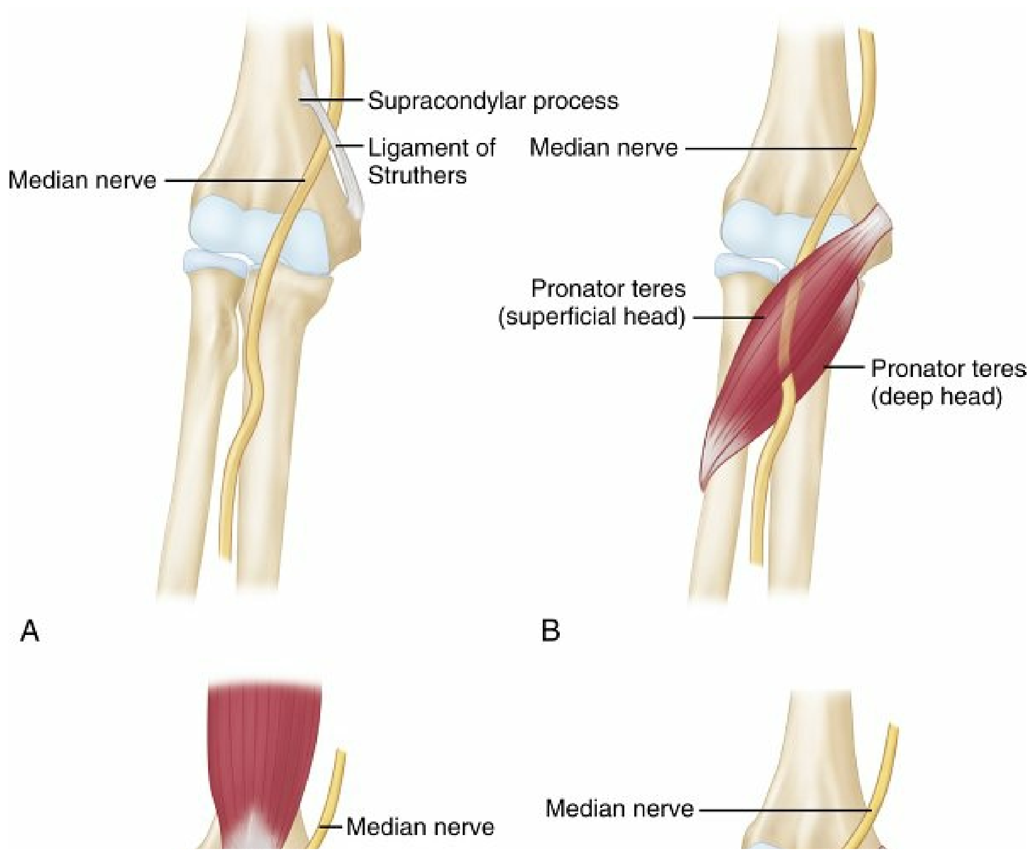
- **Involves motor loss of FPL, index ± long FDP, and PQ**
    - No sensory disturbance
- Precision sign: Index FDP and thumb FPL tested by asking patient to make an “OK” sign
- Provocative test: PQ involvement tested by resisted pronation with elbow maximally *flexed*
- Differential diagnosis
    - Transient AIN palsy is associated with Parsonage-Turner syndrome (viral brachial neuritis), especially if motor loss was preceded by intense shoulder pain or viral illness.
    - Isolated tendon rupture (e.g., Mannerfelt syndrome in RA with isolated FPL rupture as the tendon runs over the carpus within the wrist) must be ruled out.

- EMG may help confirm diagnosis.
- Sites/causes of median nerve compression in AIN syndrome, in addition to those listed for pronator syndrome, include
    - Enlarged bicipital bursa at the elbow
    - Gantzer muscle (accessory head of the FPL)
- Vast majority of patients recover with observation
- Nonoperative treatment: Activity modification and elbow splinting in 90 degrees of flexion
- Results of surgical decompression generally satisfactory if done within 3–6 months after onset of symptoms

▪ **Ulnar nerve**

□ **Cubital tunnel syndrome (see Fig. 7.49)**

- Second most common compression neuropathy of upper extremity
- Definition of the cubital tunnel
    - Deep (floor): medial collateral ligament (MCL) and elbow joint capsule
    - Walls of the tunnel: medial epicondyle and olecranon
    - Roof: FCU fascia and arcuate ligament of Osborne (fibrous band that traverses cubital tunnel from medial epicondyle to olecranon)
- Sites of compression (Fig. 7.52) (mnemonic: AO TEAM [©Kakar])



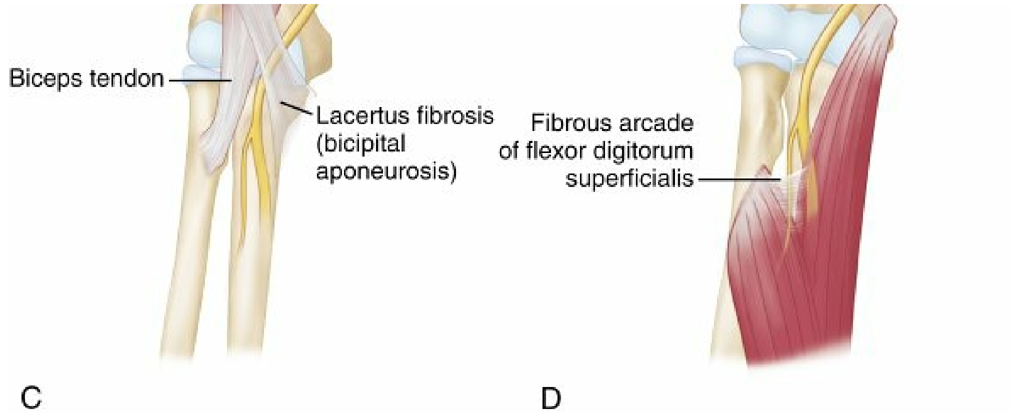


FIG. 7.51 (A) The ligament of Struthers bridges the supracondylar process of the humerus to the medial epicondyle or the origin of the humeral head of the pronator teres. (B) The median nerve may be compressed between the two heads of the pronator teres. (C) The lacertus fibrosis is an aponeurosis layer of the distal biceps, coursing obliquely in a distal and medial orientation. (D) The most distal site of proximal median nerve compression occurs at the fibrous arcade of the flexor digitorum superficialis.
From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 243.

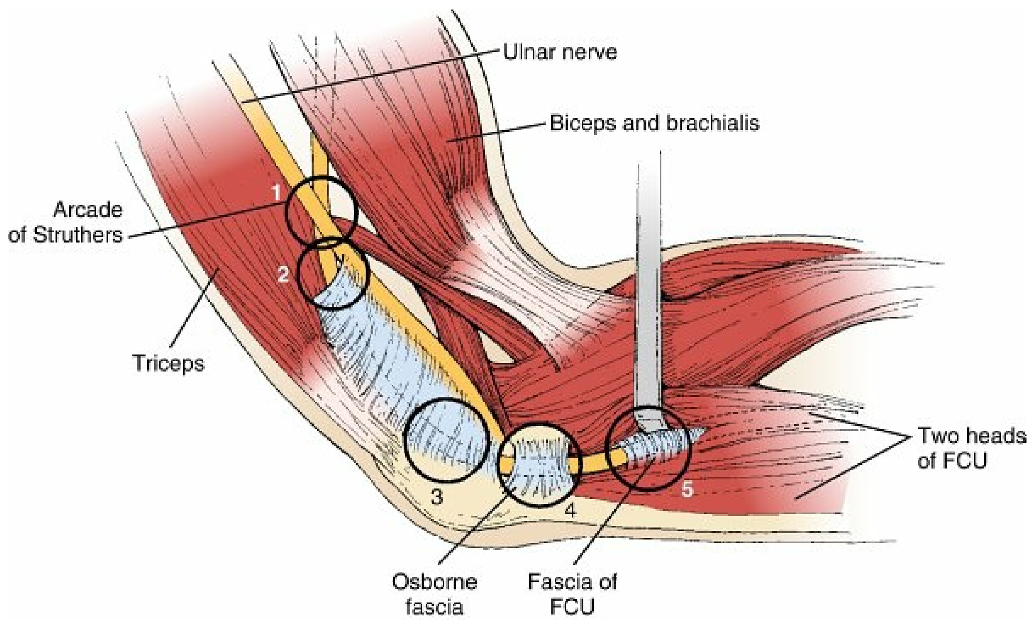


FIG. 7.52 Sites of ulnar entrapment. The nerve may be entrapped by *(1)* the arcade of Struthers, *(2)* the medial intermuscular septum, *(3)* the distal transverse fibers of the arcade of Struthers, *(4)* the Osborne ligament, and/or *(5)* the fascia (aponeurosis) of the FCU and fascial bands within the FCU.
From Miller MD et al: *Surgical atlas of sports medicine,* Philadelphia, 2003, Saunders, p 402.

- **A**rcade of Struthers: fascial thickening at hiatus of medial intermuscular septum as the ulnar nerve passes from anterior to posterior compartment
  - Location: ≈8 cm proximal to the medial epicondyle
- **O**sborne ligament

        - Medial head of **t**riceps
        - Anconeus **e**pitrochlearis: Anomalous muscle originating from medial olecranon and inserting on medial epicondyle
        - **A**poneurosis of proximal edge of FDS or two heads of FCU
        - **M**edial intermuscular septum
    - External sources of compression: Tumors, ganglions, osteophytes, heterotopic ossification (HO), medial epicondyle nonunion
    - Other associations: Burns, cubitus valgus deformities, medial epicondylitis, and repetitive elbow flexion/valgus stress during occupational or athletic activities
    - Differential diagnosis: Special awareness of thoracic outlet syndrome and cervical radiculopathy (C8–T1)
    - Presentation: Paresthesias of the ulnar 1½ digits (ulnar half of ring and small) and dorsal ulnar hand
    - Provocative tests: Direct cubital tunnel compression, Tinel test, and prolonged elbow hyperflexion
        - Examiner should check for subluxation of ulnar nerve over medial epicondyle during elbow flexion-extension arc
    - Classic examination findings secondary to motor weakness
        - Froment sign
            - Compensatory thumb IP joint flexion (FPL) during key pinch due to weak adductor pollicis
        - Jeanne sign
            - Hyperextension of thumb MCP with key pinch due to weak adductor pollicis
        - Wartenberg sign
            - Persistent abduction and extension of small digit during attempted adduction due to weak third volar interosseous and small finger lumbrical
        - Masse sign
            - Flattening of palmar arch and loss of ulnar hand elevation due to weak opponens digiti quinti and decreased small digit MCP flexion
        - Interosseous and/or first web space atrophy

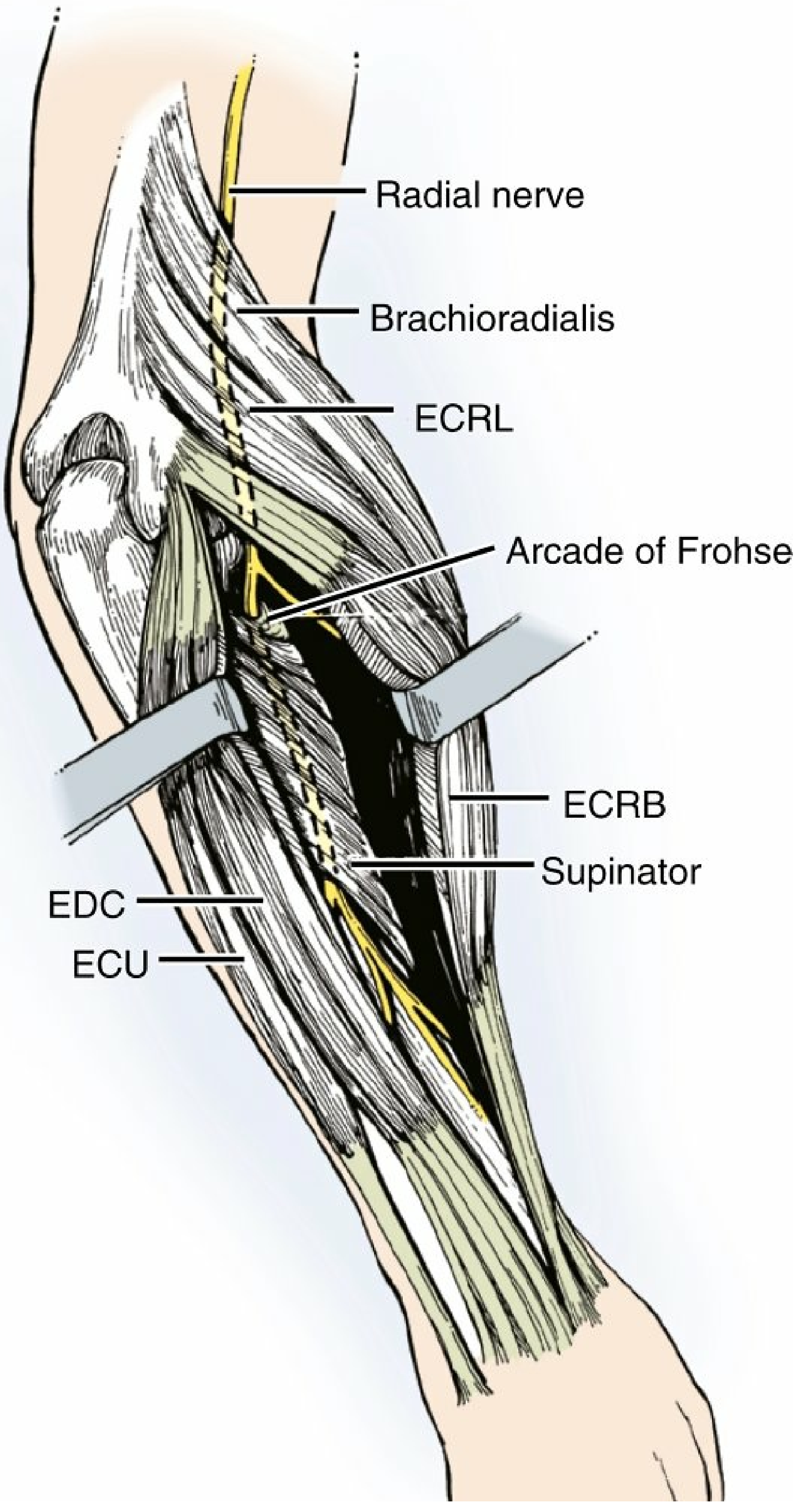
- Ring and small digit clawing due to FDP contraction and paralysis of the intrinsic muscles
- Electrodiagnostic tests are helpful for diagnosis and prognosis
    - Conduction velocity of less than 50 m/sec across elbow is the typical threshold for diagnosis; larger decreases in conduction velocity signal worse disease.
- Nonoperative treatment: Activity modification, night splints (elbow held in relative extension), FCU stretching, NSAIDs
- Numerous surgical techniques described
    - In situ decompression
    - Anterior transposition
        - Subcutaneous
        - Submuscular
        - Intramuscular
    - Medial epicondylectomy
    - Newer meta-analyses of techniques did not show statistically significant difference in outcomes between simple decompression and transposition when there is no ulnar nerve instability
    - Higher rate of recurrence than after carpal tunnel release
    - Better outcomes if release performed before motor symptoms appear
    - Promising early outcomes, but no long-term studies for endoscopic techniques
- Persistent postoperative medial/posterior elbow pain: Neuroma formation from iatrogenic injury to branches of the medial antebrachial cutaneous nerve should be considered as possible cause.

□ **Ulnar tunnel syndrome (see Fig. 7.49)**

- Compression neuropathy of ulnar nerve in Guyon canal
- **Most common cause: Ganglion cyst (80% of nontraumatic cases)**
- Other causative factors: hook of hamate nonunion, ulnar artery thrombosis, lipoma, palmaris brevis hypertrophy, other anomalous muscle
- Borders of the Guyon canal: volar carpal ligament (roof), TCL (floor), hook of hamate (radial), and pisiform and ADM muscle belly (ulnar)
- Ulnar tunnel divided into three zones
    - Zone I: Proximal to bifurcation of ulnar nerve;

associated with mixed motor/sensory symptoms
        - Zone II: Deep motor branch; associated with pure motor symptoms
        - Zone III: Distal sensory branches; associated with pure sensory symptoms
    - Useful adjunctive tests include
        - CT: Hamate hook fracture
        - MRI: Ganglion cyst or other space-occupying lesion
        - Doppler ultrasonography: Ulnar artery thrombosis
    - Success of treatment depends on identifying the cause
    - Nonoperative treatment: Activity modification, splints, NSAIDs
    - **Surgical treatment: Decompression followed by addressing of underlying cause**
    - Concurrent CTS: Guyon canal is adequately decompressed by release of the transverse carpal ligament.

- **Radial nerve**
  - **Radial nerve proper**
    - Rarely compressed by lateral head of triceps, typically compromised in setting of humerus trauma or related surgical approaches
    - Saturday night palsy: Intoxicated patient passes out with arm hanging over chair, wakes up with wristdrop
        - Presentation: Weakness of muscles innervated by radial nerve proper, such as triceps, brachioradialis, and ECRL, plus all muscles innervated by the PIN
        - Sensory deficits in the distribution of the superficial sensory branch
        - EMG may be helpful to determine severity and prognosis.
        - Treatment: Initial observation, but case should be explored if no recovery at 3–6 months
  - **PIN compression syndrome**
    - Presentation: Lateral elbow pain and distal muscle weakness


Radial nerve
Brachioradialis
ECRL
Arcade of Frohse
ECRB
Supinator
EDC
ECU

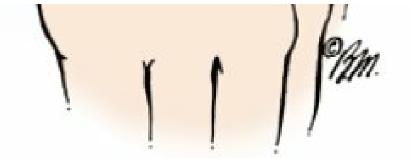


FIG. 7.53 Anatomic sites of compression include ECRB, arcade of Frohse (most common site, at proximal edge of supinator), and supinator.
From Green DP et al, editors: *Green's operative hand surgery,* ed 5, Philadelphia, 2005, Churchill Livingstone, p 1039.

- Radial deviation occurs with active wrist extension, because ECRL is innervated by radial nerve proper more proximally.
- PIN innervates the ECRB, supinator, EIP, ECU, extensor digitorum communis (EDC), extensor digiti minimi (EDM), APL, EPB, and EPL
    - First muscle innervated is the brachioradialis
    - Last muscle innervated (and last to recover after injury) is the EIP
- Patients may also have dorsal wrist pain where the terminal nerve fibers provide sensory innervation to the dorsal wrist capsule
    - Terminal branch is located on the floor of the fourth extensor compartment
- EMG helps confirm diagnosis
- **Anatomic sites of compression include (Fig. 7.53) (mnemonic: LEAFS [©Kakar])**
    - Recurrent **l**eash of Henry
    - Edge of the **E**CRB
    - **A**rcade of **F**rohse (most common site, at proximal edge of supinator) and fascial band at the radial head
    - Distal edge of the **s**upinator
- Unusual causes include chronic radial head dislocation, Monteggia fracture-dislocation, radiocapitellar rheumatoid synovitis, and space-occupying elbow mass (e.g., lipoma)
- PIN palsy is differentiated from extensor tendon rupture by a normal wrist tenodesis test result
- Nonoperative treatment: Activity modification, splinting, NSAIDs
- Surgical treatment (if no recovery by 3 months): Surgical decompression of anatomic sites of compression provides good to excellent results for 85% of patients

□ **Radial tunnel syndrome (see Fig. 7.49)**

- Presentation: Lateral elbow/radial forearm pain without motor or sensory dysfunction

- The point of maximum tenderness is several centimeters distal to lateral epicondyle.
- Provocative tests include resisted long-finger extension (positive result: resistance reproduces pain at the radial tunnel) and resisted supination.

- Lateral epicondylitis coexists in a small percentage of patients.
- Electrodiagnostic test results are typically inconclusive
- Nonoperative treatment: Prolonged (up to 1 year); activity modification, splints, NSAIDs, other modalities
- Surgical decompression: Results less predictable than for PIN syndrome; good to excellent results in only 50%–80% of cases after prolonged postoperative recovery

□ **Cheiralgia paresthetica (Wartenberg syndrome) (see Fig. 7.49)**

- Compressive neuropathy of SBRN
- Nerve is compressed between brachioradialis and ECRL with forearm pronation (by a scissor-like action between the tendons).
- Presentation: Pain, numbness, and paresthesias over the dorsoradial hand, inability to wear a watch or jewelry secondary to pain over the nerve
  - Provocative tests: Forceful forearm pronation for 60 seconds, Tinel test
- Nonoperative treatment: Activity modification, splinting, NSAIDs
- Surgical decompression: Warranted if 6-month trial of nonoperative treatment fails

▪ **Thoracic outlet syndrome**

□ **Vascular**

- Subclavian vessel compression or aneurysm, diagnosed by physical examination and angiography
- Adson test
  - Patient keeps arm at the side, hyperextends neck, and rotates head to the affected side; a diminished radial artery pulse with inhalation is a positive result.
- Duplex ultrasonography has better than 90% sensitivity and specificity

□ **Neurogenic**

- Entrapment neuropathy of the lower trunk of the brachial plexus
- Often overlooked or undetected by history and physical examination

- Fatigue is common, particularly when arm is used in a provocative position.
- Nonspecific paresthesias are most common initial complaint; present in about 95% of patients.

- Electrodiagnostic studies are rarely helpful.
- Sensory disturbance of medial brachial and antebrachial cutaneous nerves may differentiate the condition from cubital tunnel syndrome.
- Roos sign
    - Presence of heaviness or paresthesias in the hands after they have been held above the head for at least 1 minute

Table 7.9

Classifications of Nerve Injury

Classification			
Seddon	**Sunderland**	**Injury**	**Prognosis**
Neurapraxia	First degree	Demyelination injury	Temporary conduction block; resolves in 1–2 days
Axonotmesis	Second degree	Axonal injury	Regeneration is usually complete but may take several weeks or months.
	Third degree	Endoneurium injured	Regeneration occurs but is not satisfactory.
	Fourth degree	Perineurium injured	Spontaneous regeneration is unsatisfactory, resulting in neuroma-in-continuity.
Neurotmesis	Fifth degree	Severed nerve trunk	Spontaneous regeneration is not possible without surgery.

From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 227.

- Cervical and chest radiographs: to rule out cervical rib or Pancoast tumor
- Physical therapy focuses on shoulder girdle strengthening and proper posture and relaxation techniques.
- Transaxillary first rib resection by thoracic surgeon yields good to excellent results when cervical rib is cause.
    - Combined approach including anterior and middle scalenectomy also described

Nerve Injuries and Tendon Transfers

- **Peripheral nerve injuries**
  - Introduction
    - Peripheral nerve function may be compromised by compression, stretch, blast, crush, avulsion, transection, or tumor invasion.
    - Evaluation and treatment of traumatic peripheral nerve dysfunction are guided by mechanism of injury and presence of other injuries.
    - Most important prognostic factor for nerve recovery is **patient age**
      - Good prognosis: With stretch injuries or clean wounds, and after direct surgical repair
      - Poor prognosis: With crush or blast injuries and infected or scarred wounds, and after delayed surgical repair
  - Classification
    - Seddon and Sunderland (Table 7.9)
      - Neurapraxia
        - Injury type: Mild nerve stretch or contusion
        - Focal conduction block
        - No wallerian degeneration
        - Disruption of myelin sheath
        - Epineurium, perineurium, endoneurium intact
        - Prognosis: Excellent; recovery expected
      - Axonotmesis
        - Injury type: Incomplete nerve injury
        - Focal conduction block
        - Wallerian degeneration distal to injury
        - Disruption of axons
        - Sequential loss of axon, endoneurium, perineurium (Sunderland classes 2, 3, 4)
        - Neuroma-in-continuity may develop
        - Prognosis: Recovery unpredictable
      - Neurotmesis
        - Injury type: Complete nerve injury
        - Focal conduction block

- Wallerian degeneration distal to injury
- Disruption of all layers, including epineurium

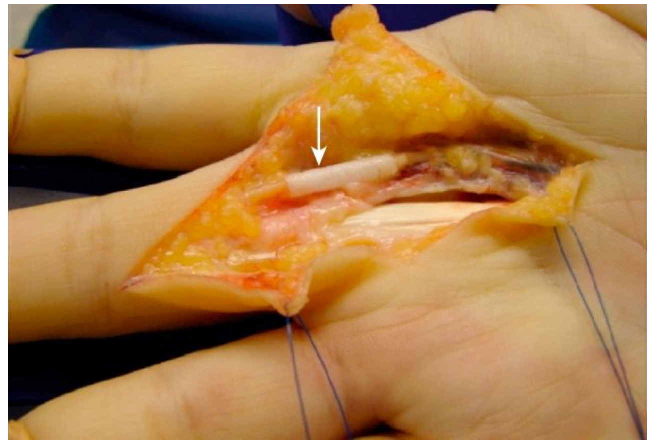


FIG. 7.54 View of a collagen-based nerve conduit *(arrow)* used to span a gap in the radial digital nerve of the right middle finger.
From Haug A et al: Sensory recovery 1 year after bridging digital nerve defects with collagen tubes, *J Hand Surg Am* 38:90–97, 2013.

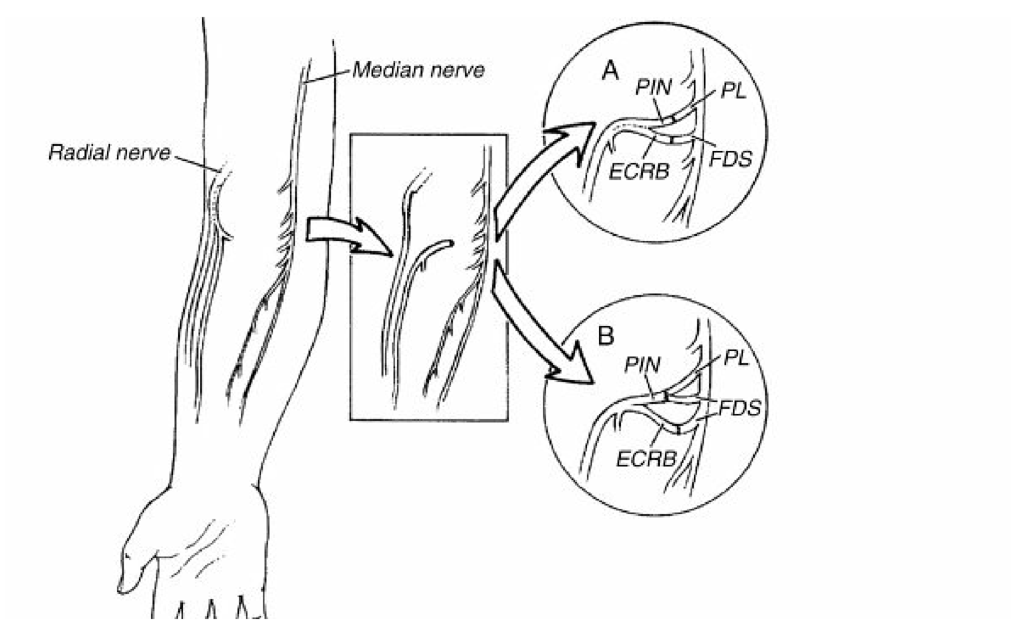
- Neuroma formation by proximal nerve end
- Glioma formation by distal end
- Prognosis: Worst recovery

- In axonotmesis and neurotmesis, the distal nerve segment undergoes wallerian degeneration.
  - The degradation products are removed by phagocytosis.
    - Myelin-producing Schwann cells proliferate and align themselves along the basement membrane, forming a tube that will receive regenerating axons.
    - **Nerve cell body enlarges as rate of structural protein production increases.**
    - **Each proximal axon forms multiple sprouts that connect to the distal stump and migrate at a rate of 1 mm/day.**

□ **Surgical repair**
- Best results are achieved when performed within 10–14 days

of injury

- Key point: Repair must be tension-free within clean, well-vascularized bed.
- Nerve length may be gained by neurolysis or transposition.
- Repair techniques (no best technique)
    - Epineurial
    - Individual fascicular
    - Group fascicular
- Use of nerve conduits (polyglycolic acid and collagen-based; Fig. 7.54) has gained popularity for digital nerve gaps between 8 and 20 mm.



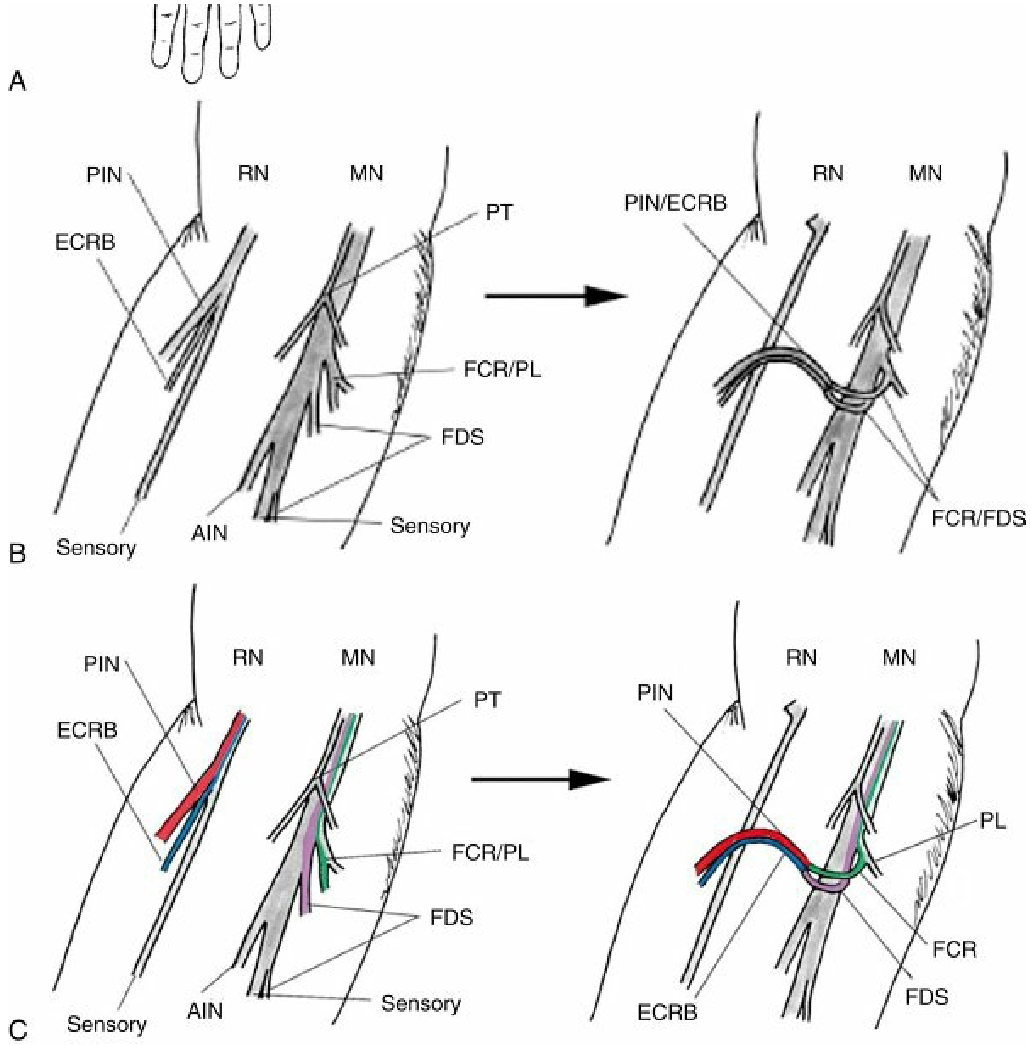


FIG. 7.55 (A) Median nerve–to–radial nerve transfers in the forearm for high radial nerve palsy. (B) Branch of the median nerve (MN) to the FDS transferred to ECRB branch of the radial nerve (RN), and (C) branch of the median nerve to the FCR transferred to the PIN. From Ray WZ, Mackinnon SE: Clinical outcomes following median to radial nerve transfers, *J Hand Surg Am* 36:201–208, 2011.

- Larger gaps, especially of mixed nerves, require grafting
  - Autogenous (e.g., sural, medial/lateral antebrachial cutaneous, terminal/PIN)
  - Vascularized
- Limited data available on decellularized nerve allografts, with promising early results, especially for sensory recovery
- Growth factor augmentation (e.g., insulin-like growth factor [IGF], fibroblast growth factor [FGF]) showed promise in animal models.
- Chronic peripheral nerve injuries treated with nerve transfers and/or tendon transfers are shown in Fig. 7.55.

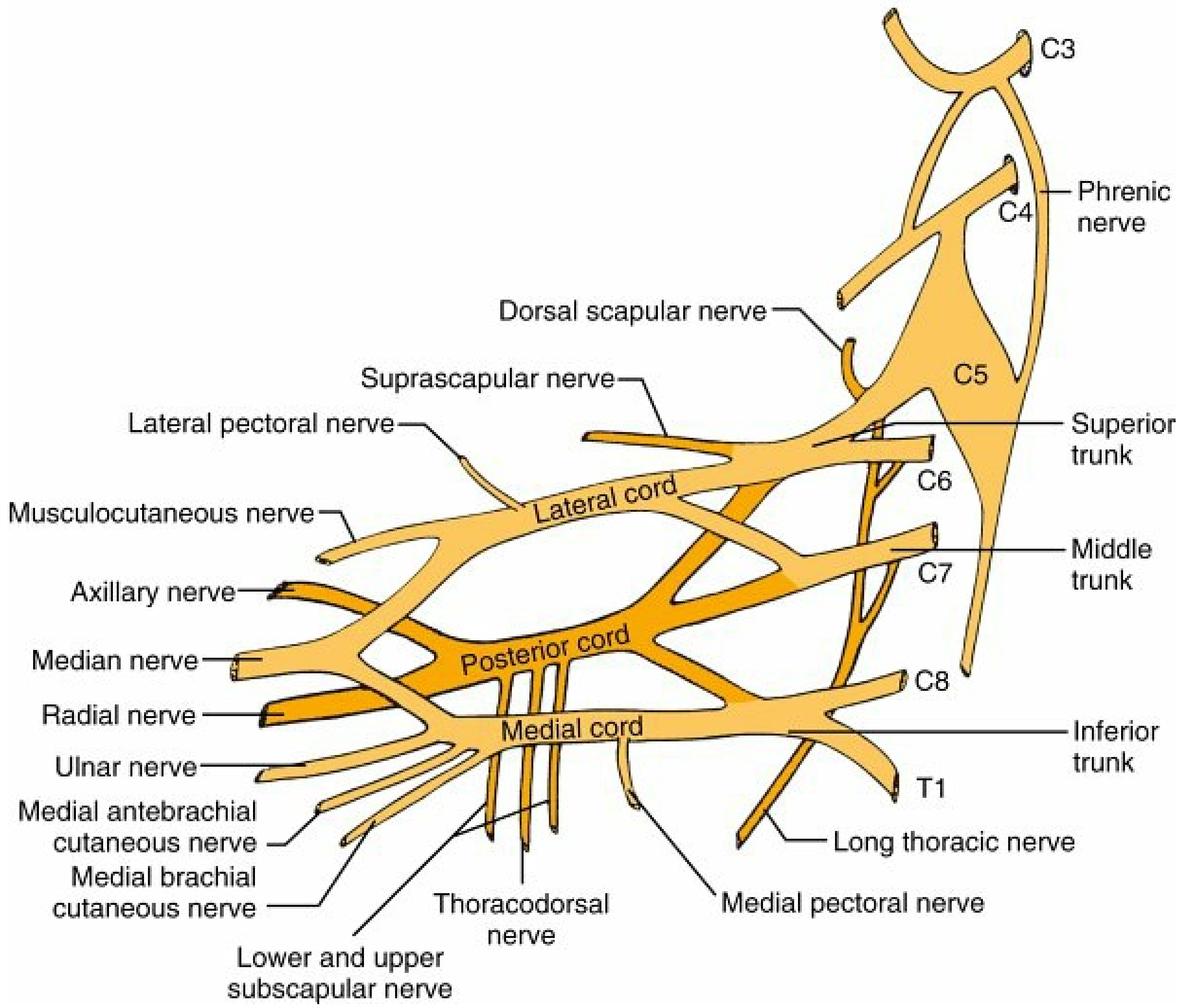


FIG. 7.56 Brachial plexus anatomy.
From Brushart TM, Wilgus EF: Brachial plexus and shoulder girdle injuries. In Browner BD, Jupiter JB, editors: *Skeletal trauma,* ed 2, Philadelphia, 1998, Saunders, p 1696.

- **Traumatic brachial plexus injury**
  - **Knowledge of brachial plexus anatomy is critical for understanding the evaluation and diagnosis of brachial plexus lesions (Fig. 7.56).**
  - High-energy mechanisms are associated with more severe lesions such as nerve root avulsions.
  - Diagnosis
    - Location and severity of injury
    - Comprehensive motor and sensory evaluation
    - Supraclavicular versus infraclavicular
    - **Preganglionic brachial plexus lesions (nerve root avulsions) have worst prognosis**
      - **Horner sign (sympathetic chain): Ptosis, miosis, anhidrosis**
      - **Winged scapula from serratus anterior (long thoracic)**
      - **Weak rhomboids (dorsal scapular)**
      - **Motor deficits with intact sensory function (cell bodies in dorsal root ganglia)**

        - EMG shows loss of innervation to paraspinal muscles.
        - Elevated hemidiaphragm (phrenic)
    - Complete radiographic series should include cervical spine, chest, and shoulder girdle.
        - Inspiratory and expiratory chest radiographs: Paralyzed hemidiaphragm
        - Finding of transverse spinal process fractures may indicate nerve root avulsions.
        - Scapulothoracic dissociation is often linked to multiple root avulsions and major vascular injury.
    - CT myelography to detect nerve root avulsions
    - MRI to search for peripheral neuromas, pseudomeningocele, mass lesions
    - EMG to evaluate extent of injury and denervation (fibrillation potentials), and to monitor recovery
    - NCS to assess extent of injury and to monitor recovery
    - Sensory nerve action potentials (SNAPs) measurement: Normal SNAPs but loss of sensation on examination indicates preganglionic injury
    - Somatosensory evoked potentials measurement to assess continuity of nerve roots
        - Must be performed 4–6 weeks after injury (wallerian degeneration)
- □ Timing of surgical treatment
    - Newer studies suggest that earlier operative interventions might improve outcome.
    - Immediate surgical exploration: Cases of penetrating trauma, iatrogenic injury, vascular injury, and progressive neurologic deficits
        - Exception: Gunshot wounds to the plexus may improve over time without surgery.
    - Initial treatment: Observation for 3 months to assess extent of recovery
    - Early surgical treatment (3–12 weeks): Indicated for incomplete or near-complete injuries resulting from high-energy mechanism
    - Delayed surgical treatment (3–6 months): Indicated for incomplete upper plexus lesion from low-energy mechanisms or with a plateau in recovery
    - Beyond 6 months, nerve repair or reconstruction has a less predictable outcome.
    - Most reliable clinical sign of nerve recovery: An advancing

Tinel sign
            - Muscle fibrosis occurs after 18–24 months
        - Tendon/nerve transfers
            - Isolated C8–T1 injury best treated with early tendon transfers
                - Full recovery unlikely because of distance between lesion and hand intrinsic muscles
            - For other lesions, nerve repair or reconstruction is prioritized
                - Elbow flexion > shoulder stabilization > hand function
            - Direct repair often compromised by excessive tension
                - Neuroma excision and nerve cable grafting usually necessary
                - Donor sites: Sural, medial brachial cutaneous, and medial antebrachial cutaneous nerves
                - Best outcomes obtained in young patients treated within 3 months of injury
            - Nerve transfers indicated when insufficient number of proximal axons available (e.g., nerve root avulsions)
                - **Oberlin transfer: Ulnar nerve motor branch (fascicle) to the FCU transferred to musculocutaneous nerve: Elbow flexion**
                - Descending branch of spinal accessory nerve (cranial nerve XI) transferred to suprascapular nerve: Shoulder abduction
                - Radial nerve motor branch to the triceps transferred to the axillary nerve: Shoulder abduction/forward elevation
            - Leechavengvong procedure: Transfer of triceps motor branch of radial nerve to axillary nerve
            - Tendon or muscle transfers: Indicated in patients without meaningful recovery of shoulder and elbow function after 6–12 months
                - Priorities: Elbow flexion > shoulder function > finger function.
- **Obstetric brachial plexopathy**
    - Associated with high birth weight, cephalopelvic disproportion, shoulder dystocia, and forceps delivery
    - Muscle grading system
        - M0: No contraction
        - M1: Contraction without movement
        - M2: Contraction with slight movement
        - M3: Complete movement
    - Complete recovery possible if biceps and deltoid function are M1 by 2

months

- **Incomplete recovery expected if biceps and deltoid do not contract within 3–6 months.**
- Surgery usually not recommended if biceps contraction evident by 6 months (some advocate sooner)
- Results of nerve grafting are better in infants than adults; reinnervation of the hand intrinsic muscles is possible.

- **Cerebral palsy**
  - Introduction
    - **Nonprogressive** CNS insult
    - Typical upper extremity deformities
      - Thumb-in-palm
      - Clenched fist
      - Wrist flexion
      - Forearm pronation
      - Elbow flexion
      - Shoulder internal rotation
  - Nonoperative treatment
    - Initially involves physical therapy and nighttime static splinting
    - Antispasticity medications such as diazepam, baclofen, tizanidine, and dantrolene
    - Intrathecal baclofen infusion pump
    - Botulinum toxin A is transiently effective (3–6 months) and may be used periodically for severe spasticity.
  - Operative treatment
    - Best performed on children with higher IQs (>50–70), voluntary muscle control, and good sensibility
      - Voluntary muscle control is the most important predictor of success.
    - Thumb-in-palm deformity: Release or lengthening of the adductor pollicis, first dorsal interosseous, FPB, and FPL muscles, combined with first web space Z-plasty and tendon transfers to augment thumb extension and abduction
    - Clenched fist associated with digital flexor tightness and intrinsic spasticity: Fractional lengthening or Z-lengthening of tendon with or without ulnar motor neurectomy
    - Wrist flexion deformity: FCU to ECRB/ECRL tendon transfer in patients without fixed contractures; wrist arthrodesis for fixed contractures in late stages
      - Concomitant PRC at the time of fusion may improve wrist positioning and help rebalance severe digital flexor tightness.

- Mild elbow flexion contractures: Musculocutaneous neurectomy
- Severe elbow flexion contractures: Biceps/brachialis lengthening combined with anterior joint capsulotomy
- Shoulder contractures: derotational humeral osteotomy, lengthening of the subscapularis and pectoralis major muscles, or shoulder arthrodesis.

- **Stroke**
  - Cerebral vascular accident (CVA) may lead to significant upper extremity disability
  - Spontaneous neurologic recovery 6-12 months after CVA
  - Uncontrolled muscle spasticity may lead to typical joint contractures.
    - Shoulder adduction
    - Elbow flexion
    - Forearm pronation
    - Wrist and digit flexion
    - Thumb-in-palm
    - Clenched fist
  - Contracture releases and/or tendon transfers done for functional positioning
  - Clenched fist deformity in patient without volitional control treated with superficialis-to-profundus (STP) tendon transfer to decrease pain and improve hygiene
- **Tendon transfers**
  - Indications
    - Replace irreparably injured tendons/muscles
    - Substitute for function of a paralyzed muscle
    - Restore balance to a deformed hand
  - Timing of tendon transfers is controversial and depends on age, indication, and prognosis.
  - Tendon transfers are generally deferred until tissue equilibrium is achieved and passive joint mobility is restored.
    - Sometimes over 12 months after brachial plexus injury or until spasticity resolves in a tetraplegic hand.
  - Key concepts
    - Force is proportional to the cross-sectional area of the muscle.
      - The greatest force of contraction is exerted when the muscle is at its resting length.
    - Amplitude or excursion is proportional to the length of the muscle.

Table 7.10

Classic Tendon Transfers

Palsy	Loss	Transfer
Radial	Wrist extension	Pronator teres to ECRB
	Finger extension	FCU to EDC II–V, FCR to EDC II–V FDS III to EPL and EIP, FDS IV to EDC III–V
	Thumb extension	Palmaris longus to EPL FDS to radial lateral band
Low ulnar	Hand intrinsics (interosseous and ulnar lumbricals)	ECRL to lateral band EDQ EIP to lateral band FCR + graft to lateral band Metacarpal phalangeal capsulodesis
	Thumb adduction	ECRL + graft to adductor pollicis Brachioradialis + graft to adductor pollicis
	Index abduction	EIP to first dorsal interosseous APL to first dorsal interosseous ECRL to first dorsal interosseous
High ulnar	Low problems + FDP Ring and small fingers	Suture to functioning FDP index and long index and long finger
Low median	Opposition	FDS ring to APB (FCU pulley) EIP to thumb proximal phalanx (routed around the ulna for line of pull) Abductor digiti quinti to APB Palmaris longus to APB
High median	Thumb IP flexion	Brachioradialis to FPL
	Index and long-finger flexion	Suture to functioning FDP ring and small finger or ECRL to FDP index and long finger if additional power is needed
Low median and ulnar	Thumb adduction	ECRB + graft to adductor tubercle of thumb
	Index abduction	APL to first dorsal interosseous
	Opposition	EIP to APB
	Clawed fingers	Brachioradialis + four-tailed free graft to the A2 pulley
	Volar sensibility	Neurovascular island flap from back of hand
High median and ulnar	Thumb adduction	ECRB + graft to adductor tubercle of thumb
	Thumb IP flexion	Brachioradialis to FPL
	Thumb abduction	EIP to APB

	Index abduction	APL to first dorsal interosseous
	Finger flexion	ECRL to FDP
	Clawed fingers	Tenodesis of all metaphalangeal joints, with free-tendon graft from dorsal carpal ligament routed deep to TML to extensor apparatus
	Wrist flexion	ECU to FCU
	Volar sensibility	Neurovascular island flap from back of hand

- Smith 3-5-7 rule estimates excursion of wrist flexors/extensors (3 cm), finger extensors (5 cm), and finger flexors (7 cm).
- Work capacity is force times length (F × L).
- Power is the amount of work performed in a unit of time.

□ Selection of a transfer

- What function is missing?
- What muscle-tendon units are available?
- What are the options for transfer?

□ Basic tenets

- Donor must be expendable.
- Donor must be of similar excursion and power.
- One tendon is used for one function.
- Synergistic transfers are easier to rehabilitate.
- Line of pull of tendon should be complementary to needed function.
- One grade of motor strength will be lost after transfer.

□ Tendon transfers for high radial nerve palsy

- Wrist extension: pronator teres to ECRB
- Finger extension: FCU or FCR to EDC
- Thumb extension: PL to EPL

□ Tendon transfer (opponensplasty) options for low median nerve palsy

- FDS of ring, EIP, ADM, and PL all transferred to APB.

□ **Classic tendon transfers are outlined in Table 7.10**

□ Most common complication of tendon transfer is development of motion-limiting adhesions, which requires aggressive hand therapy or secondary tenolysis if there has been minimal improvement.

Arthritis

▪ **OA**

□ Primary idiopathic degenerative joint disease

□ OA: Commonly affects DIP joints (most common) and trapeziometacarpal joint of thumb (second most common)

- Erosive form more commonly affects PIP joints.
- MCP joints not typically involved in noninflammatory arthritis
- Wrist arthritis is usually posttraumatic.

□ Classic triad: Pain, swelling, and decreased motion
□ Classic radiographic findings: Joint space narrowing, osteophytes, subchondral sclerosis, and subchondral cyst formation
□ Nonoperative treatment: activity modification, NSAIDs, splints and intraarticular corticosteroid injections
□ Specific joint findings and treatment

- DIP joint
    - Presentation: Often asymptomatic despite radiographic changes
    - Heberden nodes: Marginal DIP osteophytes
    - May be associated with symptomatic mucous cyst
        - Aspiration versus excision of cyst and osteophyte if symptomatic ± local rotational skin flap
    - Definitive surgery: For continued pain, instability, or deformity
        - Arthrodesis: Kirschner wires or headless cannulated screw

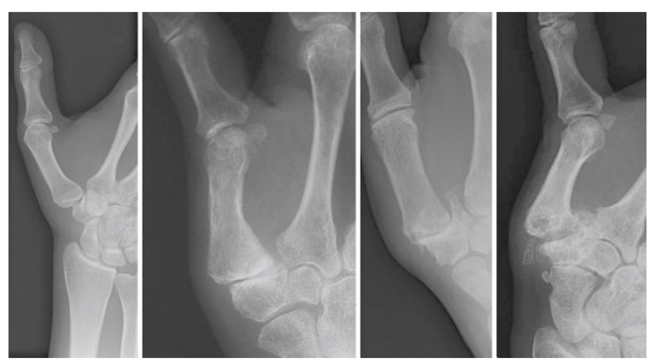


FIG. 7.57 Eaton and Littler radiographic stages of trapeziometacarpal OA. *Left to right,* Stages I through IV.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 409.

            - Position: Neutral extension to 5–10 degrees of flexion
- PIP joint
    - Bouchard nodes: Marginal PIP osteophytes
    - Surgical options: Arthrodesis and arthroplasty
    - Arthrodesis is better than arthroplasty for the

index PIP joint because of lateral pinch stresses.

        - Joint fusion position increases from radial to ulnar
            - Index: 40 degrees
            - Long: 45 degrees
            - Ring: 50 degrees
            - Small: 55 degrees
    - PIP arthroplasty is often preferred for the long, ring, and small digits, which all play an important role in power grasp.
        - Dorsal and volar approaches equivalent
        - Implant options: Silicone and pyrolytic carbon
            - Pyrolytic carbon (nonconstrained) requires competent collateral ligaments.
            - Silicone arthroplasty can be used in patients with collateral insufficiency (e.g., from RA).
        - Most common complication: Related to extensor tendon dysfunction (dorsal approach)
    - Outcomes: Predictable pain relief, preservation of motion and grip/pinch strength
        - Postoperative motion is most dependent on preoperative motion
- MCP joint
    - Inflammatory arthritis: much more common than OA
        - May be involved in patients with hemochromatosis
    - Implant options: Silicone and pyrolytic carbon
    - Arthrodesis: Severely limits hand function but may be necessary in setting of failed arthroplasty or septic arthritis or contractures (e.g., arthrogryposis)
        - Index: 25 degrees
        - Long: 30 degrees
        - Ring: 35 degrees
        - Small: 40 degrees

Table 7.11

Eaton and Littler Radiographic Stages of Trapeziometacarpal OA

Stage	Description
I	Normal-appearing joint with the exception of possible widening from synovitis
II	Joint space narrowing, with debris and osteophytes <2 mm
III	Joint space narrowing, with debris and osteophytes >2 mm
IV	Joint space narrowing of scaphotrapezial and trapeziometacarpal articulations

From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 330.

- Thumb MCP joint
  - Wide variability in ROM, depending on metacarpal head morphology
  - Rarely involved in primary OA
  - Pain is reliably relieved by arthrodesis, with the joint placed in 10–20 degrees of flexion.
- Thumb trapeziometacarpal joint
  - Also termed basal joint or CMC joint
  - Arthritis theorized by Pellegrini to result from anterior oblique ("beak") ligament attenuation
    - Leads to instability, dorsoradial subluxation, and cartilage degeneration
  - Presentation: Pain and/or crepitus, elicited with the axial grind test or combined axial compression and circumduction
    - **Late findings: Metacarpal adduction, first web space contracture, compensatory MCP hyperextension**
    - Carpal tunnel syndrome in ≈50% of patients with thumb CMC OA
  - Classification: Eaton and Littler staging (Fig. 7.57; Table 7.11)
  - Nonoperative treatment: Activity modification, corticosteroid injection
    - Hyaluronic acid injection equivalent to placebo or corticosteroid injection.

- Surgical treatment: Many options; all involve at least partial excision of trapezium.
  - Arthrodesis: Classically indicated for young laborers
    - 20 degrees of radial abduction and 40 degrees of palmar abduction
- Arthroscopic hemitrapeziectomy: Early-stage disease
- Ligament reconstruction–tendon interposition (LRTI) with trapezium excision: Most common procedure performed for CMC OA
  - FCR and APL common choices for tendon graft
  - **FCR, APL, and ECRL suspensionplasties have similarly good results and can be used if FCR is iatrogenically injured during LRTI.**
- Simple trapeziectomy ("hematoma arthroplasty"): Similar in outcome to all other procedures
- Interposition with synthetic materials and prosthetic arthroplasty have shown promising early outcomes; there are no long-term or comparison series.
  - Silicone arthroplasty: High rates of failure and synovitis
- STT joint assessed intraoperatively and treated accordingly
- Thumb MCP hyperextension: Volar capsulodesis or MCP joint arthrodesis
- Proximal migration (settling) of first metacarpal during pinch not correlated with clinical outcome.
  - Pinch force at the thumb CMC joint is 12-fold stronger than that seen at the tip between the index finger and thumb.

▪ **Rheumatoid arthritis (Fig. 7.58)**

□ Overview

- Systemic autoimmune inflammatory disease that primarily affects the hand and wrist (Fig. 7.59)
- Comparison with OA: DIP joints more often affected by OA,

MCP joints by RA; PIP joints affected by both
- Emergence of more effective disease-modifying antirheumatic drugs (DMARDs) has dramatically reduced the frequency of surgical intervention for patients with arthritis.

□ Diagnosis
- Symmetric complaints of pain, morning stiffness, hand swelling
- Tenosynovitis and tendon rupture are common
- Serologic study results may be positive (rheumatoid factor found in 70%–90% of patients) within several months of disease onset
- Classic radiographic features: Diffuse osteopenia, periarticular erosion, joint subluxation; however, they may not appear for several years.
- MRI with IV contrast: More sensitive for detecting early disease, with findings of enhanced synovial proliferation, bone marrow edema, and periarticular erosion
- Medical management with DMARDs has markedly improved control of RA and resultant hand involvement in years.

□ Treatment
- **Rheumatoid nodules**
    - Subcutaneous masses consisting of chronic inflammatory cells surrounded by collagenous capsule
    - Occur over bony prominences on extensor surfaces
    - May erode through skin and cause chronic draining sinuses
    - Treatment: Surgical excision for symptomatic or cosmetic management (high recurrence rate)
- **Tenosynovitis**
    - Hyperplasia and inflammatory cell infiltration of synovium-lined tendon sheaths that may precede joint manifestations
    - May involve flexor and/or extensor tendons of hand/wrist
    - Nonoperative treatment: Activity modification, splinting, and antiinflammatory medication should be tried for 4–6 months.
    - Tenosynovectomy: Reserved for cases in which conservative treatment fails or when impending tendon rupture is evident

- **Tendon rupture (see Fig. 7.58)**
  - Occurs from chronic tenosynovitis or mechanical abrasion over bony prominences
  - Vaughan-Jackson syndrome: Progressive rupture of extensor tendons, starting with EDM and progressing radially
    - Etiology: Attrition over prominent distal ulnar head (caput ulnae syndrome)
  - EPL rupture: Attrition over the Lister tubercle
  - Mannerfelt syndrome: FPL and/or index FDP rupture secondary to attrition over a volar STT joint osteophyte
  - Treatment: Direct repair is prone to failure because tendon is of poor quality, so tendon transfer is preferred method of treatment (Fig. 7.60).
- **Caput ulnae syndrome (see Fig. 7.58)**
  - End-stage finding of DRUJ instability/arthritis from chronic synovitis and surrounding capsular and ligamentous laxity
  - Etiology: ECU subsheath attrition leading to ECU tendon ulnar and volar subluxation, resulting in carpal supination and dorsal capsule attrition
    - Piano key sign: Dorsal subluxation of ulnar head
  - Attritional rupture of extensor tendons (see Vaughn-Jackson syndrome)
  - Surgical treatment: Darrach distal ulna resection, Sauvé-Kapandji procedure, resection hemiarthroplasty, ulnar head prosthetic replacement
- **Rheumatoid wrist (see Fig. 7.58)**
  - Extensive synovitis and pannus formation weaken the capsular and ligamentous structures that stabilize the radiocarpal joint and DRUJ.
  - Carpus subluxes in volar and ulnar direction
  - **Chronic SL ligament** disruption can lead to rotatory subluxation of the scaphoid and progressive carpal collapse (SLAC pattern).
  - **Presence of SL disruption**
    - Acute: Traumatic injury most likely
    - Chronic: Acute-on-chronic trauma or

inflammatory arthritis likely

- Early disease: Synovectomy may delay severe joint destruction and deformity.
- Intermediate-stage disease: Radiolunate arthrodesis (Chamay) centralizes the lunate and diminishes further carpal subluxation and ulnar translocation.
    - Goal: To preserve midcarpal motion
- Total wrist arthrodesis: Gold standard for advanced radiocarpal destruction (Fig. 7.61)

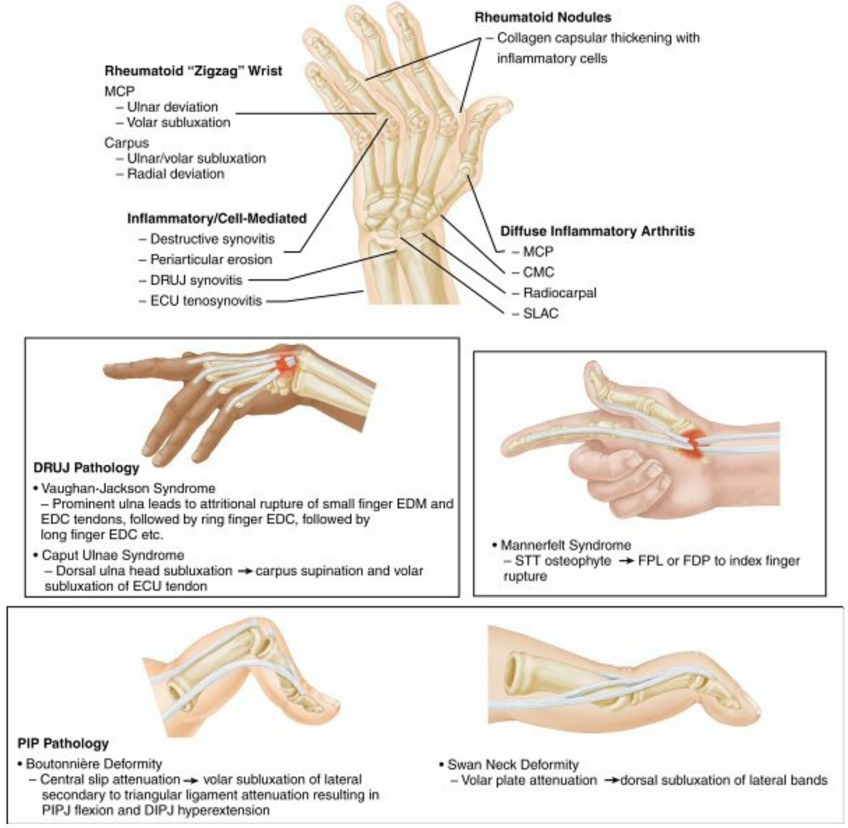


FIG. 7.58 Rheumatoid arthritis is associated with many classic findings in the hand.

- The classic “zigzag” wrist involves carpal ulnar and volar subluxation with associated radial deviation, leading to MCP ulnar deviation and volar subluxation.
- There is diffuse inflammatory and cell-mediated arthritis, synovitis, and periarticular erosions.
- The DRUJ has multiple classic findings, including the Vaugh-Jackson syndrome (extensor tendon rupture from prominent ulna) and caput ulnae syndrome (dorsal ulnar head subluxation with ECU subluxation).
- The Mannerfelt syndrome involves the rupture of the FPL or index FDP from an osteophyte of the STT joint.
- Two classic PIP joint (J) pathologies involve the boutonnière and swan neck deformities. The boutonnière deformity is associated with a central slip attenuation or injury leading to volar subluxation of the lateral bands. The swan neck deformity is associated with volar plate attenuation leading to dorsal subluxation of the lateral bands.

- Bilateral arthrodesis: Improved outcomes if no ipsilateral elbow/shoulder/finger pathology.
- Historical position (controversial):

Fusion of one wrist in slight extension and the other in slight flexion

- Total wrist arthroplasty: Reserved currently for functionally low-demand patients with adequate bone stock, minimal deformity, and intact extensor tendon function (Fig. 7.62)
    - Both total wrist arthrodesis and total wrist arthroplasty have been shown to be cost-effective procedures for the treatment of rheumatoid wrist arthritis.
    - Bilateral disease: Some prefer arthroplasty of the dominant wrist and fusion of the nondominant wrist.

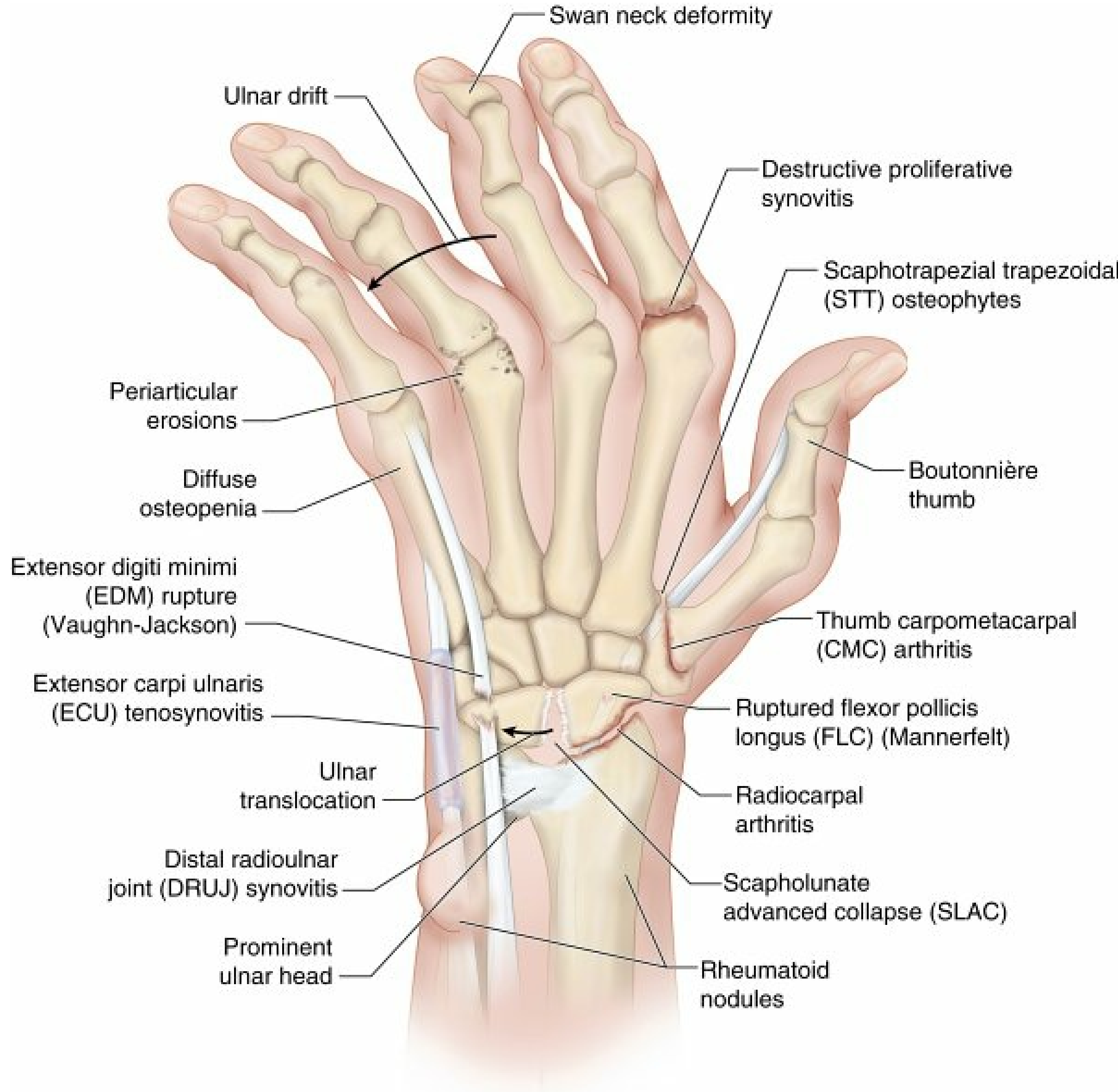


FIG. 7.59 Composite image showing pathologic manifestations of rheumatoid disease in the hand and wrist.

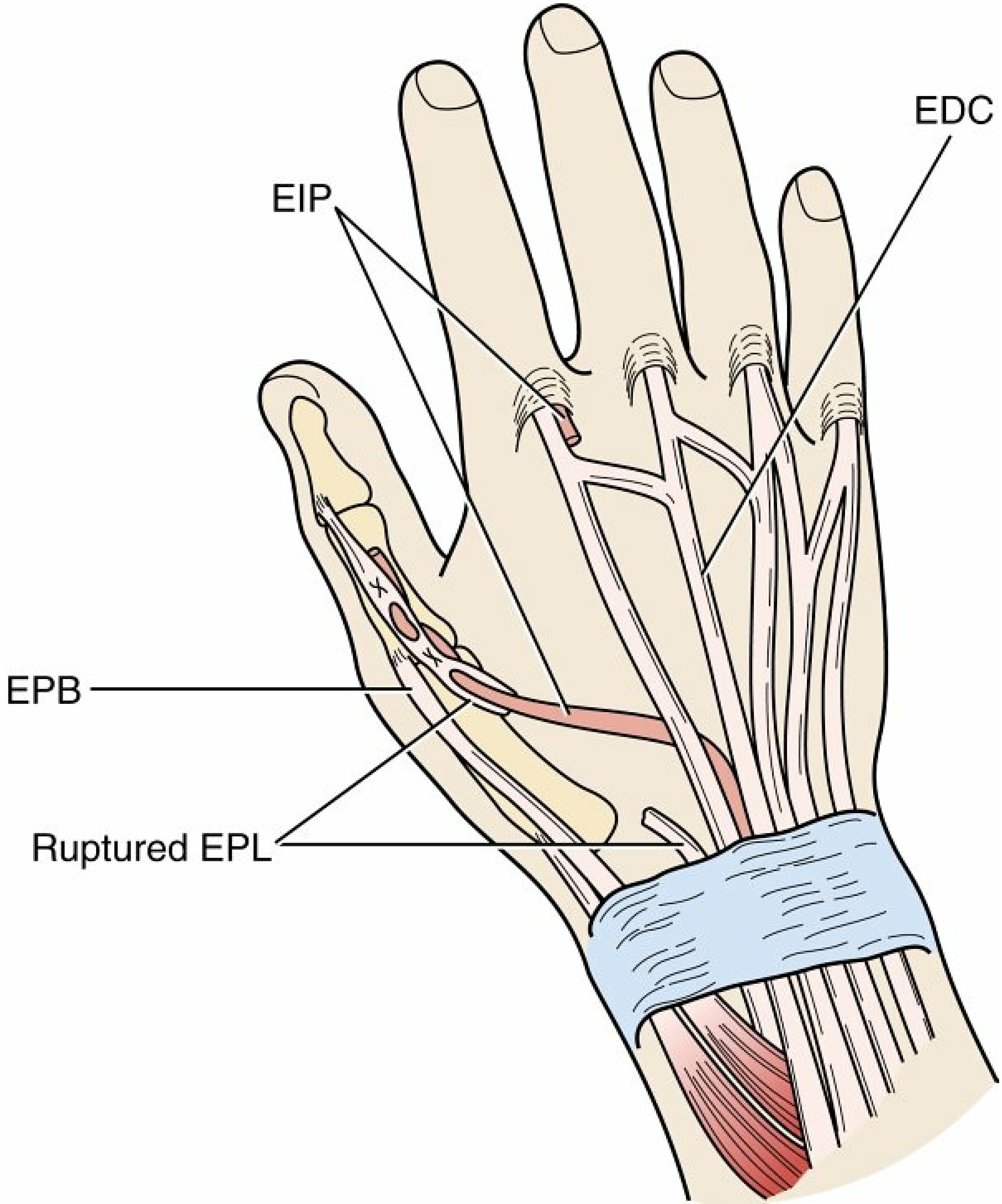


FIG. 7.60 Transfer of the EIP for an EPL rupture.
From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 365.

FIG. 7.61 Posteroanterior radiograph of the wrist following total wrist arthrodesis with a dorsal plate.

From Wehbe MA, editor: Arthroplasty around the wrist: CMC, radiocarpal, DRUJ, *Hand clinics*, Philadelphia, 2013, Elsevier, p 88.

FIG. 7.62 (A) Scaphoid nonunion advanced collapse in a 57-year-old man. (B) After treatment with total wrist arthroplasty.
From Nydick JA et al: Clinical outcomes of total wrist arthroplasty, *J Hand Surg Am* 37:1580–1584, 2012.

- **Z deformity**
  - Ulnar translocation and radial deviation of wrist, ulnar deviation of digits
- **MCP joint involvement**
  - Characteristic deformity: Ulnar deviation and volar subluxation
    - Initial presentation: Often, extension lag
  - Etiology: Synovitis and pannus formation stretch the weaker radial sagittal bands, and extensor tendons subluxate ulnarly.
    - Concurrent loss of volar plate and collateral ligament integrity
    - Contracture of the intrinsic muscle tendons leads to ulnar deviation of fingers.
  - Simultaneous wrist involvement leads to Z-

deformity.

- Ulnar translocation and supination of carpus
- Radial deviation of metacarpals
- Ulnar deviation of digits

- Early-stage treatment: Synovectomy and recentralization of the extensor tendons
- Silicone MCP arthroplasty: Definitive treatment to relieve pain, improve cosmesis
    - Ultimate function less predictable
    - Complications: Implant failure and recurrent deformity
    - Concomitant correction of wrist deformity is paramount to the success of MCP arthroplasty, because straightening the wrist decreases the ulnar deviation deformity at the MCP joints.

- PIP joint involvement
    - Synovitis leads to attenuation of stabilizing structures and characteristic deformities.
        - Boutonnière: Attenuation of central slip/triangular ligament leads to volar subluxation of lateral bands and consequent PIP hyperflexion and DIP hyperextension.
        - Swan neck: Attenuation of volar plate and transverse ligaments leads to dorsal subluxation of lateral bands and consequent PIP hyperextension and DIP hyperflexion.
- Rheumatoid thumb
    - Classified into six types by Nalebuff: Most common is type I boutonnière thumb
    - Treatment dictated by deformity: Synovectomy, soft tissue reconstruction, arthrodesis, arthroplasty

▪ **Juvenile rheumatoid arthritis**

- Age of onset before 16 years
- Other rheumatic diseases must be excluded
- **A classic difference between juvenile RA (JRA) and adult form is radial deviation of the MCP joints and ulnar deviation of the wrist in JRA.**

- □ Nonoperative treatment favored to avoid damage to growing physes.
- □ Three disease types: Systemic (20%), polyarticular (40%), and pauciarticular (40%)
    - • Systemic form (Still disease)
        - • May be associated with transient arthritis in the setting of fever, anemia, hepatosplenomegaly, uveitis, and lymphadenitis
        - • Rheumatoid factor is absent
        - • Chronic disabling arthritis develops in only 25% of patients.
    - • Polyarticular form
        - • Symmetric form affecting at least five joints
        - • Small percentage of patients do have rheumatoid factor
        - • More closely resembles adult form
        - • Chronic progression likely
    - • Pauciarticular form
        - • Asymmetric form affecting less than five joints
        - • Produces more involvement of large joints and lower extremities involvement
        - • Female patients typically have earlier disease onset and test positive for antinuclear antibody (ANA)
        - • Presence of HLA-B27 and sacroiliitis are more common in males

- ▪ **Psoriatic arthritis**
    - □ Seronegative spondyloarthropathy affecting approximately 20% of patients with psoriasis
    - □ Skin involvement precedes joint manifestations by several years.
    - □ Classic clinical findings: nail pitting and sausage digits
    - □ PIP flexion and MCP extension contractures
    - □ **Radiographs: DIP joint pencil-in-cup deformity**
    - □ Operative treatment: DIP arthrodesis
- ▪ **SLE**
    - □ Most often affects young women (age 15–25 years)
    - □ Rheumatoid-like presentation of inflammatory small joint arthritis in hand and wrist
    - □ Swan neck deformity more common than boutonnière deformity in SLE
    - □ MCP joints have characteristic ulnar deviation and volar subluxation.
    - □ Other potential findings in SLE include marked joint laxity, Raynaud phenomenon, facial butterfly rash, ANA positivity, and anti-DNA antibodies

- Radiographic findings largely normal
- DMARDs are mainstay of treatment
- Surgical treatment (with failure of nonoperative treatment): Arthrodesis is more reliable than arthroplasty.

- **Scleroderma (systemic sclerosis)**
  - Hand manifestations: Raynaud phenomenon, PIP flexion contractures, skin ulceration, fingertip pulp atrophy, calcific deposits within digits (calcinosis cutis)
  - Radiographs: Absorption of distal phalangeal tufts
  - Raynaud phenomenon with digital ulceration: Periadventitial digital sympathectomy
    - Results of sympathectomy better for scleroderma than for atherosclerotic disease.
  - Arthrodesis: Indicated for fixed PIP flexion contractures
  - Symptomatic calcific deposits may be excised.
  - Fingertip ulcerations/necrosis: Débridement and possible amputation
- **Gout**
  - Caused by precipitation of monosodium urate crystals, which deposit in joints and/or tendon sheaths or may even coalesce as tophi in the soft tissues (Fig. 7.63)
  - Most cases (90%) occur in men.
  - Elevated uric acid values do not necessarily correlate with the prevalence of gout attacks.
  - Gout may be associated with any state of high metabolic turnover (e.g., tumor lysis syndrome).
  - Radiographs: Periarticular erosions and soft tissue tophi in chronic cases
  - Aspiration yields **negatively birefringent monosodium urate crystals.**
  - Acute attacks: High-dose NSAIDs, oral steroids, or colchicine
  - Long-term prophylaxis: Allopurinol
- **Calcium pyrophosphate deposition disease (pseudogout)**
  - Causes an acute monoarticular arthritis that mimics septic arthritis
  - Wrist is second most commonly affected joint (knee).

FIG. 7.63 Tophaceous gout.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 81.

- Aspiration yields **positively birefringent calcium pyrophosphate dihydrate crystals.**
- Radiographs: Chondrocalcinosis of the TFCC and/or other carpal ligaments
- Acute attacks: High-dose NSAIDs
- Chronic arthritis (scaphotrapeziotrapezoid, SLAC patterns): treat according to stage of disease

Idiopathic Osteonecrosis of the Carpus

- **Kienböck disease (idiopathic osteonecrosis of the lunate)**
  - Overview

- Progressive, often debilitating disease
- Characterized by fragmentation and collapse of lunate
- Demographics: Men aged 20–40 years
  - Rare in children but they have a better prognosis
  - Rarely bilateral
- Multifactorial etiology postulated
  - Lunate geometry
  - Anatomic variability of lunate blood supply
    - Single arterial supply; limited intraosseous branching most susceptible
  - Increased intraosseous pressure from venous stasis
  - Negative ulnar variance
    - Increased shear stress on marginally perfused lunate
  - Decreased radial inclination

□ Diagnosis

- Dorsal wrist pain, mild swelling, limited motion, weakness
- Ulnar variance determined with wrist posteroanterior in neutral rotation
- Radiographic findings initially normal or show a linear fracture
  - Advanced stages: Lunate sclerosis followed by lunate collapse

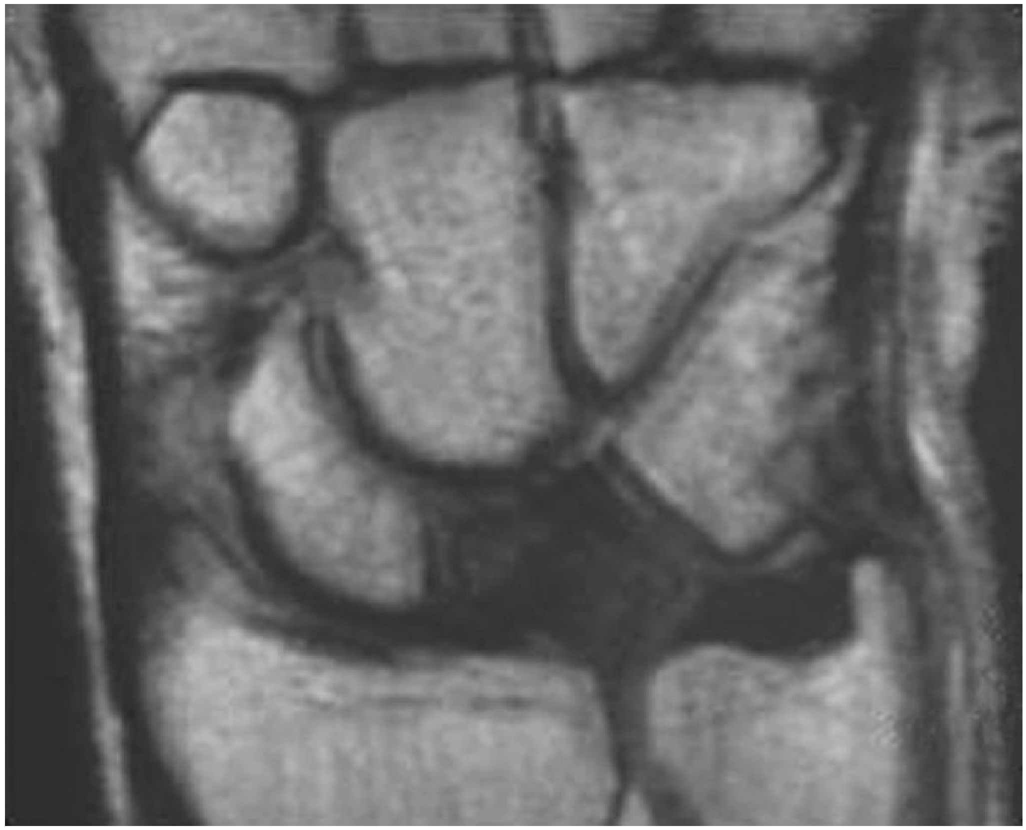


FIG. 7.64 T1-weighted MR image of the carpus that shows decreased signal within the lunate, indicative of Kienböck disease.
From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 179.

- Presentation: Unexplained persistent, non–activity-related dorsal wrist pain in young adult with negative ulnar variance should prompt MRI evaluation.
- MRI (early diagnosis): Diffuse low signal intensity throughout lunate on T1- and T2-weighted images (Fig. 7.64)
    - Increased signal intensity on T2-weighted images suggests revascularization.
- Lichtman classification (Table 7.12)
    - Modification using radioscaphoid angle more than 60 degrees to distinguish between stage IIIA and stage IIIB increases interobserver reliability

□ Treatment

- Based on Lichtman stage and ulnar variance
- In general, goal in stages I–IIIA is to save the lunate; surgery in stages IIIB–IV, consists of salvage procedures because lunate pathology prevents its revascularization.
- Stage I: Trial of cast immobilization, but long-term success is limited.
- Stage II or higher: Surgical treatment according to MRI findings
- First-line surgical treatment: Joint-leveling procedure
    - Ulnar-negative variance: Radial shortening

        - osteotomy is preferred over ulnar lengthening with bone grafting (goal is neutral or 1-mm positive).
        - Ulnar-positive variance: Capitate shortening with capitohamate fusion.
- Early stages: Core decompression of the radius and ulna is an option.
    - Thought to incite local vascular healing response
- Vascularized bone grafting (stages I–IIIA)
    - Preferred pedicle is the fourth and fifth extracompartmental artery (4–5 ECA)
        - May be combined with scaphocapitate pinning and/or external fixation to “unload” the lunate temporarily
- Other options: Pedicled vascularized transfers from pisiform and index metacarpal as well as free vascularized bone transfers
- There is little evidence to support one procedure over another for the treatment of stages I–IIIA disease.
- Treatment of stage IIIB disease must address the associated carpal instability.
    - Options: Scaphoid-trapezium-trapezoid fusion, scaphocapitate fusion, PRC

Table 7.12

Stages of Kienböck Disease

Lichtman Stage	Description
I	Normal radiographic appearance or linear fracture
	Increased uptake on bone scan
	MRI shows low signal intensity in lunate on T1-weighted images
II	Lunate sclerosis
	One or more obvious fracture lines
	Possible early lunate collapse at radial border
IIIA	Lunate collapse with normal carpal alignment
IIIB	Lunate collapse with fixed scaphoid rotation (ring sign)
	Proximal capitate migration
IV	Severe lunate collapse
	Degenerative changes at midcarpal and/or radiocarpal joint

Adapted from Allan CH et al: Kienböck's disease: diagnosis and treatment, *J Am Acad Orthop Surg* 9:128–136, 2001.

    - Stage IV disease (radiocarpal and/or midcarpal arthrosis): Either PRC or wrist fusion

- **Preiser disease (idiopathic osteonecrosis of the scaphoid)**
  - Rare diagnosis based on radiographic evidence of sclerosis and fragmentation of the scaphoid without evidence of prior fracture
  - Predisposing vascular patterns have not been determined.
  - Demographics: Average age at onset is 45 years
  - Presentation: Insidious dorsoradial wrist pain
  - Classification: Four-stage radiographic classification similar to that for Kienböck disease
    - May also more simply be classified by MRI into complete and partial involvement
  - Initial treatment: Cast immobilization
  - Surgical treatment: Core decompression, curettage, allograft replacement, vascularized bone grafting with 1,2 ICSRA, PRC, scaphoid excision and four-corner fusion, or total wrist fusion

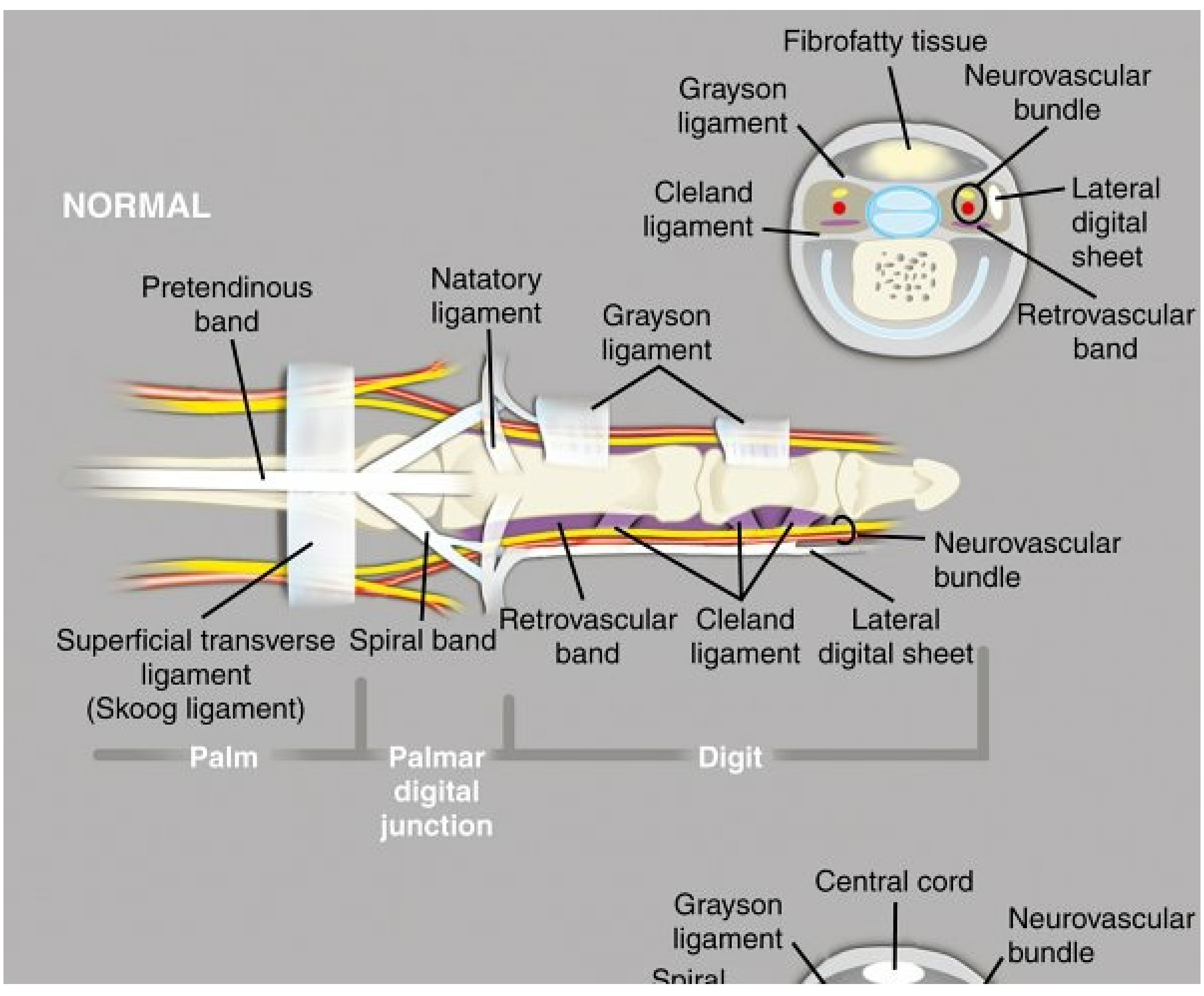
Dupuytren Disease

- **Introduction**

- A benign fibroproliferative disorder of unclear etiology
- Progression: Begins as a nodule in the palmar fascia, progresses insidiously to form diseased cords and eventually to MCP and/or PIP joint flexion contractures
- Demographics: White men of northern European descent
- Inheritance: Although an autosomal dominant inheritance pattern with variable penetrance is suspected, the offending gene has not been isolated, and sporadic cases are still more common.
- Risk factors: Tobacco and alcohol use, diabetes, epilepsy, chronic pulmonary disease, tuberculosis, and HIV/AIDS
- No association with occupation has been determined.

▪ **Pathophysiology**

- □ Cytokine-mediated (transforming growth factor-β [TGF-β]) transformation of normal fibroblasts into **myofibroblasts** has been implicated.
- □ Myofibroblast contractile properties are abnormal and exaggerated.
- □ **Increase in ratio of type III to type I collagen**
- □ Increase in free radical formation
- □ Three stages of disease are recognized.
    - Proliferative, involutional, and residual



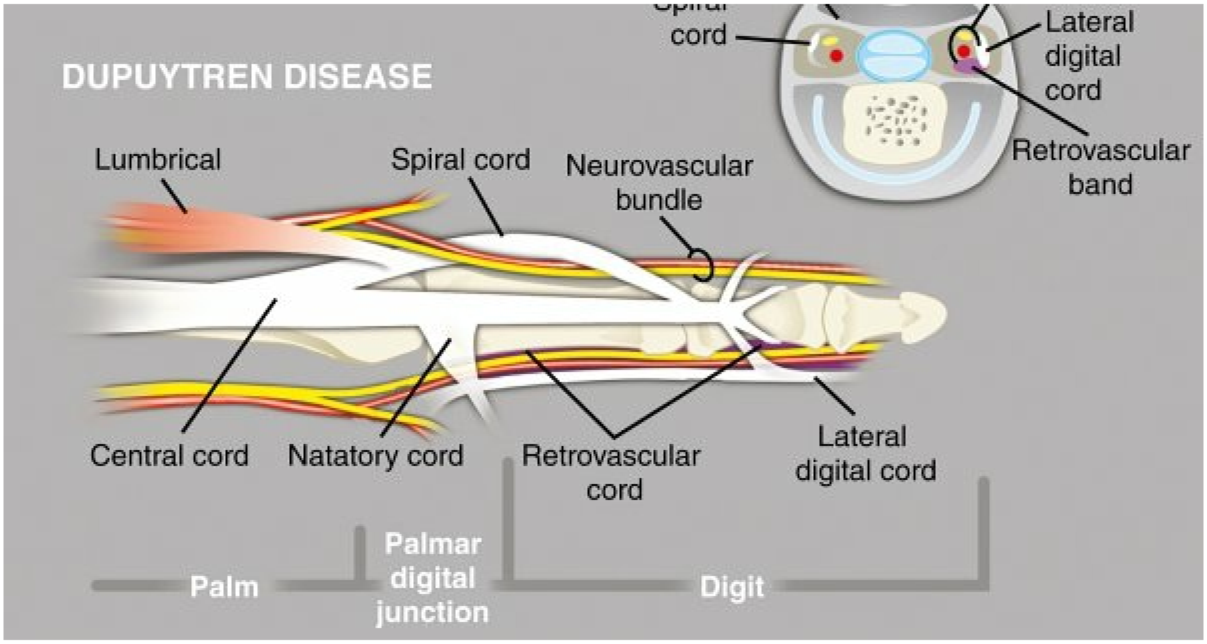
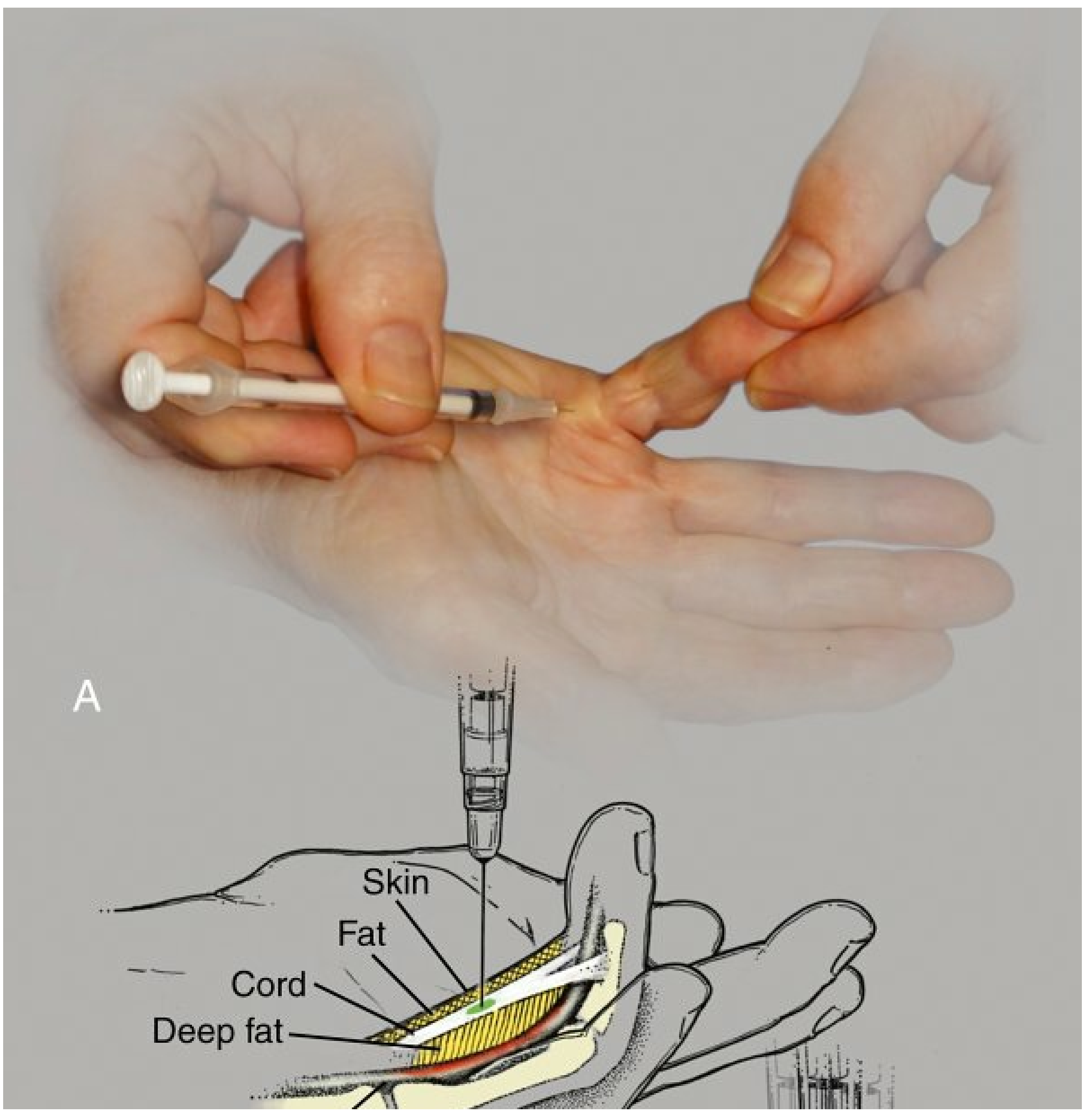


FIG. 7.65 Normal fascial anatomy and the pathoanatomy of fascial cords in Dupuytren disease.
Courtesy of School of Medicine, SUNY Stony Brook, NY.

- **Structural anomalies**
  - Normal fascial structures that become involved (Fig. 7.65)
    - Pretendinous band
    - Natatory band
    - Spiral band
    - Retrovascular band
    - Grayson ligament
    - Lateral digital sheet
  - Cleland ligaments are not involved (Cleland ligaments dorsal to the volar Grayson ligaments).
  - **Natatory ligament involved in web space contracture.**
  - Normal bands become diseased cords (see Fig. 7.65).
    - Spiral cord
      - Contributions from the pretendinous band, spiral band, lateral digital sheet, and Grayson ligament
      - Lead to PIP contracture
      - Put neurovascular bundle at risk during surgery by displacing it more centrally and superficially
    - Central cord
    - Lateral cord
    - Natatory cord
    - Retrovascular cord
    - ADM cord
    - Intercommissural cord of first web space
- **Diagnosis**
  - May manifest early as tender palmar nodule or later as flexion contractures that impair simple activities (shaking hands, placing hand

in a pocket, etc.)

- Distribution of digit involvement, in decreasing order of frequency, are the ring, small, long, thumb, and index digits



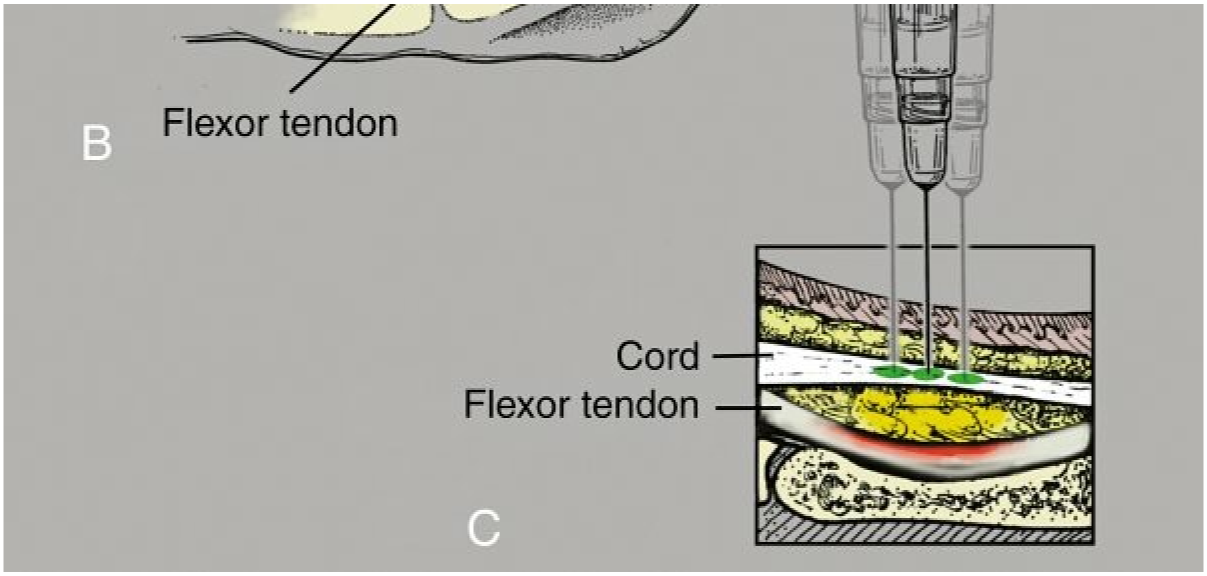


FIG. 7.66 Enzymatic fasciectomy for Dupuytren disease. (A) Collagenase injected into a central cord. (B) Enzyme diffuses in cord. (C) One third of collagenase dose disseminated in each of three different locations within a cord.
Courtesy of School of Medicine, SUNY Stony Brook, NY.

- Dupuytren diathesis: Early disease onset and rapid progression of joint contractures, often bilateral and including more radial digits
  - Higher recurrence rates after surgical intervention
- Additional extrapalmar locations: Dorsum of the PIP joint (Garrod knuckle pads or Dupuytren nodules), penis (Peyronie disease), and plantar surface of the foot (Ledderhose disease)
  - **Dupuytren nodules or Garrod knuckle pads: Well-circumscribed fleshy nodules on the dorsum of fingers; require no intervention**

- **Treatment**
  - Nonoperative
    - **Collagenase injection (derived from *Clostridium histolyticum*): Alternative to surgery with early promising outcomes; later studies have shown a high recurrence rate (Fig. 7.66)**
      - Technique: Cord is injected directly with enzyme, and patient returns the following day for manipulation of the contracture with use of digital block anesthesia.
      - Outcomes: Pooled results of open-label studies demonstrate average MCP correction of up to 85% and PIP correction of up to 60%.

Box 7.3 Tumors of the Hand and Upper Extremity

Most common benign soft tissue tumor —GANGLION

Most common malignant soft tissue

tumor—EPITHELIOID or SYNOVIAL SARCOMA
Most common skin malignancy—SQUAMOUS CELL CARCINOMA
Most common benign bone tumor—ENCHONDROMA
Most common malignant bone tumor—CHONDROSARCOMA
Most common primary site for acral metastases—LUNG

- Adverse outcomes: Temporary pain, swelling, and bruising
- Complications:
  - Skin tears (up to 12%)
  - Flexor tendon rupture (rare), especially in the small finger; therefore collagenase is indicated mainly for cords in the palm rather than within the finger
- **Needle aponeurotomy (NA)**
  - **Technique: 22- or 25-gauge needle used to release cords with use of local analgesia, followed by manipulation and night splint**
  - Outcomes: More successful for mild contractures with MCP than PIP joints.

□ Surgery: Open fasciectomy

- Indications: Functional limitations; inability to place hand flat on tabletop (Hueston test), such as if the patient has MCP flexion contracture more than 30 degrees or any PIP flexion contracture with functional impairment
- Painful nodules are not an indication for surgery.
- Open limited fasciectomy: Usually preferred procedure
  - Iatrogenic digital nerve injury in up to 7% of cases in some series
  - After large contracture release, tourniquet should be deflated prior to closure for assessment of digital perfusion.
  - Total palmar fasciectomy no longer favored because of high complication rate.
- Open-palm McCash technique with skin healing by second intention may still be used to reduce hematoma formation, decrease edema, and allow early motion.

- Skin deficits after contracture release may be addressed with Z-plasty, V-Y advancement, FTSGs, or healing by second intention.
- Most common complication: Recurrence, with long-term rates as high as 50% (higher in Dupuytren diathesis)
  - Judicious postoperative therapy, with active ROM and static nighttime splinting to maintain extension correction, is critical for improved outcomes and the prevention or delay of recurrence.
  - Early postoperative flare reactions are more common in women and may be treated with short courses of oral steroids or NSAIDs.
- Other complications: Hematoma, infection, digital neurovascular injury, CRPS, amputation

Hand Tumors

- Box 7.3 lists the most common tumors (and metastases) of the hand and upper extremity.
- **Benign soft tissue tumors**
  - Ganglion
    - Most common soft tissue mass of the hand and wrist: Contains either joint or tendon sheath fluid

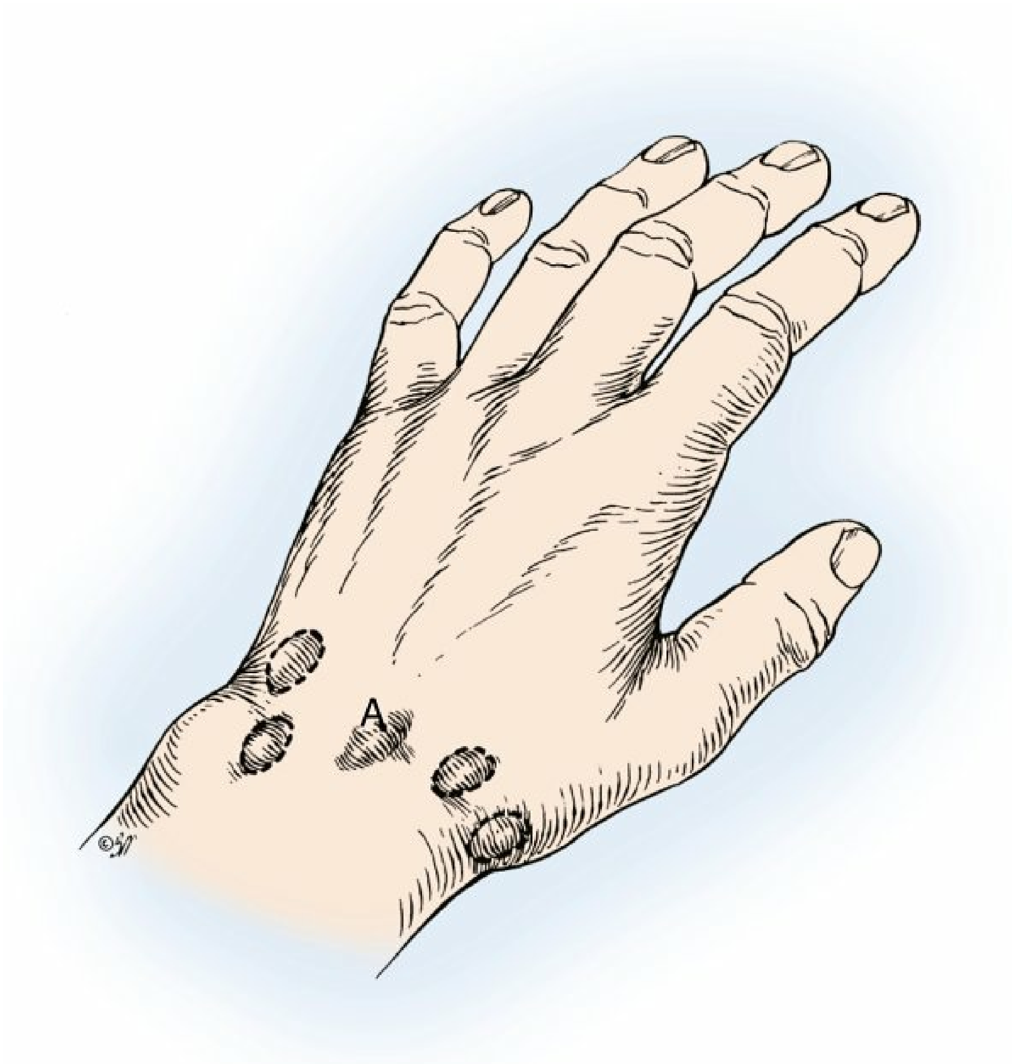


FIG. 7.67 A few of the many locations of dorsal wrist ganglions. The most common site *(A)* is directly over the scapholunate ligament.

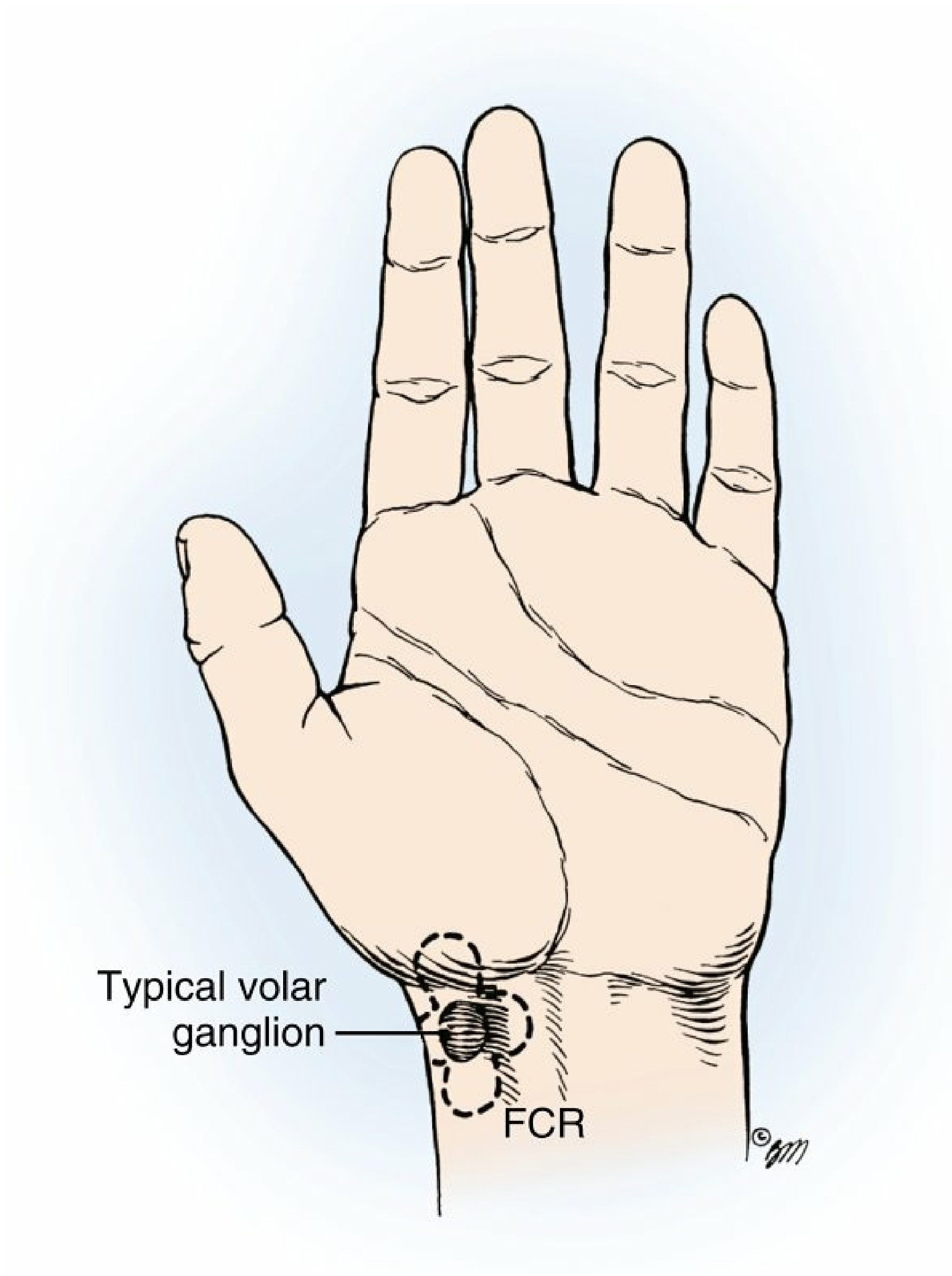


FIG. 7.68 Typical location of a volar wrist ganglion. Possible subcutaneous extensions *(dashed lines)* are often palpable.

- Encapsulating tissue does not have true epithelial lining.

- These masses often fluctuate in size over time.
- A traumatic etiology is suspected in many cases (e.g., scapholunate ligament injury).
- Ganglions are often firm and well circumscribed and may transilluminate on physical examination.
- Site of 70% of cases is the dorsal wrist, usually originating from scapholunate articulation (Fig. 7.67).
- Small (occult) dorsal ganglions may be more symptomatic than larger ones.
- Majority of volar wrist ganglions originate from radioscaphoid or scaphotrapezial joints (Fig. 7.68).

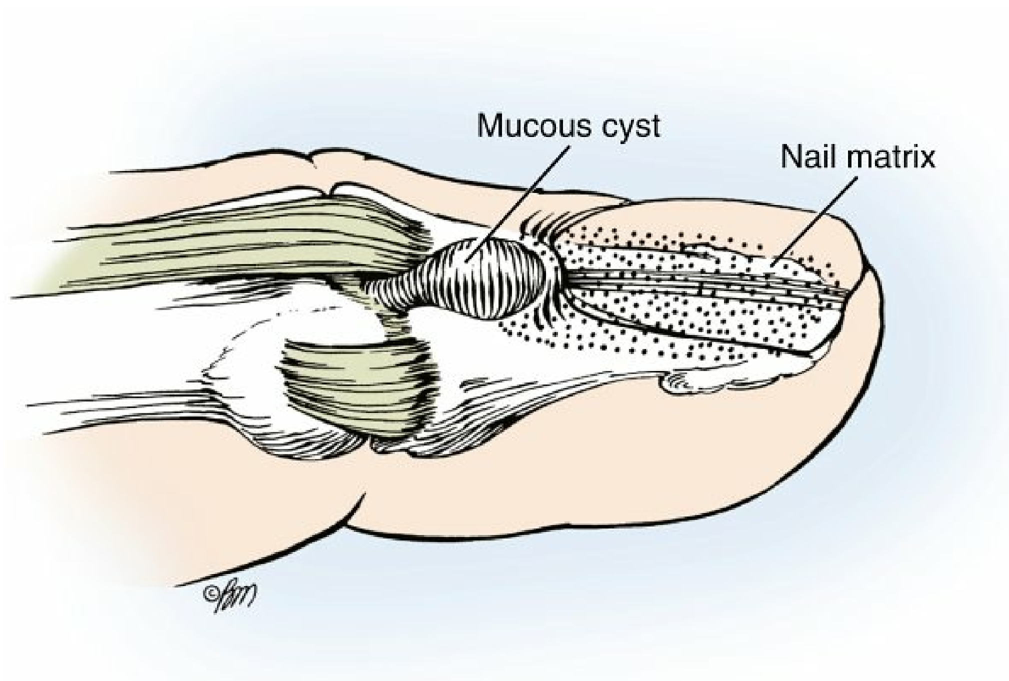


FIG. 7.69 A mucous cyst originating from the DIP joint may put pressure on the nail matrix, resulting in longitudinal grooving in the nail plate.

    - They emerge in close proximity to radial artery and its branches.
    - Higher recurrence rate than dorsal wrist ganglions
- Mucous cysts occur at dorsum of DIP joint in patients with OA (Fig. 7.69).
    - Surgery must address underlying osteophytes.
- Retinacular cysts form from herniated tendon sheath fluid.
- Overall recurrence rate after aspiration of ganglions is approximately 50%.
- **Ganglions can be diagnosed on MRI or ultrasound as homogenous anechoic masses.**

- Treatment: Open excision is usually preferred, although many dorsal ganglions can be effectively removed arthroscopically.
    - The cyst stalk and a portion of the capsule should be removed.

□ Giant cell tumor of tendon sheath
- Second most common soft tissue mass of the hand
- Other names include *xanthoma* and *localized nodular synovitis.*
- Manifests as slow-growing, nontender, nodular, or multilobulated mass
- Contains multinucleated giant cells, round stromal cells, and lipid-laden foam cells with hemosiderin deposits (histologic findings similar to those in pigmented villonodular synovitis)
- Treatment: Marginal excision
- Multilobulated lesions with extension into tendon or joint capsule associated with higher recurrence rate (≈45% in some series)

□ Lipoma
- Common
- Tumor of adipose cell origin
- Though usually painless, lipomas may reach substantial size over time.
- Lipoma in the palm may compress the carpal tunnel or the Guyon canal, leading to neurologic deficits.
    - MRI may be helpful for preoperative planning in these cases.
        - Lesions have same bright signal characteristics as subcutaneous fat on T1-weighted images.
- Treatment: Either observation or marginal excision
- Low recurrence rate

□ Epidermal inclusion cyst
- Common painless, slow-growing mass arising after penetrating injury that drives keratinizing epithelium into subcutaneous tissue
- Curative treatment: Marginal excision

□ Neurilemoma (schwannoma)
- Most common peripheral nerve tumor of the upper extremity
- Typically painless mass with which Tinel sign may be present
- Cell of origin is the myelin-forming Schwann cell
    - The tumor is composed of Antoni A (cellular) and Antoni B (matrix) regions.

- Treatment: Marginal excision
    - Because the tumor is eccentric and encapsulated, it can be shelled out of the nerve without disruption of axons.
- Neurologic injury in less than 5% of cases
- Low recurrence rate

□ Neurofibroma
- Slow-growing, painless mass arising from nerve fascicle
- May be solitary in hand and wrist (no history of neurofibromatosis)
- Treatment: Portion of nerve usually sacrificed during excision ± grafting

□ **Glomus tumor**
- Smooth muscle tumor of perivascular temperature-regulating bodies
- Usually occurs in subungual region and may cause nail ridging and erosions of the distal phalanx
- Also reported in palm
- Characterized by exquisite pain and cold intolerance
- MRI with gadolinium is a potentially helpful adjunctive diagnostic study.
- **Treatment: Marginal excision**
- Low recurrence rate

□ Hemangioma
- Vascular proliferation divided into capillary (superficial) and cavernous (deep) types
- Many infantile hemangiomas become involuted by patient age 7, and those that arise during childhood are observed.
- Kasabach-Merritt syndrome is a rare complication resulting from entrapped platelets and a potentially fatal coagulopathy.
- In adults, MRI with gadolinium may help distinguish this benign vascular tumor from arteriovenous malformation and angiosarcoma.
- Treatment: Marginal excision of small and accessible lesions
    - Embolization may be more feasible alternative for larger lesions.

□ Pyogenic granuloma (lobular capillary hemangioma)
- Rapidly growing, pedunculated cutaneous lesion with friable tissue that bleeds easily (Fig. 7.70)
- Histologic appearance that of a vascular tumor with lobules of endothelial cells and luminal structures in edematous stroma

- Treatment: Many methods described, all with high recurrence rates
  - Some evidence to support simple silver nitrate cauterization

- **Malignant soft tissue tumors**
  - Squamous cell carcinoma

FIG. 7.70 Pyogenic granuloma.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 81.

- Most common malignancy of the hand
    - Usually seen in elderly men with premalignant conditions such as actinokeratosis and chronic osteomyelitis
        - Such lesions on dorsum of hand are high risk.
    - Primary risk factor: Excessive exposure to ultraviolet radiation
- Also most common subungual malignancy
- Higher metastatic potential than basal cell carcinoma
- Consultation with dermatologist recommended
- Treatment: Mohs micrographic surgery has highest cure rate (highest for all nonmelanotic skin cancers).
    - Excision of aggressive lesions that are poorly differentiated or greater than 2.5 cm requires at least 6-mm margin.
    - Lymph node biopsy may be necessary.
- Adjuvant irradiation for tumor recurrence, lesions over 2 cm wide and/or 4 mm deep, perineural invasion, or lymph node metastases

□ Sarcoma

- Most common sarcomas are epithelioid and synovial.
- Other common sarcomas of the upper extremity include liposarcoma and malignant fibrous histiocytoma.
- Evaluated by MRI
- Most soft tissue sarcomas metastasize to the lungs.
- Lymph nodes are the second most common area.

□ Epithelioid sarcoma

- Firm, slow-growing mass manifesting in young to middle-aged adult
- Locations include digits, palm, and forearm.
- May eventually ulcerate and drain
- Commonly spreads to regional lymph nodes
- Composed of malignant epithelial cells and central areas of necrosis
- Treatment: Wide or radical excision accompanied by sentinel lymph node biopsy
- Adjuvant chemotherapy or radiation therapy may be considered but is controversial for this tumor.

□ Synovial sarcoma

- Firm, slow-growing mass manifesting in young to middle-aged adults
- Usually forms adjacent to the carpus
- Composed of epithelial and spindle cells with multiple histologic patterns
- Treatment: Wide or radical excision, with 5-year survival rates of approximately 80%
    - More recently, adjuvant chemotherapy and external beam radiation therapy have proved successful in reducing local recurrence rates.

□ Tumors that metastasize via the lymphatics (mnemonic: **RACES** **[**©Kakar])

- **R**habdomyosarcoma
- **A**ngiosarcoma
- **C**lear cell sarcoma
- **E**pithelioid sarcoma
- **S**ynovial sarcoma

▪ **Benign bone tumors**

□ Enchondroma

- Most common benign bone tumor of the upper extremity
- Typically occurs in second to fourth decades of life
- Most cases asymptomatic and discovered incidentally
- Arises from metaphyseal medullary canal and spreads to diaphysis (Fig. 7.71)
- Usually involves proximal phalanx or metacarpal (Fig. 7.72)
- Symmetric fusiform expansion of bone with endosteal scalloping and intramedullary calcifications
- May manifest as pathologic fracture
- Hand enchondromas are distinguished histologically by their high cellularity.
    - Presence of mitotic figures may signal low-grade chondrosarcoma.
- Treatment: Curettage
    - Benefit of void augmentation with autograft, allograft, cement, and so forth, not clearly shown in the literature.

□ Osteochondroma

- Benign tumor characterized by a bony surface outgrowth capped by cartilage that grows away from the joint
- Rarely seen in the hand except in multiple hereditary exostoses
- Distal aspect of P1 is most common location in hand.
- May be seen near DRUJ or arising from shaft of radius/ulna

- Low chance of malignant transformation
- Asymptomatic lesions observed
- Treatment: Symptomatic lesions may be associated with bursitis/periostitis and are excised, with low recurrence rate.

□ Osteoid osteoma

- May manifest as swelling without pain in the hand
- Usually found in carpus (scaphoid) or proximal phalanx
- Radiolucent nidus within sclerotic lesion
- Treatment: Nonoperative management with immobilization/NSAIDs
    - Excision of nidus is curative.
    - Radiofrequency ablation also effective

FIG. 7.71 Multiple enchondromatosis (Ollier disease).
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2005, Churchill Livingstone, p 2179.

- Unicameral bone cyst
  - Common tumor in children
  - Occasionally seen in metacarpals, phalanges, or metaphyseal portion of distal radius
  - Most resolve spontaneously.
  - Treatment: Aspiration and injection of methylprednisolone acetate.
- Giant cell tumor
  - Characterized as benign but may be locally aggressive
  - More common in young to middle-aged women
  - Manifests as pain, swelling, and/or pathologic fracture
  - Distal radius is most common location (Fig. 7.73).
  - An eccentric, lytic lesion is seen in metaphysis and epiphysis.
  - May cause cortical destruction and associated soft tissue mass
  - Histologic examination shows osteoclast-like multinucleated giant cells and stromal cells with matching nuclei.

- Treatment: Wide excision (curettage alone yields high local recurrence rate)
  - Packing the lesion with polymethylmethacrylate (PMMA) has been successful.
  - Occasionally requires reconstruction with allograft or vascularized free fibula

▪ **Malignant bone tumors**

□ Most common hand malignancy is metastatic lung carcinoma, usually involving distal phalanx.

□ Breast and kidney metastases also reported

□ Acral metastasis is poor prognostic sign, with less than 6-month survival expected at time of discovery.

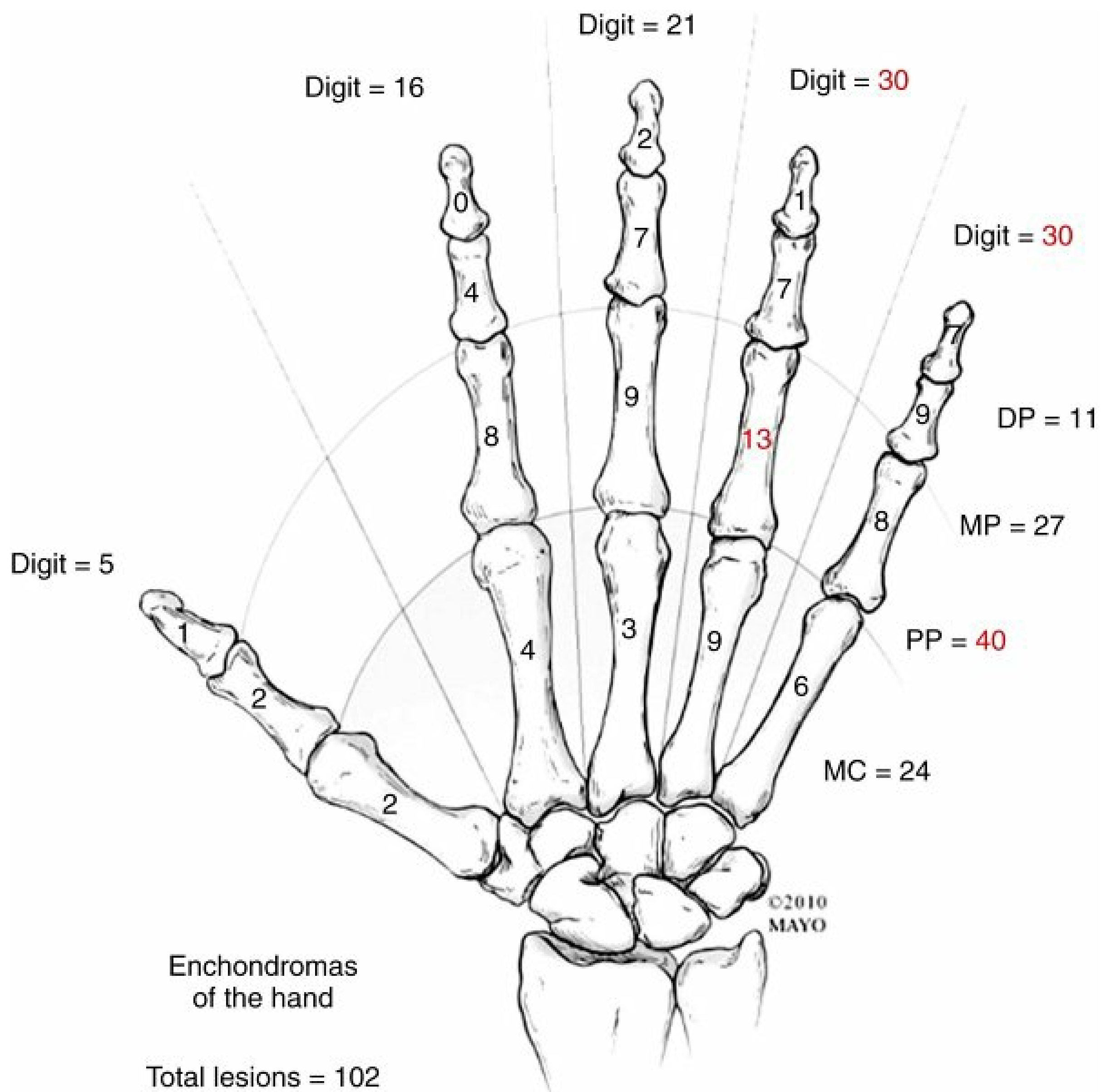


FIG. 7.72 Locations of 102 enchondromas in a series of 80 patients.
From Sassoon AA et al: Enchondromas of the hand: factors affecting recurrence, healing, motion and malignant transformation, *J Hand Surg Am* 37:1229–1234, 2012, Fig. 1.

□ The three most common primary malignant bone tumors of the hand are:

- Chondrosarcoma
- Osteosarcoma
- Ewing sarcoma

- Location usually metacarpal or phalanx
- Treatment for each tumor is the same as elsewhere in the body.

Hand Infections

- **Introduction**
  - Hand infections can involve any tissue type and a variety of pathogens (Table 7.13).

FIG. 7.73 Posteroanterior wrist radiograph showing a giant cell tumor of the distal radius, characterized by an expansile, lytic epiphyseal lesion without a sclerotic rim.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, Philadelphia, 2011, Churchill Livingstone, p 2184.

- *Staphylococcus aureus*: Overall most common pathogen
- *Streptococcus* second most common
- Gram-negative and anaerobic bacteria are seen in intravenous drug abusers (IVDAs), diabetic patients, and in patients with farmyard injuries or bite wounds.
- Community-acquired methicillin-resistant *S. aureus* (MRSA) is becoming more prevalent, especially in urban communities.
    - Risk factors: Antibiotic use in previous year, close and crowded living conditions, compromised skin integrity, sharing of items (towels, whirlpools, fitness equipment)
    - Risk groups: IVDAs, homeless people, children in daycare, prison inmates, military recruits, athletes in contact sports

- High complication rate in diabetic patients
- IV treatment with vancomycin or clindamycin; outpatient treatment with oral trimethoprim-sulfamethoxazole or clindamycin

- **Paronychia/eponychia**
  - Infections involving the nail fold are more common in the hand.
  - Typically *S. aureus*
  - Treatment: Incision and drainage, partial or total nail plate removal, oral antibiotics, soaks, and dressing changes
    - Eponychial fold (cuticle) must be preserved if possible.
  - Chronic paronychia unresponsive to oral antibiotic therapy often secondary to fungal infection *(Candida albicans)*
  - In rare cases, marsupialization (excision of the dorsal eponychium) may be required to eradicate the infection.
- **Felon**
  - Infection of the septated fingertip pulp
  - *S. aureus* is most common pathogen
  - Treatment: Incision and drainage through a central or midlateral incision
    - Septae must be broken up to adequately decompress the fingertip.
    - Midlateral digital incisions are usually placed ulnarly, except in the thumb and small digit, where they are placed radially (Fig. 7.74).
    - Incision should be left open to heal by second intention.
    - Delayed treatment: Concurrent flexor tenosynovitis, osteomyelitis, or digital tip necrosis

Table 7.13

Hand Infections

Type	Location	Pathogen	Antibiotic	Comment
Paronychia	Nail complex	*Staphylococcus aureus*	Dicloxacillin or clindamycin PO *or* nafcillin IV	Partial or comple remova release eponyc fold
Felon	Pulp space	*S. aureus*	Dicloxacillin or clindamycin PO *or* nafcillin IV	Release of septae

Human bite	MCP and PIP	*Streptococcus* spp. *S. aureus* *Eikenella corrodens*	Ampicillin/sulbactam IV Penicillin for *E. corrodens*	Treatment with cephalo usually *E. corro*
Dog and cat bites	Varied	α-Hemolytic streptococci *Pasteurella multocida* *S. aureus* Anaerobes	Ampicillin/sulbactam IV followed by amoxicillin/clavulanate PO	Failure of c treatme commo bites ha higher need fo operativ débride
Necrotizing fasciitis	Varied	Clostridia Group A β-hemolytic streptococci	Broad-spectrum triple antibiotic—penicillin, clindamycin, gentamicin	High mort amputa frequer
Fungal	Cutaneous	*Candida albicans*	Topical antifungal	Common i diabetic patients chronic parony
	Nail	*Trichophyton rubrum*	Ketoconazole or itraconazole PO	Pulse dosin week p month
	Subcutaneous	*Sporothrix schenckii* *Mycoplasma* spp.	Based on results of culture	

- **Human bite**
  - Potentially serious infection treated promptly with incision and drainage (I&D), especially if joint or tendon sheath is violated
  - Most commonly involves the third or fourth MCP joint (fight bite)
  - Most frequently isolated organisms: group A streptococci, *S. aureus, Eikenella corrodens,* and *Bacteroides* spp.
  - Antibiotics for empiric therapy: IV ampicillin/sulbactam and oral amoxicillin/clavulanate
- **Dog and cat bites**
  - More than 2 million cases per year in the United States
  - Vast majority are dog bites, with lower rate of serious infection.

- More likely to avulse or crush soft tissue but often amenable to local wound care

□ Minority are cat bites, but they have a higher rate of serious infection.
- Deeper penetrance, smaller wounds, and longer time to initiation of treatment

□ Nonoperative treatment: If patient presents immediately after bite

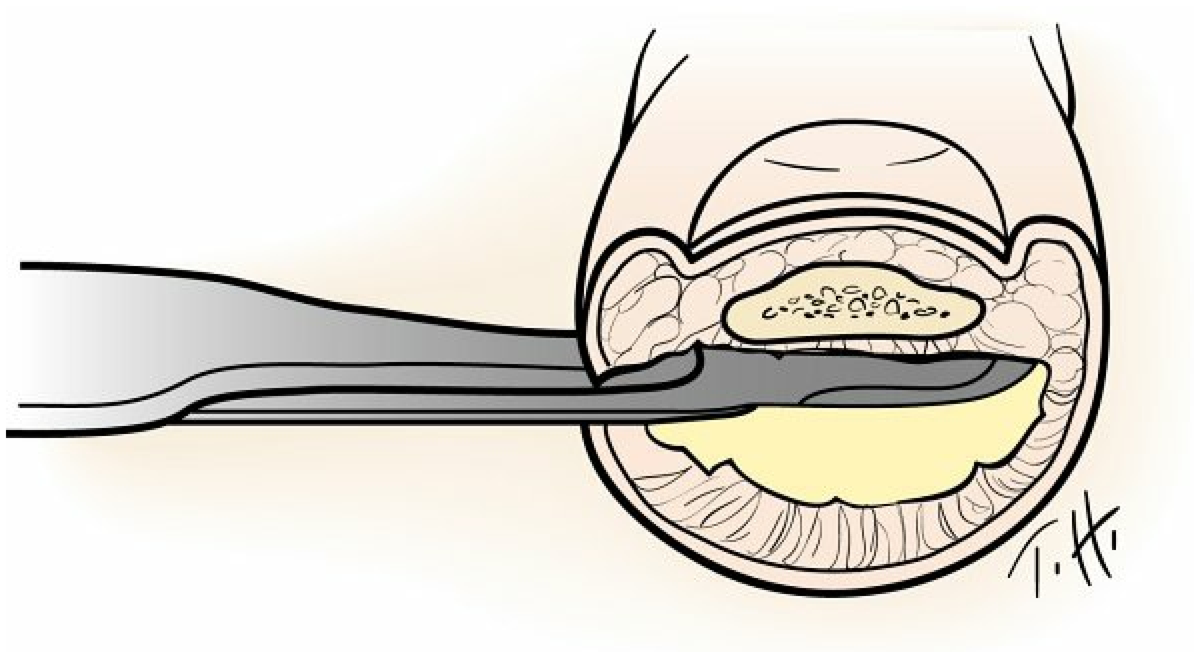


FIG. 7.74 Incision and drainage of felon through midlateral incision.

- Splinting, elevation, soaks, and antibiotics, followed by aggressive therapy once infection controlled

□ Delayed treatment: Abscess formation and need for operative I&D
- Further delay could lead to septic tenosynovitis, septic arthritis, and/or osteomyelitis

□ Antibiotics for empiric therapy: Ampicillin/sulbactam and amoxicillin/clavulanate
- In patient with penicillin allergy: Ciprofloxacin, doxycycline, or tetracycline
- Covers *Pasteurella multocida* (part of animal oral flora), *S. aureus*, and *Streptococcus* spp.

▪ **Pyogenic flexor tenosynovitis (FTS)**

□ Infection of flexor tendon sheath

□ May occur in delayed fashion after penetrating trauma

□ *S. aureus* is most common pathogen

□ **Kanavel signs (four)**
- **Flexed resting posture of digit**
- **Fusiform swelling of digit**
- **Tenderness of flexor tendon sheath**

- **Pain with passive digit extension**

□ Early treatment: Hospital admission, splinting, IV antibiotics, and close observation

- If signs improve within first 24 hours, surgery may be avoided.

□ Late treatment: Incision and drainage of flexor tendon sheath

- Technique (Fig. 7.75)
  - Open drainage: Long midaxial or Bruner incision
  - Closed-catheter irrigation (CCI): Two small incisions placed distally (open A5 pulley) and proximally (open A1 pulley) with use of a pediatric feeding tube
  - Studies show similar outcomes for open and catheter irrigation techniques.

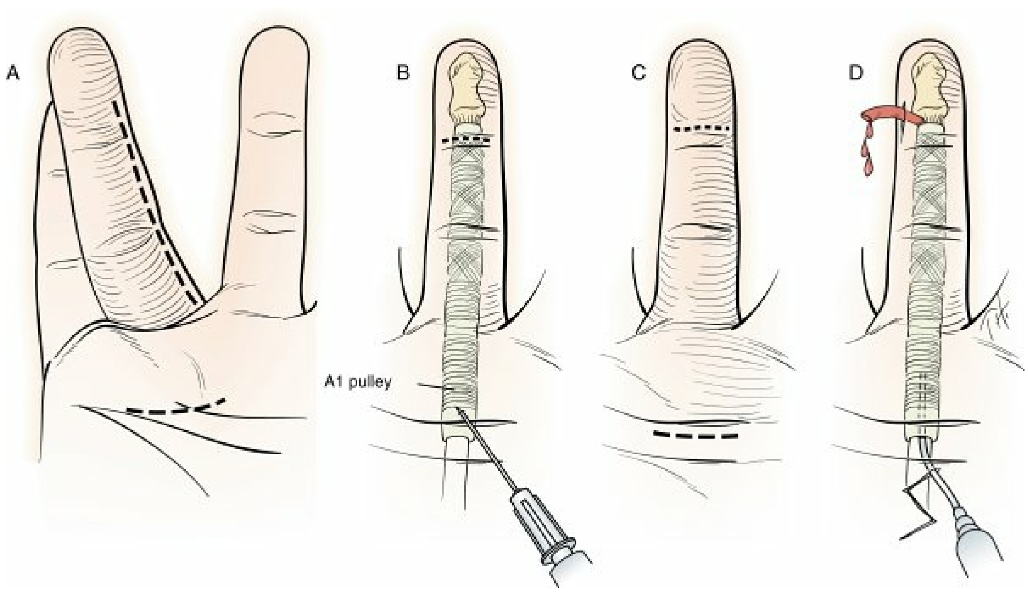


FIG. 7.75 Incisions for drainage of septic digital flexor tenosynovitis, including midlateral (A), and variations of closed catheter irrigation (B–D).

From Neviaser R: Closed tendon sheath irrigation for pyogenic flexor tenosynovitis, *J Hand Surg* 3:462–466, 1978.

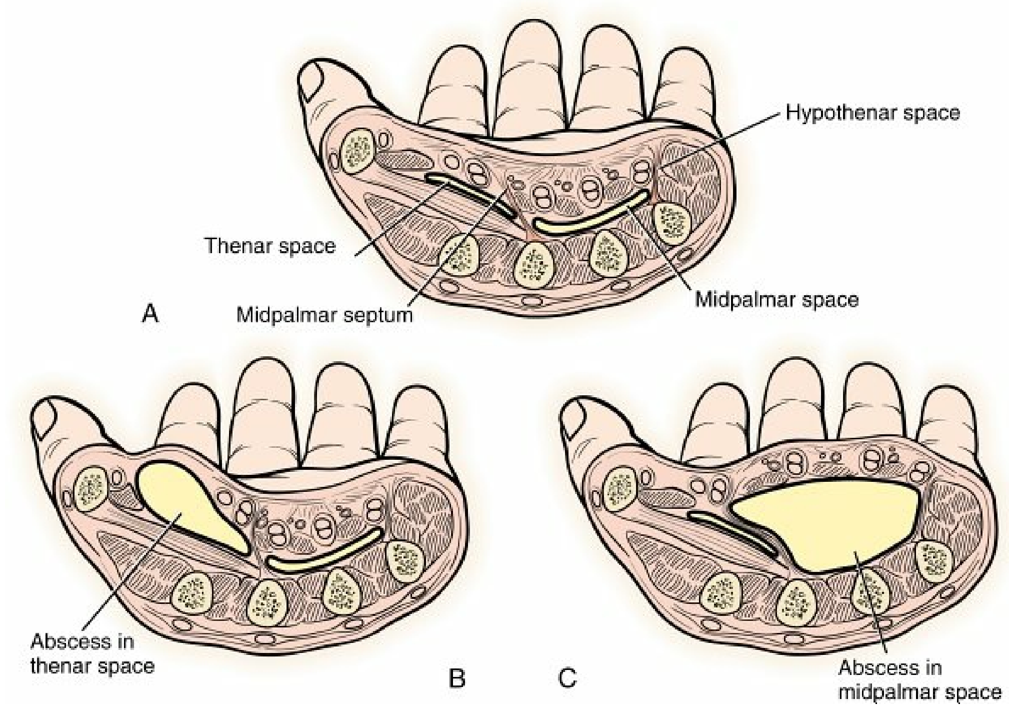


FIG. 7.76 (A) Potential spaces of the deep palm. (B) Thenar space abscess. (C) Midpalmar space abscess.
From Green DP et al, editors: *Green's operative hand surgery,* ed 6, New York, 2011, Churchill Livingstone, p 58.

- Classic horseshoe abscess: Proximal communication between the thumb and small finger flexor tendon sheaths in the Parona space (potential space between the PQ and FDP tendons)
- Aggressive postoperative hand therapy is paramount because tendon adhesions and digital stiffness are likely.

▪ **Herpetic whitlow**
- □ Caused by herpes simplex virus (HSV) type 1
- □ Dental hygienists, health care workers, and toddlers at risk
- □ Manifests as digit pain and erythema, followed by formation of small vesicles that may coalesce into bullae
- □ Associated symptoms: Fever, malaise, lymphadenitis
- □ Diagnosis: Tzanck smear and antibody titers
- □ Self-limiting; usually resolves within 7–10 days
- □ Incision and drainage are not recommended, because the rates of secondary bacterial infection are high.
- □ Treatment with acyclovir may shorten the duration of symptoms.
- □ Recurrence may be stimulated by fever, stress, and/or sun exposure.

▪ **Deep potential-space infections**
- □ A *collar button abscess* occurs in the web space between digits.
  - Treatment: Incision and drainage with volar and dorsal incisions (avoiding the skin in the web itself) and IV antibiotics
- □ Midpalmar space infections are rare

- Clinically, there is loss of midline contour of the hand
- Palmar pain elicited with flexion of the long, ring, and small fingers

□ Thenar and hypothenar space infections are rare

- Manifest as pain and swelling over respective areas, exacerbated by flexion of the thumb or small finger

□ Incision and drainage and IV antibiotics are required for all of these deep potential-space infections (Fig. 7.76)

FIG. 7.77 Characteristic appearance of necrotizing fasciitis.
From Green DP et al, editors: *Green's operative hand surgery*, ed 6, New York, 2011, Churchill Livingstone, p 78.

▪ **Necrotizing fasciitis**

□ Severe infection with devastating outcomes and potential death when treatment delayed (Fig. 7.77)

□ Group A β-hemolytic *Streptococcus* is the most common organism.

□ Groups at risk include immunocompromised patients (those with diabetes, cancer, or AIDS) as well as alcoholics and IVDAs.

□ Clinical signs: Patients tend to have an elevated temperature, to be hypotensive and tachycardic, and to be have great tenderness over the infected region of skin with, at times, crepitus.

□ **Treatment: Emergent radical débridement and broad-spectrum IV antibiotic coverage**

- Intraoperative findings may include liquefied subcutaneous fat, dishwater pus, muscle necrosis, and venous thrombosis.
- Hemodynamic monitoring is critical.
- Amputation may be necessary when the infection is life threatening.

□ Mortality rate is high and correlates with time to initiation of treatment.

- **Gas gangrene**
  - Caused by *Clostridium perfringens* and other *Clostridium* spp. (gram-positive rods)
  - Condition occurs in devitalized contaminated wounds and leads to myonecrosis
  - Treatment: Extensive surgical débridement is necessary to prevent systemic infection.
- **Fungal infection**
  - Serious infection usually seen in immunocompromised patients
  - Divided according to location into cutaneous, subcutaneous, and deep
    - Cutaneous infection
      - Chronic paronychia usually caused by *C. albicans* and treated with topical or oral antifungal agents and nail marsupialization
      - Onychomycosis is a destructive, deforming infection of the nail plate that is usually caused by *Trichophyton rubrum* and treated with topical or oral antifungal agents.
    - Subcutaneous infection
      - Usually caused by *Sporothrix schenckii;* follows penetrating injury incurred during handling of plants or soil (the rose thorn is the classic vehicle of transmission)
      - Starts with papule at site of inoculation, with subsequent lesions developing along the lymphatic vessels
      - Treatment: Potassium iodine solution
    - Deep infection
      - Several forms of deep infection exist, including tenosynovitis, septic arthritis, and osteomyelitis.
      - Treatment: Surgical débridement and culture-specific antifungal agents
      - Endemic infections: Histoplasmosis, blastomycosis, and coccidioidomycosis
      - Opportunistic infections: Aspergillosis, candidiasis, mucormycosis, and cryptococcosis
- **Atypical nontuberculous mycobacterial infections**
  - Mycobacteria are widely distributed in the environment but are infrequent human pathogens
  - Infection is often indolent and fails to respond to usual treatments.
  - Musculoskeletal manifestations (papules, ulcers, nodules) involve hand in majority of cases.
  - May progress to tenosynovitis, septic arthritis, or osteomyelitis

- Average incubation period 2 weeks; can be more than 6 months
- Average time to diagnosis and appropriate treatment often more than 1 year
- Most common organism: *Mycobacterium marinum*
  - Proliferates in freshwater and saltwater enclosures, especially in stagnant environment (e.g., aquarium)
  - Patients come into contact with infected water, fish hooks, spiny sea creatures, etc.
- Histologic findings: Granulomas are common; may or may not show acid-fast bacilli.
- Cultures require a special medium (Lowenstein-Jensen) at exact temperatures (32°C).
- Treatment: Surgical débridement and an oral antibiotic (e.g., ethambutol, trimethoprim-sulfamethoxazole, clarithromycin, azithromycin, or tetracycline)
  - Combination of agents often used
  - Rifampin added for bone involvement.
  - Oral therapy continued 3–6 months.

Injection injury

- **High-pressure injection injuries can be devastating.**
- **High rate of digital amputation**
  - **Organic solvents more toxic to tissue**
  - **Oil-based paint worse than latex or water-based**
- **Treatment: Emergent wide surgical débridement**

Congenital Hand Differences

- **Introduction**
  - Limb bud appears during fourth week of gestation.
  - Hand begins as a paddle, with digital separation occurring between 47 and 54 days.
  - Development of lower limb lags behind by 48 hours.
  - All limb structures are present by end of embryogenesis at 8 weeks.
    - Most congenital anomalies occur by 8 weeks.
  - Signaling centers that control limb development
    - Apical ectodermal ridge
      - Function: Mediates proximal-to-distal growth
      - Factor: FGF
    - Zone of polarizing activity
      - Function: Mediates radial-to-ulnar growth

            - Factor: Sonic hedgehog protein (Shh)
        - Wingless-type pathway
            - Function: Mediates dorsal-to-volar growth
            - Factor: LMX-1 protein
    - Congenital hand anomalies occur at a rate of 1 in 600 live births.
    - Three most common types
        - Polydactyly (1 in 600)
        - Syndactyly (1 in 2000)
        - Bifid thumb (radial polydactyly) (1 in 3000)
    - Classification
        - Failure of formation
        - Failure of differentiation
        - Duplication
        - Overgrowth
        - Undergrowth
        - Amnion disruption sequence
        - Generalized skeletal abnormalities
    - In general, surgical intervention for congenital hand deformities should be performed before the child establishes compensatory mechanisms and before he or she starts school.
    - Cosmesis should not be prioritized over function.
    - Early genetic counseling is a critical part of the care in the setting of other anomalies.
- **Failure of formation**
    - **Transverse absence (aka congenital amputation)**
        - Usually occurs at proximal forearm level
        - Majority are unilateral and are thought to be result of vascular insult to apical ectodermal ridge rather than part of a syndrome.
        - Amputation through proximal third of forearm most common
        - End of limb may have nubbins or dimpling.
        - Treatment: Early prosthetic fitting, before child is 2 years old
    - Longitudinal absence
        - **Radial dysplasia (radial clubhand)**
            - Characterized by deficiency of the radius and radial carpal structures (Fig. 7.78)

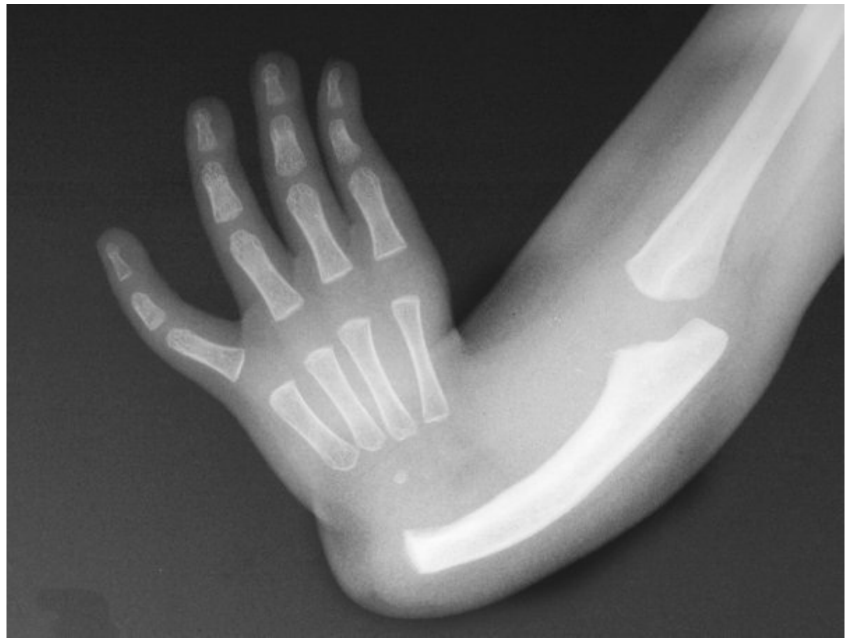


FIG. 7.78 Type IV radial deficiency and absence of thumb in an 18-month-old.
Courtesy of Shriners Hospitals for Children, Philadelphia.

- Thumb dysplasia is included in the spectrum of presentation (see the section Undergrowth).
- Both extremities are affected in more than 50% of cases.
- Associated systemic syndromes
    - Thrombocytopenia with absence of the radius (TAR)
    - VACTERL syndrome (vertebral, anal, cardiac, tracheal, esophageal, renal, and limb anomalies)
    - Holt-Oram syndrome
    - Fanconi anemia
        - Life-threatening; treated with bone marrow transplantation
- Four types recognized
    - Type I: Short radius
    - Type II: Hypoplastic radius
    - Type III: Partial absence of radius
    - Type IV: Complete absence of radius
- Early therapy to preserve passive ROM is critical.
- Surgical treatment: Centralization procedure to realign the carpus on the distal ulna may be attempted when the child is between 6 and 12 months of age.
    - Inadequate elbow ROM is a contraindication to a centralization

procedure.

- **Ulnar dysplasia (ulnar clubhand)**
    - Characterized by deficiency of the ulna or ulnar carpal structures
    - This type of dysplasia is 10-fold less common than its radial counterpart and is not associated with systemic syndromes.
    - Additional hand anomalies, however, such as a digit absence and syndactyly, are prevalent.
    - Elbow abnormalities are frequently evident.
    - Other musculoskeletal anomalies, including proximal femoral focal deficiency, fibula deficiency, phocomelia, and scoliosis, are also common.
    - Five types recognized
        - Type 0: Deficiencies of hand/carpus only
        - Type I: Small ulna with both physes present
        - Type II: Complete absence of ulna
        - Type IV: Radiohumeral synostosis
    - Clinical considerations: Position of the hand, function of the thumb, stability of the elbow, and presence of syndactyly
        - The condition of the thumb is the most important determinant of surgical intervention in ulnar dysplasia.
- **Cleft hand**
    - Also known as split hand-foot malformation
    - Often bilateral and familial, involves the feet, and has associated absence of metacarpals, differentiating it from symbrachydactyly
    - Severity of this anomaly varies widely, from a cleft between the middle and ring fingers to absence of the radial digits and syndactyly of the ulnar digits.
    - Cleft closure and thumb web construction are the top priorities.
    - Syndactyly should be released early.
    - Thumb reconstruction may require web space deepening, tendon transfer, rotational osteotomy, and/or toe-to-hand transfer.

            - Web deepening should not precede cleft closure; deepening might compromise the flaps for cleft closure.
        - Transverse bones should be removed because they widen the cleft as the child grows.

- **Failure of differentiation**
    - Radioulnar synostosis
        - Bony bridge between proximal radius and ulna
        - Bilateral in more than 60% of cases
        - Associated with chromosomal abnormalities, particularly duplication of sex chromosomes
        - Physical examination reveals a fixed pronation deformity.
        - Radius is wide and bowed, whereas ulna is narrow and straight.
        - Treatment for significant pronation deformity: Rotational osteotomy at ≈5 years of age for better hand positioning
    - **Symphalangism (congenital digital stiffness)**
        - Hereditary symphalangism is autosomal dominant and associated with correctable hearing loss
        - More common in ulnar digits
        - Nonhereditary symphalangism is seen in conjunction with syndactyly, Apert syndrome, and Poland syndrome.
        - Surgical treatment: Angular osteotomies performed toward the end of adolescent growth may improve appearance and function of the digits.
    - **Camptodactyly (congenital digital flexion deformity)**
        - Classically occurs at small-finger PIP joint
            - Type I: Occurs in infancy and affects the sexes equally
                - Responds to splinting and stretching
            - Type II: Occurs in adolescent girls
                - Deformity: From either abnormal lumbrical insertion or an abnormal FDS origin and/or insertion
                - Treatment: If full PIP extension can be achieved actively with the MCP held in flexion, the digit can be explored and the abnormal tendon transferred to the radial lateral band.
            - Type III: Involves multiple digits with more severe flexion contractures and is usually associated with a syndrome

- Nonoperative treatment: Favored for all three types: progressive stretching
- Surgical treatment: Corrective osteotomy may improve alignment and function if functional deficit exists after skeletal maturity.

□ **Clinodactyly (congenital curvature of the digit in the radioulnar plane)**

- Small finger most common
- Type I: Most common; minor angulation, normal digit length
- Type II: Present in 25% of children with Down syndrome; minor angulation, short middle phalanx
- Type III: Marked angulation and a delta phalanx
    - C-shaped epiphysis and longitudinally bracketed diaphysis
    - Early excision is performed when the delta phalanx is a separate bone and involved digit is excessively long.
    - Otherwise, opening wedge osteotomy to correct angulation

□ **Flexed thumb**

- Two main causes: Pediatric trigger thumb and congenital clasped thumb
- Pediatric trigger thumb
    - Common developmental condition
    - Mechanical catching/locking of thumb; may progress to fixed flexion deformity at IP joint
    - Postural hyperextension of MCP joint
    - Nonoperative treatment: Some cases respond to early splinting or observation.
    - Surgical treatment (with failure of nonoperative treatment): A1 pulley release (similar to that in adult); low recurrence rate
        - Thumb radial digital nerve in jeopardy as it crosses more centrally near MCP joint flexion crease
- Congenital clasped thumb
    - Flexion-adduction thumb deformity at MCP joint
    - Typically caused by absence or hypoplasia of the EPB
    - Supple deformities may be treated by splinting or long/ring FDS tendon transfer to EPB.
    - Rigid deformities are associated with hypoplastic extensors, MCP joint contractures, UCL deficiency, thenar muscle hypoplasia, and first

web space skin deficiency.
    - Complex cases: Treatment according to pathology: release of MCP capsule; release of adductor pollicis, FPB, or first dorsal interosseous; Z-lengthening of the FPL; extensor or opposition tendon transfer; and/or deepening of the first web space.

- □ Arthrogryposis (congenital curved joints)
  - Results from defect in the motor unit and may be either neurogenic (90%) or myopathic (10%)
  - Immobility in the womb results in symmetric joint contractures.
  - Three types
    - Type I: Single localized deformity such as fixed forearm pronation or complex clasped thumb, which may be surgically corrected in usual fashion
    - Type II: Full expression, with absence of shoulder musculature, tubular limbs, elbow extension contractures, wrist flexion and ulnar deviation contractures, finger flexion contractures, and thumb adduction contractures
    - Type III: Type II contractures plus polydactyly and other organ system involvement
  - Treatment: Types II and III are treated with a combination of splinting, serial casts, and therapy to decrease the severity of joint contractures.
  - Once passive joint mobility is restored, tendon transfers may be performed.
  - An attempt is made to provide child with functional elbows and wrists; however, arthrodesis may provide greater ability to perform activities of daily living.
- □ **Syndactyly**
  - Common congenital hand anomaly (1 in 2500 live births) that results from failure of apoptosis to separate digits
  - Classification based on absence (simple) or presence (complex) of bony connections between the involved digits and whether the bony connections are complete or incomplete (Fig. 7.79)
  - *Acrosyndactyly*: Fusion between more distal portions of the digit, often seen in constriction ring syndrome
  - Pure syndactyly: Autosomal dominant inheritance with reduced penetrance and variable expression that yield a

positive family history in 10%–40% of cases

- Distribution of digit involvement
  - Long-ring: 50%
  - Ring-small: 30%
  - Index-long: 15%
  - Thumb-index: 5%
- Release performed at approximately 1 year of age
- Rays of unequal length should undergo release before 6 months of age.
- Acrosyndactyly requires distal release in neonatal period.
- Multiple-digit syndactyly releases are performed in two stages, with only one side of the digit released during one operation to reliably preserve circulation of digit.
- Full-thickness skin grafting invariably required
- Possible complications include web creep and nail deformities.
- Poland and Apert syndromes are commonly tested conditions with associated syndactyly

▪ **Duplication**

□ Preaxial polydactyly (thumb duplication)

- Classified by Wassel (Table 7.14)
  - Type IV is the most common (43%), characterized by duplicated proximal phalanx (Fig. 7.80).
  - Thumb duplication usually unilateral, sporadic, and not associated with a syndrome except in type VII
  - Type VII associations include Holt-Oram syndrome, Fanconi anemia, Blackfan-Diamond anemia, hypoplastic anemia, imperforate anus, cleft palate, and tibial defects.
- Best possible thumb is reconstructed from the available anatomic structures.
- If duplicate thumbs are of equal size, ulnar thumb is preserved to retain ulnar collateral ligament for pinch.
  - Soft tissue from ablated thumb should be preserved and used to augment retained thumb.
- Most reconstructed thumbs have satisfactory length and girth, but nail deformity and interphalangeal joint angulation are reported problems.

□ **Postaxial polydactyly (small-finger duplication)**

- Ten times more common in African Americans (1 in 143 live births) than whites (1 in 1339 live births)
  - Autosomal dominant inheritance

- More extensive genetic workup mandatory in whites because of multiple known chromosomal abnormalities

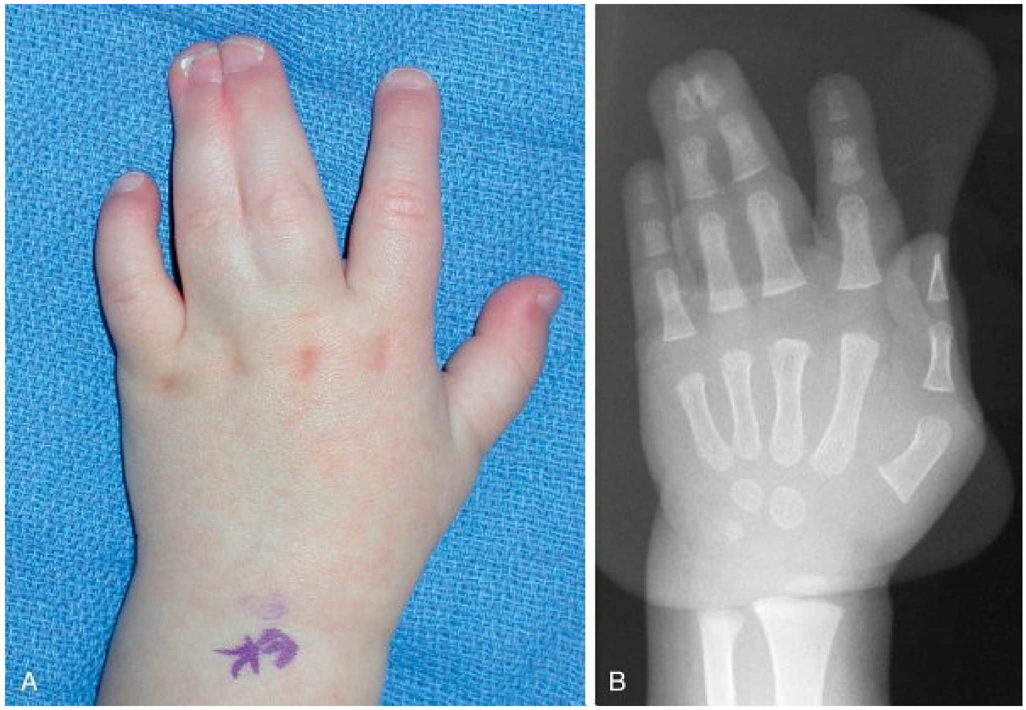


FIG. 7.79 Clinical (A) and radiographic (B) images of complex syndactyly.
From Goldfarb CA: Congenital hand anomalies: a review of the literature, 2009-2012, *J Hand Surg Am* 38:1854–1859, 2013.

Table 7.14

Wassel Classification of Preaxial Thumb Polydactyly

Type	Description	Frequency (%)
I	Bifid distal phalanx	2
II	Duplicated distal phalanx	15
III	Bifid proximal phalanx	6
IV	Duplicated proximal phalanx	43 (most common)
V	Bifid metacarpal	10
VI	Duplicated metacarpal	4
VII	Triphalangia	20

- Type A is a well-formed duplicated digit
    - Ulnar digit removed
- Type B is a rudimentary skin tag
    - May be tied off shortly after birth

□ **Central polydactyly**
- Usually associated with syndactyly
- Early surgery indicated to prevent angular deformity with

growth

- Impaired motion from interposed digits or symphalangism of adjacent digits
- Tendons, nerves, and vessels may be shared to the point that only one finger may be obtainable from three skeletons.
- Treatment: Ligament reconstruction and/or osteotomy for angular deviation

▪ **Overgrowth**

□ Macrodactyly

- Characterized by nonhereditary congenital digital enlargement
- Unilateral in 90% of cases; 70% of cases involve multiple digits
- Adult analogue is lipofibromatous hamartoma of the median or other peripheral nerves.
- Associated pathologies: Angular deviation, joint stiffness, and nerve compression syndromes

FIG. 7.80 Type IV duplication with duplicated proximal and distal phalanges that articulate with a bifid metacarpal head.
Courtesy Shriners Hospitals for Children, Philadelphia.

- Static macrodactyly is present at birth, and growth is linear with the adjacent digits.
- Progressive macrodactyly is not always evident at birth, but exponential growth occurs thereafter.
- Most favorable outcome for severely affected single digit is amputation.
- When the thumb or multiple digits are involved, the

following procedures may offer improvement
            - Epiphyseal ablation, angular and/or shortening osteotomies, longitudinal narrowing osteotomies, nerve stripping, and debulking
        - Stiffness and neurovascular compromise are common.
- **Undergrowth**
    - **Thumb hypoplasia**
        - Classified by Blauth (Table 7.15)
        - Critical structure is CMC joint
            - Separates type IIIA from type IIIB

Table 7.15

Blauth Classification of Thumb Hypoplasia

Type	Characteristics
I	Minor hypoplasia with all structures present
II	Normal articulations
	MCP ulnar collateral ligament instability
	Thenar hypoplasia
	Adduction contracture
IIIA	Extensive intrinsic and extrinsic musculotendinous deficiencies
	Normal CMC joint
IIIB	Extensive intrinsic and extrinsic musculotendinous deficiencies
	Abnormality or absence of CMC joint
IV	Total or subtotal metacarpal aplasia
	Rudimentary phalanges
	Thumb attached to hand by a skin bridge (pouce flottant)
V	Complete absence of thumb

            - Determines whether the thumb is reconstructable (types II, IIIA) or whether it requires pollicization (types IIIB–V)
        - Type I is a small thumb with slender bones and normal thenar musculature, which typically requires no treatment.
        - Types II and IIIA are treated with stabilization of the MCP joint UCL, web deepening, and extrinsic extensor tendon reconstruction.
        - Types IIIB to V are best treated with index pollicization.
- **Amnion disruption sequence (constriction ring syndrome)**
    - Sporadic occurrence with no evidence of hereditary predisposition
    - Manifested in four ways

- Simple constriction rings
- Rings with distal deformity, with or without lymphedema
- Acrosyndactyly
- Amputation

□ Neonatal surgery is indicated when edema jeopardizes digital circulation.

□ Release accomplished by multiple circumferential Z-plasties

▪ **Generalized skeletal abnormalities**

□ Congenital dislocation of the radial head

- May be distinguished from traumatic origin by bilateral involvement, other congenital anomalies (60%), and familial occurrence
- Typically irreducible by closed means
- Some helpful radiographic clues
  - Hypoplastic capitellum
  - Short ulna with long radius
  - Convex radial head
- Surgical indications include pain, limited motion, and cosmetic dissatisfaction
  - Radial head excision performed at skeletal maturity

□ **Madelung deformity**

- Disruption of volar ulnar physis of distal radius
  - Implicated tethering structure is Vickers ligament.
- As child grows, the distal radius exhibits excessive radial inclination and volar tilt (spectrum of abnormality seen).
- Hypothesized to be due to an X-linked dominant disorder, Léri-Weill dyschondrosteosis, which is caused by a mutation in the short-stature homeobox-containing *(SHOX)* gene

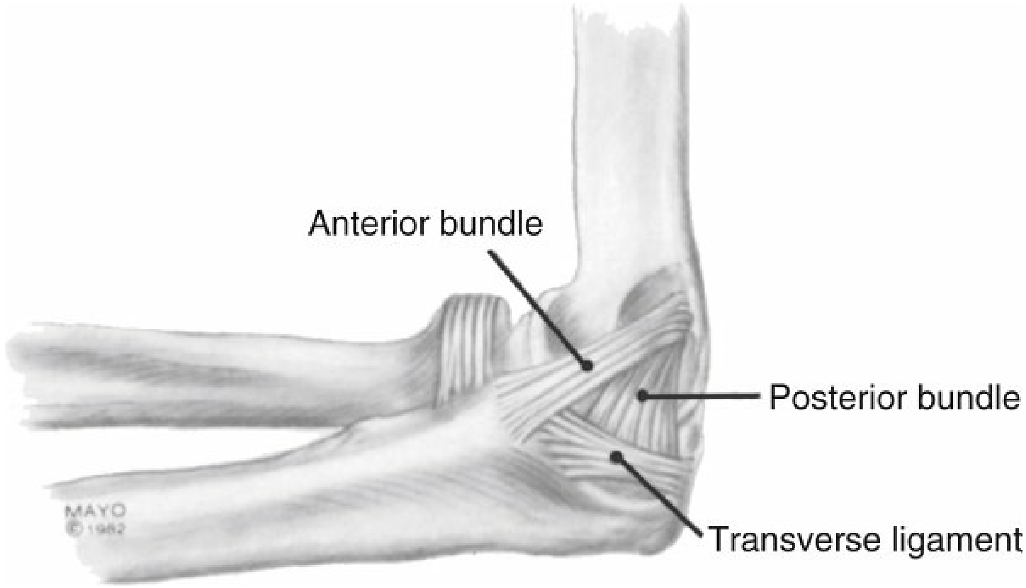


FIG. 7.81 Anatomic distribution of the medial collateral ligament complex.
Courtesy the Mayo Foundation.

- Often asymptomatic and found incidentally in adulthood after minor wrist injury prompts radiographic examination
- Treatment: Early release of Vickers ligament
- Symptoms arise from ulnocarpal impaction, restricted forearm rotation, and median nerve compression.
    - Corrective osteotomy of the radius with or without distal ulna resection

Elbow

- **Articular anatomy**
    - □ Ulnohumeral, radiocapitellar, and proximal radioulnar joints
    - □ Articular surface of distal humerus angled 30 degrees anterior to humeral shaft axis
    - □ Distal humerus consists of medial and lateral columns
    - □ Normal range of elbow flexion/extension: 0–150 degrees
    - □ Normal forearm pronosupination (rotation): 80–85 degrees in each direction
    - □ Functional ROM: 30° to 130° flexion/extension and 50 degrees pronosupination
    - □ Normal valgus carrying angle of the elbow is 5–10 degrees for men and 10–15 degrees for women
    - □ In full extension, 60% of axial load is transmitted through the radiocapitellar joint.
- **Ligamentous anatomy**
    - □ Medial (ulnar) collateral ligament (MCL)
        - Anterior, posterior, and transverse bundles (Fig. 7.81)

- Anterior bundle is primary restraint to valgus stress within functional elbow ROM (secondary restraint is radial head).
  - Originates on posterior medial epicondyle and inserts on sublime tubercle of medial coronoid process
- Posterior bundle is primary restraint to valgus stress with elbow in maximal flexion.
- Stability in full extension is provided by MCL, joint capsule, and ulnohumeral articulation

▪ **Lateral collateral ligament (LCL) complex**

- Composed of radial collateral ligament (RCL), lateral ulnar collateral ligament (LUCL), accessory collateral ligament, and annular ligament (Fig. 7.82)
- LUCL originates on posterior lateral epicondyle and inserts on crista supinatoris of proximal ulna
- LUCL is primary restraint to varus and external rotational stress throughout elbow motion (posterolateral rotatory instability)

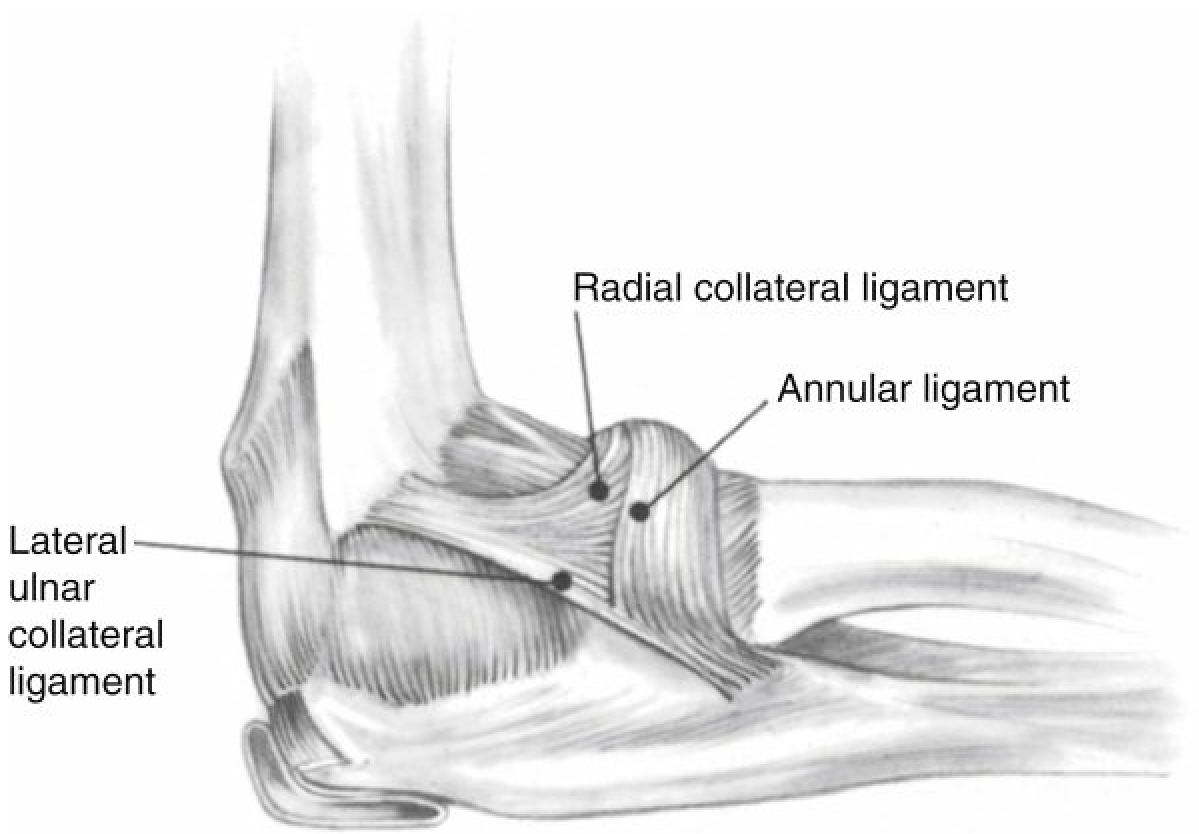


FIG. 7.82 The lateral collateral ligament complex consists not only of the radial collateral ligament but also a lateral ulnar collateral ligament.
Courtesy the Mayo Foundation.

▪ **Joint aspiration or injection**

□ Best performed through lateral soft spot

- Within triangle of bony landmarks (Fig. 7.83)
- Radial head
- Lateral epicondyle
- Tip of olecranon

- Therapeutic aspiration of hemarthrosis after trauma
- Corticosteroid injection for diagnostic differentiation between intran and extra-articular pain generators

- **Elbow imaging**
  - Plain radiographs: AP, lateral, and oblique views
  - CT: Provides superior bony detail
    - Complex fractures of the distal humerus, radial head and coronoid process; ossified loose bodies; HO
  - MRI: Provides superior soft tissue detail
    - Ligamentous injuries, occult fractures, osteochondritis dissecans (OCD), nonossified loose bodies, tendinous injury, and soft tissue masses
- **Tendon disorders**
  - **Lateral epicondylitis (tennis elbow)**
    - Common tendinopathy of ECRB origin
    - Degenerative rather than inflammatory process
      - Histologic finding: Angiofibroblastic hyperplasia
    - Precipitated by repetitive wrist extension and forearm rotation
      - Associated with occupation more often than racquet-sport play
    - Provocative maneuvers: Resisted wrist extension with the elbow extended and forearm pronated
    - Grip strength diminished with elbow extended in comparison with elbow flexed at 90 degrees
    - Treatment
      - Nonoperative treatment (primary approach): Avoidance of aggravating activities, antiinflammatory drugs, counterforce bracing, occupational therapy for local modalities (ice, heat, ultrasonography, iontophoresis)
      - Efficacy of corticosteroid injection controversial
        - **Shown to be equivalent to placebo in pain, grip strength, and patient-reported outcome measures by prospective double-blind randomized clinical trial**
        - May actually have long-term detrimental effects on muscle

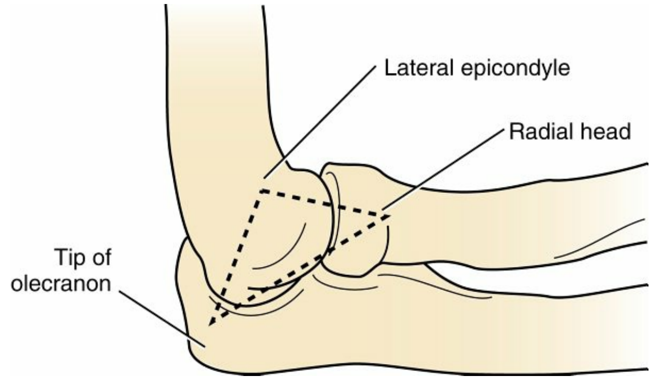


FIG. 7.83 The anconeal soft spot (lateral infracondylar recess) is the most sensitive area in which to detect a joint effusion, aspirate a hemarthrosis, and/or inject corticosteroid. This triangular area located on the lateral aspect of the elbow is outlined by the radial head, tip of the olecranon, and lateral epicondyle.
From Trumble TE et al, editors: *Core knowledge in orthopaedics: hand, elbow, and shoulder,* Philadelphia, 2006, Mosby, p 489.

    - Poor outcomes: Depression/anxiety and ineffective coping skills strongest predictors of perceived arm-specific disability
  - Extracorporeal shock wave therapy: Shown equivalent to placebo at 6 months
  - Platelet-rich plasma (PRP) injection showed promise in early case series
  - Surgical treatment: For recalcitrant cases with symptoms lasting more than 1 year
    - Open or arthroscopic ECRB debridement ± lateral epicondylectomy
    - Nirschl scratch test to check for degenerative, friable tendon
    - Iatrogenic injury to LUCL must be avoided.
    - Watertight deep closure to avoid synovial fistula
  - Other causes of lateral elbow pain if surgery fails: LUCL injury, OCD, radiocapitellar osteoarthrosis, synovial plicae, radial tunnel syndrome

□ **Medial epicondylitis (golfer's elbow)**
  - Common tendinopathy of flexor-pronator mass origin
  - Provocative maneuver: Pain with resisted forearm pronation and wrist flexion

- Treatment: Prolonged conservative management recommended because success of surgical débridement less predictable than in lateral epicondylitis
- Associated pathology: Cubital tunnel syndrome

□ **Distal biceps tendon injury**

- Mechanism: Eccentric loading of the flexed elbow during manual labor, weight lifting, or other poorly executed lifting activity
- Demographics: Almost exclusively in middle-aged males
- Risk factors: Steroid and tobacco use
- Presentation: Patient may experience a painful "pop" deep in proximal forearm.
- Physical examination: Supination strength is diminished more than flexion strength (biceps is main forearm supinator, brachialis is main elbow flexor).
    - Abnormal hook test result
- If left untreated, ≈50% supination and ≈70% flexion strength regained by 1 year
- Key point: Biceps muscle belly unlikely to be proximally retracted if lacertus fibrosis (bicipital aponeurosis) remains intact

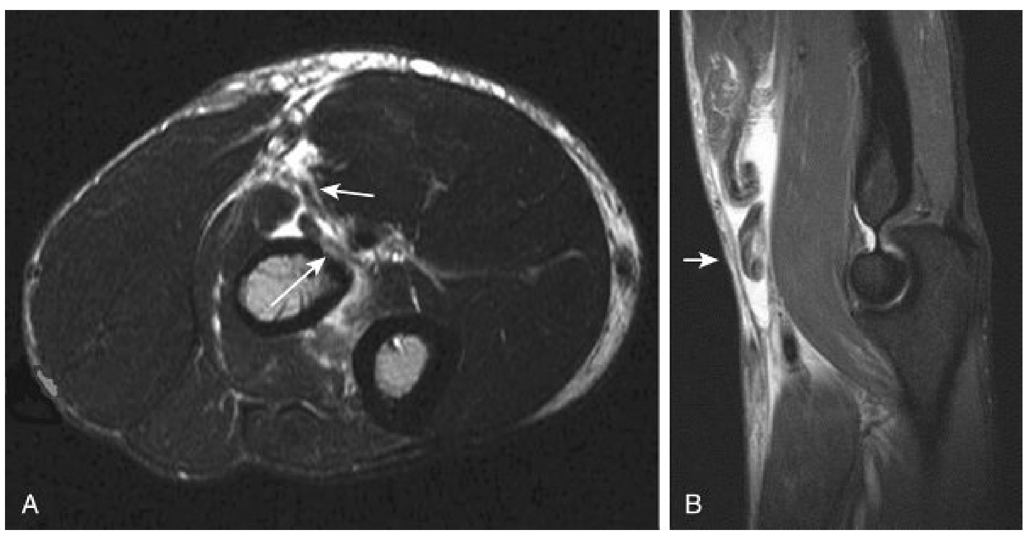


FIG. 7.84 Distal biceps tendon rupture. (A) Axial T2-weighted MR image shows disruption of the distal biceps tendon from its insertion at the radial tuberosity *(long arrow)*, accompanied by surrounding edema and increased fluid within the bicipitoradial bursa *(short arrow)*. (B) Sagittal T2-weighted image shows a completely torn and retracted distal biceps tendon with surrounding high-intensity fluid and soft tissue edema *(arrow)*.

A modified from Brunton LM et al: The elbow. In Khanna AJ, editor: *MRI for orthopaedic surgeons*, New York, 2010, Thieme; **B** modified from Brunton LM et al: Magnetic resonance imaging of the elbow: update on current techniques and indications, *J Hand Surg Am* 31[6]:1001–1011, 2006.

- MRI helps distinguish partial from complete injuries in

equivocal cases (Fig. 7.84).
    - Associated bicipitoradial bursitis may be seen with chronic tendinopathy.
- Partial ruptures
    - Occur on the radial side of the tuberosity footprint owing to its function as a supinator
    - Initially treated nonoperatively with rest, NSAIDs, and therapy
    - May eventually require detachment, débridement, and reattachment
- Surgical treatment: Reattachment to radial aspect of the tuberosity recommended in active individuals with complete rupture to regain strength
    - Techniques: Single-incision and two-incision techniques equally effective
        - Classic single-incision risk: Neurologic injury (lateral antebrachial cutaneous nerve in up to ≈25% of cases)
        - Classic two-incision risk: Radioulnar synostosis
    - Fixation: Bone trough/drill holes, suture anchors, interference screw, or titanium fixation button (Endobutton, Smith & Nephew, Andover, MA) (Fig. 7.85).
        - Biomechanical studies have shown Endobutton to have superior strength
    - Chronic injuries (>6 weeks): Tendon autograft or allograft augmentation
        - Strength recovery less than with acute repair using native tendon
- Strengthening exercises must be avoided for approximately 8–10 weeks postoperatively.

□ **Distal triceps tendon injury**

- Mechanism: Direct blow to posterior elbow or sudden forceful flexion of extended elbow
- Presentation: Posterior elbow pain and swelling ± a palpable defect proximal to the olecranon tip
- Physical examination: Diminished elbow extension strength, although active extension still possible through intact anconeus
    - ≈50% of these injuries are initially missed.

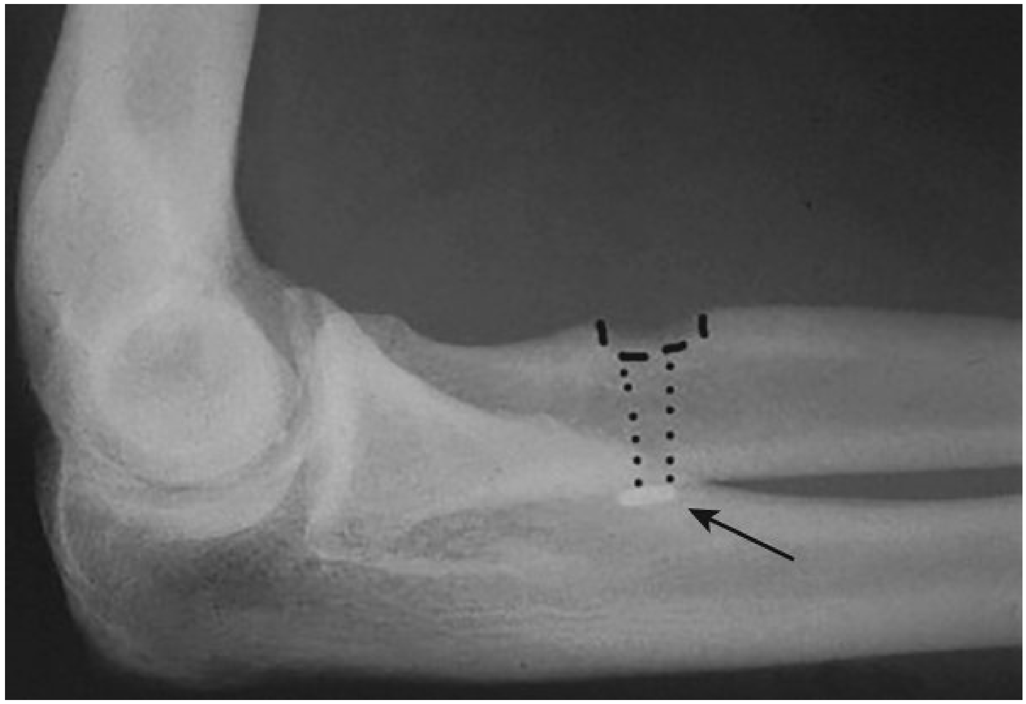


FIG. 7.85 Lateral radiograph shows Endobutton *(arrow)* in the desired position and orientation on the posterior aspect of the proximal radius. Also visible is the trough *(dashed lines)* and the 4-mm-wide channel *(dotted lines)*.
From Greenberg JA: Endobutton repair of distal biceps tendon ruptures, *J Hand Surg Am* 34:1541–1548, 2009.

- Rupture often occurs at musculotendinous junction or olecranon insertion.
- Risk factors: Anabolic steroid use, multiple local corticosteroid injections, chronic olecranon bursitis
- Treatment: Surgical repair/reattachment for high-grade partial (>50% of tendon width) and complete tears, typically through transosseous tunnels
- Slow rehabilitation with progressive elbow flexion

▪ **Elbow trauma**

□ **Distal humerus fractures**

- Anatomic morphology is two columns around articular surface
  - Most adult fractures involve both columns and articular surface.
- Mechanism: High-energy trauma (younger patients), low-energy trauma (elderly)
  - CT helps characterize fracture pattern.
- Nonoperative treatment: Recommended only for elderly patients with multiple comorbidities and low functional demands; goal is a stiff, painless elbow.
- Surgical treatment: Majority of injuries treated by ORIF.
  - Approaches: Triceps-splitting, triceps-sparing, and olecranon osteotomy

        - Articular surface reconstructed with headless compression screws ± lag screws
        - Anatomically precontoured column locking plates often used
        - Plate orientation: Orthogonal (90-90, direct medial and posterolateral) or parallel (medial and lateral) with interdigitation of screw threads
    - Semiconstrained total elbow arthroplasty (TEA): Possibly better for healthy, active elderly patients with severe articular comminution to allow early motion
        - Limitation: Patient restricted to 10-pound weight-lifting limit for life
        - In patients older than 65 years, Mayo Elbow Performance Score (MEPS) was higher at 2-year follow-up for those randomized to TEA than to ORIF.

□ **Radial head fracture**

- Presentation: Lateral elbow pain and swelling after trauma
- Radiographs: Fat pad sign should be sought on plain radiographs if there is no obvious fracture.
- Key point: Mechanical block in forearm rotation should be assessed via aspiration of hemarthrosis and injection of local anesthetic.
- CT helpful in borderline cases, because block is often difficult to characterize on plain radiographs
- Associated injuries: MCL, other periarticular fractures
    - Key point: Forearm and wrist should be assessed for Essex-Lopresti injury.
- Classification by Mason, modified by Hotchkiss
    - Type I: Nondisplaced or minimally displaced without mechanical block
        - Treatment: Nonoperative with early motion
    - Type II: more than 2 mm of articular displacement with or without mechanical block
        - Treatment: ORIF for mechanical block
    - Type III: Comminuted
        - Treatment: Either ORIF or implant arthroplasty
    - Type IV: Associated with elbow dislocation

    - Overstuffing leads to early capitellar wear/late instability.
    - Radial head excision contraindicated by incompetent MCL/interosseous membrane, coronoid fracture, or other destabilizing injuries
    - Forearm interosseous membrane instability: more than 3 mm of translation when radius and ulna are pulled in opposite directions
- □ **Essex-Lopresti injury**
    - Longitudinal radioulnar instability caused by sequential injury to the DRUJ, interosseous ligament, and radial head
    - Radial head injury: Either internally fixed or replaced to prevent proximal migration of radius and resulting ulnocarpal impaction
        - TFCC pathology treated concurrently
    - Notoriously difficult injury to treat
        - Multiple reconstructions of interosseous ligament described; no consensus
- □ Coronoid fractures
    - Occur most often in setting of elbow dislocation
    - Classifications
        - Regan and Morrey: Based on size of process fracture
        - O'Driscoll: More comprehensive; recognizes fractures of the anteromedial facet that may lead to varus posteromedial rotatory instability if left untreated
    - Surgical treatment: Unstable fractures treated with ORIF
        - Technique: Suture, screw, and miniplate fixation
- □ **Olecranon fractures**
    - Typically result from direct blow to proximal forearm
    - Proximal fragment displaced by triceps pull
    - Treatment: Depends on displacement and articular congruity
        - Simple transverse fractures: Tension band constructs work well but are associated with high rate of symptomatic hardware (>50%).
        - Comminuted fractures: Articular displacement best treated using plate-and-screw construct
        - Elderly patient with severely comminuted fractures may benefit from excision of the proximal fragment and reattachment of triceps tendon.
- □ Elbow dislocation
    - Most common direction: Posterolateral

- Simple or complex (with associated fractures)
- Closed reduction performed promptly after assessment of neurovascular status
    - Elbow stability tested through flexion-extension arc after reduction, and elbow immobilized initially at 90 degrees with forearm in pronation
- Simple dislocations treated with early ROM within 3 weeks of injury
- Persistent instability within 30 degrees of full extension: Acute ligamentous repair
    - Lateral ligamentous complex always repaired, followed rarely by MCL if instability persists
- Most common complication after closed treatment: Loss of terminal extension
- "Terrible triad" injury
    - Consists of
        - Elbow dislocation
        - Radial head fracture
        - Coronoid process fracture
    - Treatment: ORIF of coronoid process, ORIF or prosthetic replacement of radial head, and lateral ± medial ligamentous repair
        - Persistent instability: Hinged external fixator or transarticular ulnohumeral pinning
        - Early ROM starting with intraoperative arc of stability
            - LCL repaired and MCL intact: Elbow kept in forearm pronation to increase stability (pronation decreases stress on LCL)
            - LCL repaired but MCL deficient: Elbow kept in forearm supination to increase stability (supination decreases stress on MCL)
            - LCL and MCL repaired: Elbow kept in neutral

□ **Monteggia fracture-dislocations**

- Proximal-third ulnar fracture accompanied by radial head subluxation/dislocation

- Bado classification into four types
- Anatomic reduction of the proximal ulna usually reduces the radial head.

FIG. 7.86 Tears of the MCL on MRI. (A) Complete tear of the MCL. Coronal fat-suppressed T2-weighted image shows discontinuity of the ligament with surrounding edema and hemorrhage *(arrow).* (B) Partial tear of the MCL. Coronal fat-suppressed T1-weighted MR arthrogram shows a T sign, with leakage of intraarticular contrast material at the undersurface of the ligament at its distal insertion on the sublime tubercle *(arrow).*
A modified from Brunton LM et al: Magnetic resonance imaging of the elbow: update on current techniques and indications, *J Hand Surg Am* 31[6]:1001–1011, 2006; **B** modified from Brunton LM et al: The elbow. In Khanna AJ, editor: *MRI for orthopaedic surgeons*, New York, 2010, Thieme.

- Persistent proximal radioulnar instability may require annular ligament reconstruction.

▪ **Elbow instability**

□ **Posterolateral rotatory instability**

- Caused by incompetence of the LUCL
- Patients relate history of previous elbow dislocation treated nonoperatively.
- Presentation: Pain and subjective instability
- LCL-deficient elbow more stable in forearm pronation
- Lateral pivot-shift test
  - Reproduces instability with combination of supination, axial compression, and valgus loading as elbow is brought from full extension to 40 degrees of flexion
  - Ulna rotates externally on trochlea and produces

posterior radial head subluxation.
    - With increasing flexion, the triceps becomes taut and the radial head reduces with palpable clunk.
    - Patient apprehension is common, and either intraarticular local anesthetic or examination with use of general anesthesia may be necessary to confirm diagnosis.
  - MRI: LUCL pathology in ≈50% of cases
  - Chronic instability: Reconstruction of the LUCL with tendon autograft
- □ **Varus posteromedial rotatory instability**
  - Increasingly recognized but poorly understood entity
  - Etiology: Fracture of anteromedial coronoid process
  - Treatment: ORIF of coronoid with buttress plate, assessment of MCL insertion
- □ **Valgus instability**
  - Etiology: Acute (elbow trauma) or chronic (repetitive loading and attenuation of the MCL)
    - Baseball players: The late cocking and acceleration phases of throwing place the highest stress on the MCL.
  - Acute injury: Primary ligamentous repair or reattachment with suture anchors
  - Chronic instability: Common in overhead-throwing athletes such as baseball pitchers and javelin throwers
    - Valgus extension overload
      - Pain during deceleration phase as elbow reaches terminal extension
      - Osteophytes of the posteromedial olecranon process block full extension.
  - Surrounding muscle stabilizers may mask clinical valgus instability in 50% of cases: FCU is the primary dynamic stabilizer, and FDS is a secondary stabilizer.
  - MRI: Evaluation of MCL, flexor-pronator mass, adjacent bone (especially in pediatric population) (Fig. 7.86)
  - Associated pathology: Ulnar neuritis/cubital tunnel syndrome
  - Nonoperative treatment: Gradual rehabilitation with symptomatic treatment, maintenance of elbow motion, local modalities, and gradual return to throwing protocol
  - Surgical treatment: MCL reconstruction with tendon autograft indicated in competitive athletes (Tommy John

surgery) in whom a trial of nonoperative treatment fails (Fig. 7.87)
    - Nearly 75%–80% of patients return to sports at the same level or better 1 year after reconstruction.
  - Unrecognized or untreated MCL insufficiency leads to capitellar wear, posteromedial impingement, olecranon osteophyte formation, and loose-body formation (valgus overload syndrome).
    - Treatment: Arthroscopic débridement of osteophytes and removal of loose bodies

- **Elbow contracture**
  - Stiffness and loss of motion are frequent complications after elbow injury.
  - Aggressive motion recovery started as soon as possible
  - Loss of 30 degrees of terminal extension well tolerated in general population
  - Loss of flexion (<130 degrees) interferes with activities of daily living
  - Intrinsic factors
    - Articular incongruity (malunion, OA, OCD), loose bodies, synovitis
  - Extrinsic factors
    - Heterotopic ossification, muscle fibrosis, hardware impingement, ligamentous/capsular contracture
  - Nonoperative treatment: Aggressive therapy and dynamic/static progressive splinting
  - Surgical treatment: Arthroscopic or open treatment depending on primary pathology
- **Elbow arthritis**
  - Rheumatoid arthritis
    - Most prevalent type of elbow arthritis
    - Elbow affected in up to 50% of patients with RA
    - Chronic inflammation and synovitis lead to ligament attenuation, periarticular osteopenia, and joint contracture
    - Primary treatment: Medical management
    - Surgical treatment
      - Synovectomy and radial head resection: Good historic short-term results
      - Semiconstrained total elbow arthroplasty: More permanent pain relief and preserved function

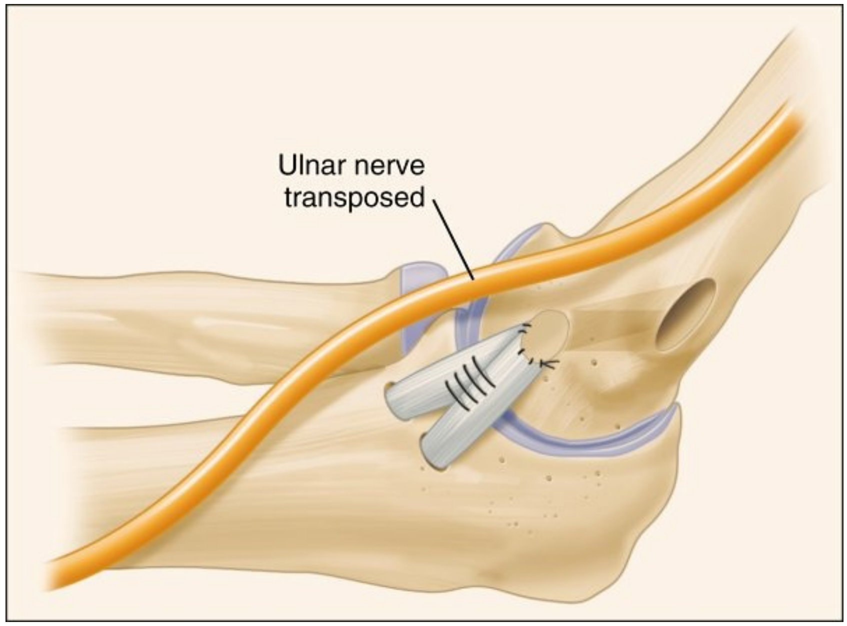


FIG. 7.87 Reconstruction of the MCL. A tendon graft is passed through tunnels and sutured in place.
From Miller MD, Thompson SR, editors: *Delee & Drez's orthopaedic sports medicine: principles and practice*, ed 4, Philadelphia, 2015, Elsevier Saunders, p 791.

- Complications: Infection, implant failure, periprosthetic fracture

□ **Posttraumatic ulnotrochlear/radiocapitellar arthritis**

- Second most common type of elbow arthritis
- Typically young patients in whom conservative management fails are treated with
  - Arthroscopic or open débridement of osteophytes, abrasion chondroplasty, and removal of loose bodies
  - *Ulnohumeral arthroplasty*, also known as Outerbridge-Kashiwagi (O-K) procedure, describes removal of anterior elbow osteophytes by trephination of the distal humerus from a posterior approach through the olecranon fossa (Fig. 7.88)
  - Interposition arthroplasty with autograft (tensor fascia latae) or allograft (Achilles)

□ **Primary OA**

- Least common form of elbow arthritis
- Typically affects middle-aged manual laborers
- Pain at extremes of motion
- Osteophyte formation may lead to mechanical block of motion
- Open or arthroscopic débridement performed to delay arthroplasty
- Postoperative continuous passive motion not shown to add

benefit postoperatively.

- **Charcot elbow (neuroarthropathy)**
    - Associated with syringomyelia
    - MRI of the cervical spine and electrodiagnostic evaluation are paramount.

- **Total elbow arthroplasty**
  - Indications
    - Refractory RA
    - Advanced OA (primary and posttraumatic)
    - Chronic instability
    - Complex distal humerus fractures in elderly patients
  - Contraindications: Prior or chronic infection (arthrodesis preferred)
  - Postoperatively, patients have lifelong weight-lifting restriction of 10 pounds.
  - Two primary types: Unconstrained (unlinked) and semiconstrained (linked)
    - Unconstrained TEA is theoretically better for patients with OA who have competent collateral ligaments and good bone quality.

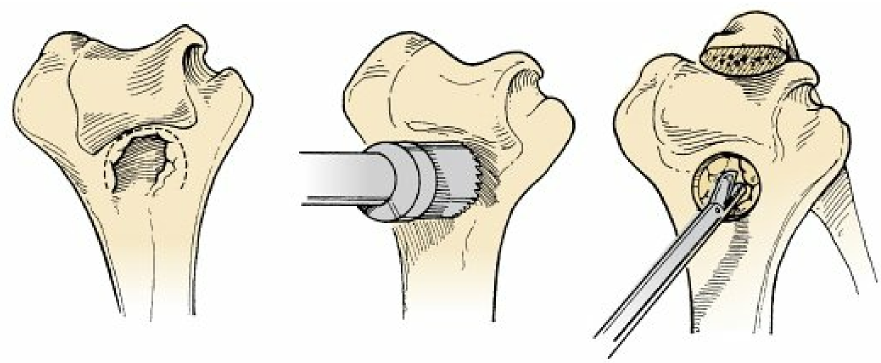


FIG. 7.88 Outerbridge-Kashiwagi procedure (ulnohumeral arthroplasty) performed through a triceps-splitting approach. The coronoid is approached through a Cloward drill hole in the olecranon fossa. The olecranon can also be débrided with this approach.
From Miller MD et al: *Review of sports medicine and arthroscopy,* Philadelphia, 1995, Saunders, p 180.

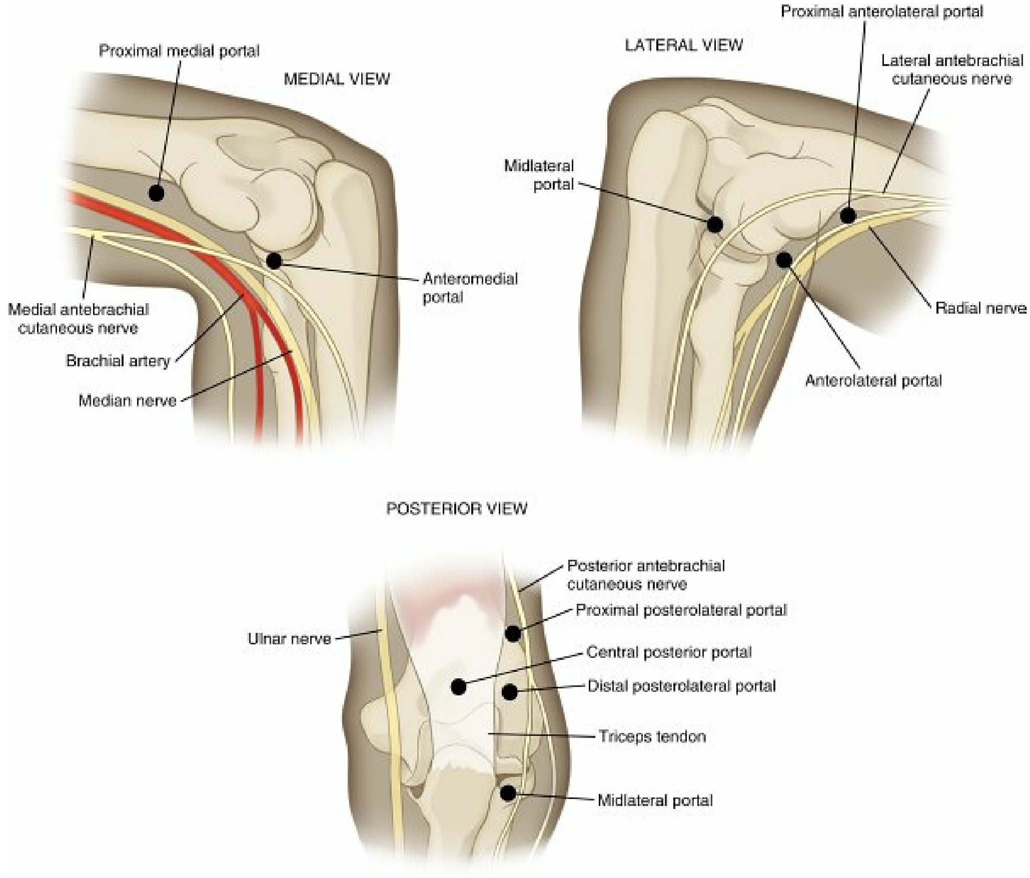


FIG. 7.89 Arthroscopic portals for elbow arthroscopy.
From Miller MD et al: *Orthopaedic surgical approaches*, Philadelphia, 2008, Elsevier.

- Semiconstrained TEA acts as "sloppy hinge" with limited rotational and coronal plane motion.
  - Ideal indications: RA, chronic instability, and distal humerus fractures in elderly patients
  - Outcome: Predictable pain relief
- □ Surgical approaches: split or spare triceps
  - Ulnar nerve transposed anteriorly and radial head often resected
  - A competent extensor mechanism is critical for good functional outcome.
- □ Complications: Infection, nerve injury, instability, periprosthetic fracture, implant loosening from polyethylene wear
- □ Staged reimplantation after infection has a poor salvage rate.

▪ **Elbow arthroscopy**
- □ Indications: Diagnosis of suspected pathology, removal of loose bodies, treatment of OCD, débridement of osteophytes, release of a capsule, synovectomy, assistance for intraarticular fracture fixation, and treatment of lateral epicondylitis
- □ Risk: Neurovascular injury risk is far higher at the elbow than at other joints treated arthroscopically.
  - Ulnar nerve palsy: The most common transient nerve palsy after elbow arthroscopy

- Risks: Prior ulnar nerve surgery and chronic elbow contractures
  - Other palsies: Superficial radial nerve, PIN, medial antebrachial cutaneous nerve, and AIN
  - Other structures at risk: Brachial artery and median nerve
  - The overall rate of neurologic injury is cited as 0%–14%
- Risk is minimized by
  - Keeping the elbow at 90 degrees of flexion
  - Joint insufflation
  - Using far proximal portals and avoiding posteromedial portals
  - Using a nick-and-spread technique
  - Appreciating scenarios that are particularly dangerous: Distorted anatomy, inflammatory arthritis, HO
- Commonly used portals (Fig. 7.89)
  - Anteromedial portal: Placed under direct visualization 2 cm distal and 2 cm anterior to the medial epicondyle
    - Risks: Medial antebrachial cutaneous and median nerves
  - Proximal anteromedial portal: Placed 2 cm proximal to the medial epicondyle and 1 cm anterior to the medial intermuscular septum
    - Risks: Medial antebrachial cutaneous nerve.
  - Proximal anterolateral portal: Placed 2 cm proximal and 1–2 cm anterior to the lateral epicondyle
    - Key point: The lateral antebrachial cutaneous and radial nerves are less at risk than with a standard anterolateral portal, which is described as 3 cm distal and 1 cm anterior to the lateral epicondyle.
  - Straight posterior (transtriceps) portal: Placed 3 cm proximal to the olecranon tip and centered to pass through the olecranon fossa
  - Posterolateral portals: Variably placed just lateral to the triceps tendon and anywhere from 1 to 4 cm proximal to the olecranon tip
    - The closest nerve is the posterior antebrachial cutaneous.

Testable Concepts

Anatomy

- Central slip: Terminal extension of EDC, aids in PIP extension
- Lateral bands: Convergence of intrinsics and EDC, extends DIP joint
- Transverse retinacular ligament: Prevents dorsal subluxation of lateral bands
  - Injury: Swan neck deformity
- Triangular ligament: Prevents volar subluxation of lateral bands
  Injury: Boutonnière deformity
- Vascular supply of flexor tendons: Both *intrinsic* (direct feeding vessels) and *extrinsic* (diffusion via synovial sheath to flexor tendons)
- A2 and A4 pulleys: Critical to prevent bowstringing of flexor tendon
- The carpal tunnel contains the median nerve and nine flexor tendons (one FPL, four FDS, and four FDP).
  - FPL is most radial; the long and ring FDS tendons are volar to index and small FDS tendons.
- Lumbrical muscles: Originate on radial aspect of FDP tendons, pass volar to TMLs, and insert on radial aspect of the extensor hood with lateral bands.
- Intrinsic tightness: Limited PIP flexion with MCP joints held in extension
  - Intrinsics on stretch, extrinsics relaxed
- Extrinsic tightness: Limited PIP flexion with MCP joints held in flexion
  - Extrinsics on stretch, intrinsics relaxed
- Median nerve: Innervates pronator teres, FDS, FCR, PL, radial two lumbricals
- Ulnar nerve: Innervates FCU, ring/small FDPs, long FDP (50% of time), ulnar two lumbricals
- Radial nerve proper: Innervates lateral portion of brachialis (also musculocutaneous), triceps, anconeus, brachioradialis, ECRL
- PIN: Innervates all remaining extensors
- Anastomoses: Martin-Gruber (median-ulnar in forearm), Riche-Cannieu (median-ulnar in palm)

Distal Radius Fractures

- Concomitant injuries: Scaphoid fracture, SL injury, ulnar styloid fracture
  - Acute carpal tunnel syndrome: Evolving paresthesias/pain requires emergent release.
- Normal anatomy (11:22:11)
  - Radial height 11 mm, radial inclination 22 degrees, volar tilt 11 degrees
- Acceptable reduction
  - Radial shortening less than 3 mm, dorsal tilt less than 10 degrees,

intraarticular step-off less than 2 mm

- Nonoperative treatment: Minimally displaced fracture
  - Complications: Stiffness and disuse osteopenia
- Surgical treatment: ORIF (volar) for volarly displaced fractures (Smith and volar Barton); also become standard for dorsally displaced fractures (Colles)
  - Dorsal approach: Direct visualization of the articular surface; intraarticular pathology, such as of the SL, should be addressed.
- The most common complication after distal radius fracture: Median nerve dysfunction
- EPL tendon rupture:
  - Occurs after ORIF because of long screw, or after nonoperative treatment because of attritional wear and/or vascular insufficiency near the Lister tubercle
  - Treated with EIP-to-EPL tendon transfer
- FPL rupture is the most common flexor injury after volar plating (watershed line)
- Associated distal ulnar styloid fracture: treated nonoperatively if DRUJ stable
- TFCC injury most common associated intraarticular problem (most treated nonoperatively unless DRUJ unstable)
  - Vitamin C (500 mg/day for 50 days) prescribed postoperatively to prevent CRPS

Carpal Fractures and Instability

- Scaphoid fracture: Most common carpal bone fracture; retrograde blood supply from dorsal branch of radial artery
  - Radiographs nondiagnostic in 1⁄3 cases: Immobilization for 2 weeks plus advanced imaging
  - Acute operative indications: More than 1 mm of displacement, intrascaphoid angle more than 35 degrees, perilunate fracture-dislocation, proximal pole fracture
  - ORIF with long, central screw (percutaneous/arthroscopic procedure for nondisplaced fracture; open procedure for displaced or chronic fracture)
  - Approach: Dorsal for proximal pole; volar for distal fracture (less disruptive to vascularity)
- Scaphoid fracture complications: scaphoid nonunion advanced collapse (SNAC), nonunion, avascular proximal pole
  - SNAC
    - Stage 1: radial styloid
    - Stage 2: radioscaphoid joint
    - Stage 3: scaphocapitate and lunocapitate
    - Radiolunate joint is least affected (PRC vs. scaphoid excision with four-corner fusion)

- Nonunion: Treated with bone graft (for vascularity and structure): for example, iliac crest for humpback deformity with vascularity, 1,2 ICSRA for avascular proximal pole *without* humpback deformity, medial femoral condyle bone for avascular proximal pole *with* humpback deformity
- Lunate fracture: Kienböck disease or perilunate dislocation should be considered.
- Triquetrum fracture: Dorsal capsular avulsion (wrist sprain) or LT injury should be considered
- Capitate neck fracture: Often occurs in combination with perilunate dislocation or scaphoid fracture.
- Pisiform fracture: Rare, treated with cast immobilization; excision for painful nonunion
- Hook of hamate fracture: Frequently associated with racquet sports or baseball
    - Diagnosis: Carpal tunnel radiographic view or CT
    - Treatment: Cast (nonoperative), excision (quickest recovery), or ORIF
- Four types of carpal instability: CID, CIND, CIA, CIC
    - Dissociative (same row; e.g., DISI, VISI), nondissociative (different rows; e.g., midcarpal, radiocarpal), adaptive (malunited distal radius fracture), complex (perilunate dislocation)
    - DISI is the most common form of carpal instability (increased SL angle)
        - SL ligament (dorsal portion strongest)
    - Scapholunate advanced collapse (SLAC) wrist: Untreated chronic instability; stages similar to those of SNAC wrist
    - VISI is the second most common (decreased SL angle or increased LT angle)
    - LT ligament (volar portion strongest)
- Perilunate dislocations are an example of CIC
    - Mayfield described four stages of progressive disruption: I, scapholunate; II, midcarpal; III, lunotriquetral; IV, circumferential
    - Prompt treatment with closed reduction (especially in acute carpal tunnel syndrome)
    - Definitive treatment with early ORIF using dorsal ± volar approach

Metacarpal and Phalangeal Injuries

- Most metacarpal and phalangeal fractures are treated nonoperatively
- Operative indications: Displacement, intraarticular fracture, malrotation, open or multiple fracture
    - Volar PIP joint dislocation requires central slip repair with splint in full extension to prevent a boutonnière deformity
    - Rotatory dislocation: Condyle is buttonholed between central slip and lateral band.
- PIP joint fracture-dislocations: Classified according to amount of middle phalanx

(P2) articular surface involved
    - Less than 30% involvement: Treated nonoperatively with dorsal block splint/pin
    - Unstable injuries with larger (>30%) P2 base fragments treated with operative intervention: Dorsal block pinning, ORIF, hemihamate reconstruction, or volar plate arthroplasty
- Irreducibility of MCP and DIP dislocations is typically due to interposition of the volar plate.
    - Treated via open reduction and extraction of the volar plate
- MCP head fracture: Fight bite; ORIF if more than 1 mm articular step-off
- MCP neck fracture: Boxer's fracture; Jahss maneuver for reduction
    - Acceptable angulation: Index/long, less than 15–20 degrees; ring, less than 30–40 degrees; small, less than 60–70 degrees
- MCP shaft fracture: High risk of malrotation
    - Acceptable angulation: Index/long, less than 10 degrees; ring/small, less than 30 degrees; less than 5 mm of shortening also acceptable
- Most common PIPJ dislocation is dorsal; results from volar plate and collateral ligament injury
- Bennett fracture is an fracture-dislocation of thumb CMC joint.
    - APL and extensors cause proximal, dorsal, and radial displacement of metacarpal shaft.
    - Anterior oblique or "beak" ligament keeps volar-ulnar base fragment reduced to trapezium.
- Skier's thumb (acute UCL injury) and gamekeeper's thumb (chronic UCL injury): Proximal phalanx supinates around intact RCL.
    - Instability in 30 degrees of flexion indicates injury to true UCL.
    - Stener lesion occurs in more than 85% of complete MCP ligament injuries when the adductor pollicis aponeurosis is interposed between the avulsed UCL and its insertion on the base of the prox phalanx
- RCL instability is due to overpull of adductor, which causes proximal phalanx to pronate around intact UCL.

Tendon Injuries and Overuse Syndromes

- Mallet finger (zone I): Nonoperative treatment (DIP extension splinting) if less than 12 weeks from injury
    - Controversial indication for surgery: Displaced bony injury with volar subluxation of P3
- Dorsal extensor tendon injury over the PIP (zone III): Danger to central slip insertion
    - Boutonnière deformity (PIP flexion, DIP extension)
    - Central slip injury causes lateral bands to sublux volarly

  - Acute injuries treated with PIP extension splinting
  - Chronic boutonnière deformity: Central slip reconstruction if flexible
- Extensor hood over MCP (zone V) (fight bite): Surgical débridement and IV antibiotics
- Principles of partial laceration treatment
  - Painful catching in tendon sheath treated with "trimming"
  - Lacerations more than 60% of tendon width treated with primary repair within 10 days of injury
- Principles of flexor tendon repair
  - Increasing strength with increasing number of core sutures (>4)
  - Dorsally placed core sutures are stronger than volarly placed sutures
  - Gap formation decreased with use of a locking-loop configuration and higher-caliber suture
  - Overall strength increased (≈10%–50%) with epitendinous repair
  - Purchase distance 0.7–1.2 cm from ends with minimal-touch technique
  - Preservation of A2 (most important) and A4 (oblique in thumb) pulleys prevents bowstringing.
- Early protected ROM increases tendon excursion and strength and decreases adhesion formation.
  - Active flexion to reduce adhesions requires minimum four-strand core suture repair.
  - Young children unable to comply with protocols; require cast immobilization for 4 weeks
- Rugger jersey finger (zone I): Forced DIP extension causes closed FDP avulsion.
- Quadrigia: Middle-ring-small FDP tendons have common muscle belly, so advancement of one more than 1 cm compromises flexion of others.
- Zone II ("no man's land") flexor tendon injury: Direct repair plus early mobilization to prevent rerupture and adhesions
  - Tendon lacerations may be at different level from skin laceration.
- Trigger finger (stenosing flexor tenosynovitis): Treated surgically with release of A1 pulley after nonoperative treatment (e.g., injections) fails.
  - Key pulleys: A2 pulley (digits), oblique pulley (thumb)
  - Comorbidities: diabetes, inflammatory arthritis (e.g., RA)
  - Failure of injection higher with diabetes
- Pediatric trigger thumb: Fixed flexion deformity of thumb IP joint; Notta node pathognomonic
  - Treatment involves A1 release at 2–4 years of age
  - Radial digital nerve is in danger during release.
- Pediatric trigger finger (less common than trigger thumb): Aberrant anatomy
  - Treated with A1 pulley release and procedures to address aberrant anatomy (e.g., FDS ulnar slip excision)
- de Quervain tenosynovitis: First extensor compartment; middle-aged women, new mothers, and golfers

- Nonoperative treatment for most: Corticosteroid injection has more than 80% success.
- Surgical release: Often multiple slips of APL and/or separate dorsal EPB compartment
- Intersection syndrome: At junction of first and second extensor compartments; rowers
  - Treatment nonoperative in vast majority
- ECU tendinitis: Racquet sports; worse in supination; nonoperative treatment in most cases
  - ECU subluxation: Forceful hypersupination plus ulnar deviation; immobilization in acute cases

DRUJ, TFCC, Wrist Arthroscopy

- Components of TFCC: Dorsal and volar radioulnar ligaments, the articular disc, a meniscus homologue, ECU, and ulnolunate and ulnotriquetral ligaments
  - Neutral variance: 80% compressive loads through radius and 20% through ulna
  - +2 mm variance: 60% through radius and 40% through ulna
- Acute (class I) TFCC tears are most commonly avulsions at the ulnar periphery (type IB) and amenable to repair (periphery well vascularized)
  - Arthroscopy: Gold standard for diagnosis
  - No clear clinical outcome difference between open and arthroscopic repair techniques
  - Surgical treatment: Peripheral (repair) or central (débridement)
- Degenerative (class II) tears are associated with positive ulnar variance and ulnocarpal impaction syndrome.
  - Treatment: Ulnar shortening osteotomy (no arthrosis) or wafer resection (arthrosis)
- Chronic DRUJ instability treated with TFCC repair or ligament reconstruction
- DRUJ OA treatment: Hemiresection interposition arthroplasty, Darrach resection (low-demand patient), Sauvé-Kapandji arthrodesis (e.g., RA) or prosthetic arthroplasty
- Wrist arthroscopy: Gold standard for diagnosis of ulnar-sided wrist pain
  - Most common complication: Injury to superficial sensory nerves

Nail and Fingertip Injuries

- Nail bed injuries: In all cases, tetanus prophylaxis and antibiotic coverage
  - Subungual hematoma less than 50% nail area: Treated without nail plate removal (nail trephination for pain)
  - Subungual hematoma more than 50% nail area: Treated with nail plate

  - removal and matrix repair
  - Repair technique: Digital block, finger tourniquet, nail plate in povidone-iodine, 6-0 suture or cyanoacrylate tissue adhesive (Dermabond) for matrix repair
  - Complications: Nail ridging (crush injury), hook nail (distal matrix advancement), hypersensitivity (resolves in up to 1 year)
- Principles of fingertip injury treatment: Preservation of digit length, maintenance of sensate fingertip pulp, prevention of joint contracture, pain-free use of digit
  - Treatment guided by orientation of amputation, degree of soft tissue loss, and presence or absence of exposed bone.
  - Less than 1 cm^2 exposed bone: Healing by secondary intention
  - Larger wounds without exposed bone: Skin graft
  - Fingertip injury with more than 1 cm^2 exposed bone: Flap for coverage
  - Volar oblique injury: Cross-finger or thenar flap
  - Transverse or dorsal oblique injury: V-Y (digit) or Moberg (thumb) advancement flap to preserve length
    - Alternative: Skeletal shortening and closure at level with available skin
  - Dorsal thumb injury: Kite flap from the index (first dorsal metacarpal artery)
  - Lumbrical-plus finger: Surgical shortening of an injury that acutely violates the FDP insertion
  - FDP tendon retracts, leading to PIP extension through intact lumbrical with active finger flexion.
  - Treated with release of the radial lateral band

Soft Tissue Coverage and Microsurgery

- Reconstruction priorities: Provide coverage of deep structures, provide barrier to bacteria, restore dynamic function of limb, and achieve cosmetic appearance (secondary)
  - Primary closure: Indicated only with minimal contamination and less than 6 hours from injury
  - Healing by second intention (VAC): Used with no exposure of nerves, vessels, tendons, or bone
- Skin grafts: FTSGs are preferred for volar hand and fingertip wounds because they are more durable, contract less, and provide better sensation.
  - STSGs: Dorsal hand wounds
- Flap failure: Caused by inadequate arterial flow, vasospasm, seroma/hematoma
- Primary indications for replantation
  - Level of amputation outside of zone II flexor tendon sheath (less stiffness, pain)

    - Amputation of multiple digits or thumb, proximal amputations, and any injury in a child
- Primary contraindications to replantation
    - Level of amputation within zone II flexor tendon sheath, single digit amputation (especially index, except thumb), segmental, crushed part, prolonged ischemia, multisystem injuries
- Ischemia: Warm (>6 hours if proximal to carpus; >12 hours if distal to carpus); cold (>12 hours if proximal to carpus; >24 hours if distal to carpus)
- Replantation sequence: BEFAVNS (bone, extensor tendon, flexor tendon, artery, vein, nerve, skin)
    - Structure-by-structure technique better than finger-by-finger
- Factor most predictive of digit survival after replantation is mechanism of injury.
    - Failure less than 12 hours due to arterial thrombosis; treated by release of bandages, placement in dependent position, administration of heparin, performance of stellate ganglion block
    - Failure more than 12 hours due to venous thrombosis; treated with leech therapy (and antibiotics effective against *Aeromonas hydrophila*)
- Tenolysis is the most commonly performed secondary procedure following successful replantation
- Forearm replantation: Arterial inflow is established before skeletal stabilization.
- Ring avulsion injury: Forceful avulsion of soft tissues; salvage outcomes often poor
- Thumb reconstruction is performed whenever possible because thumb provides 40% of hand function.

Vascular Disorders

- Allen test is used to determine the presence or absence of a complete arterial arch in the palm.
    - Approximately 20% of hands have an incomplete arch.
    - Ulnar arch mainly supplies superficial palmar arch, and radial artery mainly the deep palmar arch.
- Other tests: Cold stimulation test, digital-brachial index, three-phase bone scan, arteriography
- Hypothenar hammer syndrome: Most common posttraumatic vascular occlusive condition of the upper extremity; involves the ulnar artery in the proximal palm
    - Diagnosis: Noninvasive vascular studies or arteriography
    - Treatment: Resection of the thrombosed segment, interposition vein graft or arterial conduit (better patency rate)
- *Raynaud phenomenon*: Vasospastic disease *with* a known underlying cause
    - Treatment focused on underlying cause
- *Raynaud disease:* Vasospastic disease *without* a known underlying cause

- Treatment: Calcium channel blockers, biofeedback, digital sympathectomy
- Smoking cessation and avoidance of cold exposure for both Raynaud phenomenon and Raynaud disease

- Compartment syndrome: From crush injury, supracondylar humerus fracture (children)
    - 10 hand compartments: thenar, hypothenar, adductor pollicis, four dorsal interosseous, and three volar interosseous (carpal tunnel is not a compartment)
    - Diagnosis: Increased pain with passive stretch of affected compartment is most sensitive indicator.
    - Volkmann ischemic contracture: FDP and FPL muscles are most vulnerable.
    - Claw hand or intrinsic-minus posture
- Frostbite treatment: Initial rapid rewarming, analgesia, local wound management

Compression Neuropathy

- Sequence of sensory losses: Light touch → pressure/vibration → pain/temperature
- Electrodiagnostics: EMG (muscle innervation) or NCS (conduction along nerve)
- Double-crush phenomenon: Blockage of axonal transport at one point makes entire axon more susceptible to compression distally.

Median Nerve

- *Carpal tunnel syndrome*: Idiopathic (adults); due to mucopolysaccharidosis (children)
    - Associated with vibratory exposure at work but not repetitive activities (e.g., keyboarding)
    - Clinical diagnosis: 80% probability of CTS with all six features: symptoms along median nerve–innervated digits, night-time symptoms, thenar atrophy/weakness, positive Tinel test result, positive Phalen test result, loss of two-point discrimination
    - Treatment
    - Corticosteroid injection, which achieves pain relief in ≈80% at 6 weeks but only 20% at 1 year.
    - Carpal tunnel release (CTR): Division of transverse carpal ligament
    - Neurolysis and flexor tenosynovectomy offer no additional benefit.
        - At risk: Recurrent motor branch of median n. (radial) or ulnar n. (ulnar)
    - Endoscopic CTR: Short-term benefits (less scar tenderness, better

satisfaction, earlier return to work) but equivalent long-term results
    - Adults with chronic severe CTS may have incomplete neurologic recovery after surgery.
- *Pronator syndrome:* Compression of the median nerve in the arm/forearm.
    - Sites of compression (SLAPS): Supracondylar process, ligament of Struthers (courses between the supracondylar process and medial epicondyle), lacertus fibrosis FDS aponeurotic arch, two heads of pronator teres
    - Differentiated from carpal tunnel syndrome by presence of proximal forearm pain and paresthesias in the distribution of the palmar cutaneous branch of the median nerve
- *Anterior interosseous nerve syndrome:* Involves motor loss of FPL, index ± long FDPs, PQ
    - Precision sign (ask patient to make "OK" sign)
    - No sensory loss

Ulnar Nerve

- Signs of motor weakness: Froment (thumb IP flexion during key pinch); Jeanne (thumb MCP hyperextension during key pinch), Wartenberg (abduction/extension of small digit during attempted adduction)
- *Cubital tunnel syndrome:* Pain, numbness, weakness
    - Potential sites of compression (AO TEAM): Arcade of Struthers, Osborne ligament, medial head of triceps, anconeus epitrochlearis, aponeurosis of FDS or 2 heads of FCU, medial intermuscular septum
    - No difference between in situ decompression and anterior transposition
    - Better outcome after surgery if performed before motor symptoms appear
- *Ulnar tunnel syndrome* (compression in Guyon canal): Secondary to an extrinsic mass (e.g., ganglion, lipoma, aneurysm)
    - Zone I (mixed motor/sensory), zone II (motor), zone III (sensory)
    - Concurrent CTS: Guyon canal decompressed by release of transverse carpal ligament

Radial Nerve

- Palsy of radial nerve proper (Saturday night palsy) is differentiated from PIN compression by additional weakness of muscles innervated by radial nerve proper (triceps, brachioradialis, ECRL) and sensory disturbances in distribution of SBRN
- *PIN compression syndrome*: Distal muscle weakness
    - Potential sites of compression (LEAFS): Recurrent Leash of Henry, proximal edge of the ECRB tendon, arcade of Frohse (proximal edge of

supinator), fascial band at the radial head, distal edge of supinator

- *Radial tunnel syndrome* is marked by lateral proximal forearm pain (pain several centimeters distal to lateral epicondyle) rather than distal motor weakness of the hand and wrist
    - Sites of compression: Same as in PIN syndrome
    - Outcome of surgical decompression less predictable than for PIN syndrome
- Cheiralgia paresthetica (Wartenberg syndrome): Compressive neuropathy of SBRN
    - Inability to wear wristwatch; pain and paresthesias over dorsoradial hand (SBRN)

Thoracic Outlet Syndrome

- Vascular: Subclavian vein compression
    - Adson test: Patient hyperextends neck and rotates it to affected side; decreased radial pulse during inhalation is positive result.
- Neurogenic: Entrapment of the lower brachial plexus
    - Roos sign: Presence of heaviness in hands after they are held above head for more than 1 minute
    - Nonspecific: Paresthesias, fatigue
    - Pancoast tumor should be ruled out with chest radiograph.
    - Nonoperative management should be maximized, including shoulder and scapular strengthening exercises, injections, activity modification.
    - If present cervical rib should be resected.

Nerve Injuries and Tendon Transfers

- Good prognosis: Stretch injuries, clean wounds, direct surgical repair
- Poor prognosis: Crush injuries, scarring or infection, delayed repair
- Seddon classification divides nerve injury into neurapraxia (stretch), axonotmesis (incomplete), and neurotmesis (complete) (order of increasing severity)
    - Wallerian degeneration for axonotmesis and neurotmesis
- Peripheral nerve repair: Best if procedure is performed early (<14 days), repair is tension-free, and wound bed is clean.
    - No technique deemed superior.
    - Gaps may be addressed with nerve conduit, decellularized nerve allograft, or autograft.
- Brachial plexus injury: Usually observed for 3 months to allow recovery before intervention
    - Preganglionic lesions: Horner syndrome (sympathetic chain), scapular winging (long thoracic, rhomboids), motor deficits with intact sensory

function (cell bodies in dorsal root ganglia)
    - EMG (loss of innervation to paraspinal muscles), chest radiograph (elevated hemidiaphragm)
- Nerve transfers considered for irreparable nerve injuries
    - Advantage is providing shorter innervation distance to end-target muscle.
    - Classic nerve transfers for upper brachial plexus injury
    - Oberlin: Ulnar motor branch to FCU coapted to musculocutaneous nerve (elbow flexion)
    - Leechavengvong: Radial nerve motor branch to triceps coapted to axillary nerve (shoulder abduction)
- Tendon/muscle transfers: Indicated if no meaningful recovery of shoulder/elbow for 6–12 months
    - Priorities: Elbow flexion > shoulder function > finger function
- Basic tenets of tendon transfers
    - Donor must be expendable.
    - Donor must be of similar excursion and power.
    - One transfer should perform one function.
    - Synergistic transfers are easier to rehabilitate.
    - A straight line of pull is optimal.
    - One grade of motor strength will be lost after transfer.
- Tendon transfers for high radial nerve palsy
    - Wrist extension: pronator teres to ECRB
    - Finger extension: FCU or FCR to EDC
    - Thumb extension: PL to EPL
- Tendon transfer (opponensplasty) options for low median nerve palsy
    - FDS of ring, EIP, ADM, and PL all transferred to APB.
- Voluntary muscle control is most important predictor of success in patients with cerebral palsy undergoing surgery to augment upper extremity function.

Arthritis

- Hand OA: Affects joints in following order: DIP, thumb CMC, PIP, MCP
    - MCP more commonly involved in inflammatory arthritis
    - Surgical treatment: DIP joint, arthrodesis; PIP joint index finger, arthrodesis; PIP joint other fingers, arthroplasty; MCP joint, arthroplasty
    - PIP fusion position: index, 40 degrees; long, 45 degrees; ring, 50 degrees; small, 55 degrees
- Thumb CMC joint (basal joint or trapeziometacarpal): From anterior oblique ligament attenuation
    - Nonoperative treatment: Injections, activity modification
    - Surgical treatment: Trapeziectomy with ligament reconstruction and

    - tendon interposition
    - Arthrodesis (young laborers): 20 degrees of radial abduction and 40 degrees of palmar abduction
- Rheumatoid arthritis: Systemic autoimmune disease that often affects the synovium surrounding small joints of the hand and wrist
    - Manifestations: Rheumatoid nodules, tenosynovitis, tendon rupture, ulnar drift at MCP joint, swan neck/ boutonnière deformities, caput ulnae syndrome, carpal subluxation, and SLAC wrist
    - *Vaughan-Jackson syndrome:* Rupture of extensor tendons, starting with EDM and continuing radially, from attrition over a prominent distal ulnar head
    - *Mannerfelt syndrome:* Rupture of FPL and/or index FDP secondary to attrition over a volar STT osteophyte
    - *Caput ulnae syndrome:* DRUJ instability from ECU tendon subluxation
    - *Rheumatoid wrist:* Carpus subluxes in volar and ulnar direction
    - Total wrist arthroplasty versus total wrist arthrodesis for late disease
    - *Z deformity*: Ulnar translocation and radial deviation of wrist, ulnar deviation of digits
    - Common procedures: Synovectomy/tenosynovectomy, tendon transfers, extensor centralization at MCP joints, silicone arthroplasty, and wrist arthrodesis versus wrist arthroplasty

Idiopathic Osteonecrosis of the Carpus

- Kienböck disease (idiopathic osteonecrosis of the lunate): Most common in young men; manifests as atraumatic dorsal wrist pain and decreased grip strength
- Unexplained dorsal wrist pain in a young adult with negative ulnar variance should prompt MRI evaluation.
- Lichtman classification directs treatment.
    - Stage IIIA (lunate collapse with normal carpal alignment and height)
    - Stage IIIB (fixed scaphoid rotation with decreased carpal height and proximal migration of capitate)
    - First-line surgical treatment: Joint-leveling procedure
    - Ulnar-negative variance: Radial shortening osteotomy
    - Supplemental vascularized bone grafting described
    - Stage IIIB: Salvage procedure for associated carpal instability and/or degenerative OA: Partial wrist fusion or PRC
- Preiser disease (idiopathic osteonecrosis of scaphoid)
    - Initial treatment nonoperative; surgical procedures include core decompression, vascularize graft, PRC, and partial wrist fusion

Dupuytren Disease

- Benign fibroproliferative disorder that is sometimes inherited and sometimes sporadic
- Myofibroblasts: Predominant cell type found on histologic analysis of fascia in Dupuytren disease
    - Increase in ratio of type III to type I collagen
- Cleland (dorsal) ligaments are *not* involved; Grayson (volar) ligaments *are* involved.
- PIP contracture: Associated with spiral cord
- Neurovascular bundle at risk during surgery from central and superficial displacement
- Surgical indications: Inability to place hand flat on tabletop (Hueston test), MCP flexion contracture greater than 30 degrees, any PIP flexion contracture
- Open limited fasciectomy is preferred technique.
    - Complications: Recurrence (most common), digital nerve injury, wound breakdown
- Use of collagenase injection or NA is increasing.
    - Pooled study results show average MCP correction up to 85% and PIP correction up to 60%.
    - Pain, swelling, and bruising are likely temporary adverse effects of injection.
    - Skin tears are more common complication than flexor tendon rupture.

HAND Tumors

- Ganglions are the most common soft tissue mass of the hand and wrist
    - Dorsal wrist—scapholunate articulation
    - Volar wrist—radioscaphoid or STT joint
    - IP joint—osteophyte
    - Distal palm—flexor tendon sheath
- Giant cell tumor of tendon sheath, the second most common soft tissue tumor, manifests as a slow-growing firm mass often on the volar aspect of a digit.
    - Treatment is marginal excision, but recurrence rate is relatively high.
- Other soft tissue tumors in the differential diagnosis: epidermal inclusion cyst, lipoma, schwannoma, glomus tumor, hemangioma, pyogenic granuloma
- Box 7.3 lists the most common tumors (and metastases) of the hand and upper extremity.

Hand Infections

- *S. aureus* is the most common pathogen.
    - MRSA more common in urban areas
    - IV treatment with vancomycin or clindamycin; oral treatment with TMP-

SMX or clindamycin

- Gram-negative and anaerobic bacteria: In IVDAs and diabetic patients, and after farmyard injuries or bite wounds
- Paronychia (nail fold): *S. aureus*; I&D, nail plate removal, oral antibiotics
- Felon (fingertip pulp): *S. aureus*; I&D, second intention, oral antibiotics
- Human bites (fight bite): Potentially serious infection treated promptly with I&D, especially if joint or tendon sheath is violated
    - Most commonly isolated organisms are group A streptococci, *S. aureus*, *E. corrodens*, and *Bacteroides* spp.
- Dog bites occur more frequently than cat bites, but cat bites more commonly result in serious infections that require surgical intervention.
    - Antibiotic therapy should cover *P. multocida*, *Staphylococcus*, and *Streptococcus:* ampicillin/sulbactam and amoxicillin/clavulanate.
- Pyogenic flexor tenosynovitis is a suppurative infection of the flexor tendon sheath.
    - Kanavel signs: Flexed resting posture of digit, fusiform swelling of the digit, tenderness of flexor tendon sheath, pain with passive digit extension
    - Early: Hospital admission, splinting, IV antibiotics, close observation
    - If signs improve within first 24 hours, surgery may be avoided.
    - Late: I&D of flexor tendon sheath (open or closed catheter irrigation)
- Deep potential-space infections: Collar-button abscess (digit webspace), midpalmar, thenar or hypothenar infection; all require I&D and antibiotics
- Necrotizing fasciitis: Mortality correlates with time to initiation of treatment.
    - Most commonly β-hemolytic *Streptococcus*
    - Groups at risk: Immunocompromised people, IV drug users, alcoholics
- Gas gangrene: *C. perfringens* and other *Clostridium* spp. (gram-positive rods)
- Herpetic whitlow: Most common in toddlers, dental hygienists, other health care workers; treated nonoperatively
- Atypical mycobacterial infections (e.g., *M. marinum*) commonly involve the hand.
    - Treatment generally requires surgical débridement and oral antibiotics such as ethambutol, trimethoprim-sulfamethoxazole, clarithromycin, azithromycin, or tetracycline.
- High-pressure injection injuries can be devastating
    - Rate of digital amputation high with organic solvent is oil-based paint
    - Treated urgently with I&D.

Congenital Hand Differences

- The three signaling centers that control limb development:
    - The apical ectodermal ridge controls proximal-to-distal growth.
    - The zone of polarizing activity formation controls radial-to-ulnar growth.

- Wingless-type controls dorsal-to-volar growth.
- Radial clubhand
- Associated with systemic syndromes: TAR syndrome, Holt-Oram syndrome, VACTERL syndrome, and Fanconi anemia (life-threatening)
    - Wrist centralization performed if elbow ROM adequate
- Ulnar clubhand: Often associated with digit absence or syndactyly
- Cleft hand: Often bilateral and familial; also involves feet
- Radioulnar synostosis: Associated with duplication of sex chromosomes
- Camptodactyly: Usually small finger PIP flexion deformity
- Clinodactyly: Congenital curvature of digit in radioulnar plane
- Flexed thumb: Due to pediatric trigger finger or congenital clasped thumb
- Arthrogryposis: Congenital curved joints (contractures); neurogenic (90%) or myogenic (10%)
- Duplication can be preaxial (radial) or postaxial (ulnar).
    - Preaxial polydactyly (thumb duplication): Most commonly Wassel type IV with duplicate proximal phalanx.
    - Postaxial polydactyly (small finger duplication): 10 times more common in African Americans than whites.
- Syndactyly: Failure of apoptosis to separate digits
    - Characterized as simple (soft tissue) or complex (bony) and as complete or incomplete
    - Long-ring most common
    - Border digit syndactyly released earlier
    - Web creep is a frequent delayed complication following surgical separation.
    - Poland syndrome (absence of pectoralis major, abnormalities of chest wall) and Apert syndrome (acrosyndactyly, mental retardation) are commonly associated with syndactyly
- Macrodactyly: If single digit, most favorable outcome is associated with amputation.
- Thumb hypoplasia: Treatment based on CMC joint (separates Blauth type IIIA from IIIB); absence of thumb CMC necessitates index pollicization
- Madelung deformity: Disruption of volar ulnar physis of distal radius by tethering of Vickers ligament; treated by release of ligament

Elbow

- Anterior bundle of the medial (ulnar) collateral ligament is the primary restraint to valgus stress.
- LUCL is primary restraint to varus and external rotational stress (posterolateral rotatory instability).
- Lateral epicondylitis (tennis elbow): Degenerative tendinopathy of the ECRB

origin
    - Histologic examination demonstrates angiofibroblastic hyperplasia
    - No clear benefit from corticosteroid injection
    - Operative treatment for select recalcitrant cases in which prolonged conservative management fails (open = arthroscopic in results)
- Medial epicondylitis (golfer's elbow): Pain with resisted pronation and wrist flexion
- Distal biceps tendon rupture: Supination strength diminished more than flexion strength.
    - Diagnosis: Abnormal hook test result
    - Partial ruptures occur primarily on the radial side of the tuberosity footprint, owing to its function as a supinator.
    - Untreated: ≈50% supination and ≈70% flexion strength regained by 1 year.
    - Complete tears with retraction treated expediently.
    - Single-incision technique risks the lateral antebrachial cutaneous nerve and PIN.
    - Two-incision technique risks radioulnar synostosis/HO
    - Biceps muscle belly unlikely to be proximally retracted if lacertus fibrosis (bicipital aponeurosis) remains intact
    - Titanium fixation button (Endobutton) has been shown to have superior fixation strength.
    - Chronic untreated tears may require autograft or allograft reconstruction.
- Distal triceps injury: Elbow extension still intact due to intact anconeus
    - Risks: Anabolic steroids, multiple corticosteroid injections, olecranon bursitis
- Distal humerus fracture
    - Nonoperative treatment only in elderly patients with comorbidities
    - Surgical treatment
    - ORIF: Plate orientation 90-90 or parallel equivalent
    - TEA (semi-constrained): Possibly better for healthy, active elderly patients with severe articular comminution to allow early motion
- Radial head fracture: Mechanical block in forearm rotation should be assessed.
    - Associated injuries: Forearm fracture, Essex-Lopresti (DRUJ injury)
- Olecranon fracture: From direct blow to forearm; tension band for simple fracture, plate ORIF for complex fracture.
- "Terrible triad" injury consists of radial head fracture, coronoid fracture, and elbow dislocation
    - Treatment: ORIF of coronoid process, ORIF or arthroplasty of radial head, and lateral ± medial collateral ligament repair
    - Postoperative immobilization depends on procedure: Pronation if LCL repaired and MCL intact; supination if LCL repaired but MCL deficient;

neutral if MCL and LCL repaired.

- LUCL incompetence results in posterolateral rotatory instability.
- Anteromedial coronoid fracture results in varus posteromedial rotatory instability.
- Incompetence of the MCL leads to valgus instability, especially in overhead-throwing athletes.
    - MCL reconstruction (Tommy John) in elite athletes; about 80% return to sport at same level after at least 1 year of rehabilitation.
    - Chronic MCL incompetence: Valgus overload syndrome leads to posteromedial impinging osteophytes, capitellar wear, loose body formation, and other complications.
- Elbow contracture: Intrinsic (e.g., articular pathology, loose bodies) or extrinsic (e.g., HO, capsular contracture) factors
- Elbow RA: Surgical treatment with semiconstrained TEA in advanced cases resistant to nonoperative management
- Elbow OA: Usually affects middle-aged manual laborers
    - Operative treatment: Arthroscopic or open osteophyte débridement, loose body removal, interposition arthroplasty, TEA
- Indications for total elbow arthroplasty
    - Refractory RA
    - Advanced OA (primary and posttraumatic)
    - Chronic instability
    - Complex distal humerus fractures in elderly patients
- Elbow arthroscopy
    - Indications: Diagnosis of suspected pathology, removal of loose bodies, treatment of OCD, débridement of osteophytes, release of a capsule, synovectomy, assistance for intraarticular fracture fixation, and treatment of lateral epicondylitis
    - Risk: Neurologic injury (0%–14%)

Anatomy

1. Which of the following is not included in the contents of the carpal tunnel?
   A. Flexor pollicis longus tendon
   B. Flexor digitorum superficialis tendons
   C. Flexor digitorum profundus tendons
   D. Median nerve
   E. Flexor carpi radialis tendon
   ANSWER 1: **E**
2. Which of the following extensor mechanism structures links digital DIP and PIP extension?
   A. Sagittal band
   B. Central slip
   C. Oblique retinacular ligament
   D. Transverse retinacular ligament
   E. Lateral band
   ANSWER 2: **C**
3. Clinical findings in a patient with intrinsic tightness would include which of the following?
   A. Increased DIP flexion when MCP joints are held in extension
   B. Increased PIP flexion when MCP joints are held in extension
   C. Decreased PIP flexion when MCP joints are held in extension
   D. Decreased DIP flexion when PIP joints are held in flexion
   E. Increased MCP flexion when the wrist is held in extension
   ANSWER 3: **C**

Distal Radius Fractures

4. A 35-year-old man sustains a comminuted distal radius fracture. A closed reduction is performed, and his arm is placed in a splint. Before leaving the emergency department, he complains of severe pain and paresthesias in the ipsilateral hand and digits that is uncontrolled by pain medication. What is

the most appropriate next step in treatment?

A. Immediately remove the splint and admit him for observation overnight.

B. Loosen the splint and ask him to return to the clinic in 2 days for a repeat clinical examination.

C. Keep the splint in place and discharge him to home with instructions to elevate and ice his upper extremity.

D. Take him to the operating room for an emergent carpal tunnel release.

E. Increase his pain medication regimen.

ANSWER 4: **D**

5. A woman sustains a distal radius fracture while skiing. After evaluation and closed reduction, the orthopedist decides to proceed with nonoperative management. After a period of immobilization, what should the patient be advised regarding therapy for her wrist?

A. To return to her preinjury functional status, she must begin therapy immediately.

B. She may perform home exercises on her own, because these are shown to be more beneficial than formal therapy.

C. There is no need for her to perform therapy or home exercises, because neither modality has any proven benefit in regaining wrist motion after injury.

D. There is no functional difference in outcome between home exercises and formal therapy.

E. A trial of formal therapy followed by home exercises has been proven to be superior to home exercises alone.

ANSWER 5: **D**

6. What is the tendon most commonly ruptured after fixation of a distal radius fracture with a volar locked plate?

A. Extensor pollicis longus

B. Extensor carpi radialis brevis

C. Flexor carpi radialis

D. Flexor pollicis longus

E. Brachioradialis

ANSWER 6: **D**

Carpal Fractures and Instability

7. What is the most common mechanism of injury for fractures of the scaphoid?

A. Forced wrist hyperextension and radial deviation

B. Forced wrist flexion and radial deviation

C. Forced wrist hyperextension and ulnar deviation

D. Axial load on a flexed wrist

E. Isolated forced radial deviation

ANSWER 7: **A**

8. Which of the following has the highest sensitivity in detecting an occult scaphoid fracture?

A. Physical examination

B. Computed tomography

C. Clenched-fist radiographs obtained 4 weeks apart

D. Bone scan

E. Magnetic resonance imaging

ANSWER 8: **E**

9. Why is the volar approach commonly used for fixation of scaphoid fractures?

A. The volar approach is technically easier for most surgeons.

B. Compared with a dorsal approach, the cosmetic deformity is better with the volar approach.

C. Patients have less postoperative wrist pain.

D. The volar approach potentially avoids vascular disruption to the scaphoid.

ANSWER 9: **D**

10. A collegiate field hockey player presents to your clinic with persistent pain over the ulnar side of his palm after an injury during a recent game. In addition to standard radiographs of his hand and wrist, which view(s) should be requested to evaluate a potential cause of his pain?

A. Clenched-fist view

B. Carpal tunnel view

C. Dynamic views of radial and ulnar deviations of the wrist

D. Pronated wrist view

E. Single digital view of the small finger

ANSWER 10: **B**

11. What approximate percentage of perilunate dislocations are missed during initial emergency department evaluations?

A. 10%

B. 25%

C. 50%

D. 100%

E. 0%

ANSWER 11: **B**

Metacarpal and Phalangeal Injuries

12. Which of the following best describes the "intrinsic-plus" position of the hand?

A. Wrist in neutral, MCP joints in flexion, IP joints in flexion

B. Wrist in flexion, MCP joints in extension, IP joints in flexion

C. Wrist in extension, MCP joints in extension, IP joints in flexion

D. Wrist in extension, MCP joints in flexion, IP joints in neutral

E. Wrist in flexion, MCP joints in flexion, IP joints in neutral

ANSWER 12: **D**

13. After injury to the thumb MCP joint ulnar collateral ligament, what is the significance of a Stener lesion?

A. Represents a bony avulsion that will likely necessitate pin fixation for stability

B. Represents displacement of the torn ulnar collateral ligament superficial to the adductor aponeurosis, which can prevent proper healing of the ligament back to the insertion site and will likely necessitate surgical intervention

C. Represents an area of a chronic nonunion that will likely necessitate open reduction and screw fixation

D. Represents an incidental radiographic finding that has no clinical relevance

E. Represents avulsion of the radial collateral ligament and indicates a grossly unstable thumb MCP joint

ANSWER 13: **B**

14. A 22-year-old football players sustains a Bennett fracture at the base of his thumb. Which muscle provides the predominant deforming force?

A. Abductor pollicis longus

B. Opponens pollicis longus

C. Extensor digitorum communis

D. Abductor pollicis brevis

E. Adductor pollicis

ANSWER 14: **A**

Tendon Injuries and Overuse Syndromes

15. Simultaneous core and epitendinous suture repair within 7–10 days of injury is the standard of care for flexor tendon lacerations at least greater than what percentage of the tendon width?

A. 5%

B. 25%

C. 30%

D. 50%

E. 75%

ANSWER 15: **D**

16. Which of the following is not a proven advantage of early, protected ROM following flexor tendon repair?

A. Increased tendon excursion

B. Decreased formation of adhesions

C. Increased repair strength

D. Decreased postoperative stiffness

E. Decreased postoperative pain

ANSWER 16: **E**

17. In the treatment of de Quervain syndrome, nonoperative modalities including corticosteroid injections have been found to be useful in greater than what percentage of patients?

A. 50%

B. 25%

C. 10%

D. 80%

E. 95%

ANSWER 17: **D**

Distal Radioulnar Joint, Triangular Fibrocartilage Complex, and Wrist Arthroscopy

18. Components of the triangular fibrocartilage complex include all except which of the following?

A. Dorsal radioulnar ligaments

B. Extensor carpi ulnaris subsheath

C. Volar radioulnar ligaments

D. An articular disc

E. Extensor digitorum minimi subsheath

ANSWER 18: **E**

19. What is the preferred surgical procedure for ulnocarpal impaction syndrome caused by abutment of the ulnar head into the proximal carpal row?

A. Wrist arthroscopy with débridement of the triangular fibrocartilage complex

B. Ulnar-shortening osteotomy

C. Distal ulnar hemiresection or interposition arthroplasty

D. Radial shortening osteotomy

E. Wrist arthrodesis

ANSWER 19: **B**

20. What is the most common complication following wrist arthroscopy?

A. Infection

B. Iatrogenic cartilage injury

C. Chronic wrist swelling

D. Injury to the posterior interosseous nerve

E. Injury to superficial sensory nerves

ANSWER 20: **E**

Nail and Fingertip Injuries

21. A 30-year-old man sustains a complete amputation of the pulp of his index finger, without evidence of bone involvement or fracture. What is the most appropriate surgical treatment option for this patient?

A. Cross-finger flap

B. Volar V-Y flap

C. Full-thickness skin grafting

D. Reattachment of the pulp tissue

E. DIP joint disarticulation and primary closure of remaining tissue

ANSWER 21: **A**

22. For which of the following clinical situations would a Moberg advancement flap be a viable option?

A. Complete transverse fingertip amputation of the index finger

B. Transverse or volar oblique fingertip amputation of the thumb

C. Dorsal skin loss of the thumb just proximal to the IP joint

D. Dorsal oblique soft tissue loss of the long finger

E. Complete amputation of the thumb at the MCP joint

ANSWER 22: **B**

Soft Tissue Coverage and Microsurgery

23. In comparison with split-thickness skin grafts, full-thickness skin grafts provide all of the advantages except which of the following?

A. Improved durability

B. Decreased contraction

C. Improved sensibility

D. Improved availability of grafts

E. Improved cosmesis

ANSWER 23: **D**

24. Which of the following is not a relative contraindication to digital replantation?

A. Single-digit amputation

B. Level of amputation within zone II flexor tendon sheath

C. Segmental amputations

D. Multiple-digit amputations

E. Prolonged warm ischemia beyond 12 hours

ANSWER 24: **D**

25. A construction worker sustains traumatic amputations to the thumb and index finger of his dominant hand while using a table saw. Replantation is performed. What is the most common cause of early (within 12 hours) failure of the replanted digits?

A. Arterial thrombosis

B. Venous congestion

C. Infection

D. Irreversible nerve damage

E. Skin necrosis

ANSWER 25: **A**

26. Which of the following is the most predictive factor of digit survival following replantation?

A. Age of patient

B. Mechanism of injury

C. Level of amputation

D. Number of digits amputated

E. Choice of perioperative antibiotics

ANSWER 26: **B**

Vascular Disorders

27. Excluding the carpal tunnel, how many compartments can be found within the hand?

A. 4

B. 6

C. 8

D. 10

E. 12

ANSWER 27: **D**

28. Volkmann ischemic contracture is a classic complication of untreated acute compartment syndrome in the forearm. Which are the most likely to be affected affected in this phenomenon?

A. Flexor digitorum superficialis and palmaris longus

B. Flexor carpi ulnaris and flexor digitorum superficialis

C. Flexor pollicis longus and flexor digitorum profundus

D. Flexor pollicis longus and flexor digitorum superficialis

E. Flexor digitorum profundus and flexor digitorum superficialis

ANSWER 28: **C**

29. What is the major distinction between Raynaud phenomenon and Raynaud disease?

A. The presence or absence of a known underlying cause

B. The age of onset of vasospastic symptoms

C. Variations in success rates of treatment modalities

D. The necessity of smoking cessation for symptom management

E. Variations in gender predilection

ANSWER 29: **E**

Compression Neuropathy

30. What is the most common cause of carpal tunnel syndrome in children?

A. Juvenile diabetes

B. Metabolic abnormality in lysosome storage

C. Anatomic structural variant with persistent median artery

D. Double-crush phenomenon from congenital spinal stenosis

E. Obesity

ANSWER 30: **B**

31. Which of the following muscles is not innervated by the posterior interosseous nerve?

A. Extensor indicis proprius

B. Extensor carpi ulnaris

C. Extensor digitorum minimi

D. Extensor digitorum communis

E. Extensor carpi radialis longus

ANSWER 31: **E**

32. Cheiralgia paresthetica occurs secondary to a compressive neuropathy of which of the following structures?

A. Median nerve

B. Ulnar nerve at Guyon canal

C. Superficial sensory branch of the radial nerve

D. Anterior interosseous nerve

E. Posterior interosseous nerve

ANSWER 32: **C**

Nerve Injuries and Tendon Transfers

33. The brachial plexus can be found exiting between which two muscles?

A. Scalenus medius and levator scapulae

B. Scalenus medius and scalenus posterior

C. Scalenus anterior and scalenus medius

D. Teres major and teres minor

E. Serratus anterior and scalenus posterior

ANSWER 33: **C**

34. A 15-year-old boy is involved in a traumatic motor vehicle crash and is noted to have severe right upper extremity weakness suggestive of a brachial plexus injury. On physical examination, he is found to have miosis, ptosis, and anhidrosis of the right eye. These findings suggest all but which of the following?

A. Preganglionic level of plexus injury

B. Injury to the T1 nerve root

C. Postganglionic level of plexus injury

D. Guarded prognosis for recovery

E. Lower trunk plexus injury

ANSWER 34: **C**

Arthritis

35. Which of the following pharmacologic agents used in the treatment of rheumatoid arthritis antagonizes the TNF-α pathway?

A. Doxycycline

B. Anakinra

C. Rituximab

D. Etanercept

E. Hydroxychloroquine

ANSWER 35: **E**

36. In rheumatoid arthritis, attrition of which tendon over a volar scaphoid osteophyte can lead to rupture, otherwise known as Mannerfelt syndrome?

A. Flexor pollicis longus

B. Flexor digitorum profundus to the long finger

C. Flexor digitorum superficialis to the index finger

D. More than one of the above

ANSWER 36: **D**

37. A 65-year-old man presents to the office with chronic digital joint pain for which he takes oral medication. Physical examination demonstrates areas of tophi nodules, and radiographs reveal changes indicating periarticular erosions. An aspiration of a symptomatic joint in this patient would likely reveal which of the following?

A. Gram-positive cocci in clusters

B. Gram-positive cocci in chains

C. Negatively birefringent monosodium urate crystals

D. Positively birefringent calcium pyrophosphate dehydrate crystals

E. Normal joint fluid

ANSWER 37: **C**

Idiopathic Osteonecrosis of the Carpus

38. What is the first line of treatment for patients diagnosed with early-stage Kienböck disease?

A. Core decompression

B. Allograft replacement

C. Cast immobilization

D. Vascularized bone grafting

E. Scaphoid excision and four-corner fusion

ANSWER 38: **C**

39. A 19-year-old gymnast presents with persistent dorsal wrist pain and radiographic evidence of ulnar-negative variance. Magnetic resonance imaging confirms a diagnosis of stage IIIA Kienböck disease, and the decision is made to proceed with a joint-leveling procedure. What is the preferred surgical intervention in this scenario?

A. Radial shortening osteotomy

B. Ulnar lengthening with bone grafting

C. Distal radial ulnar joint arthrodesis

D. Core decompression of the radius and ulna

E. Proximal row carpectomy

ANSWER 39: **E**

Dupuytren Disease

40. Dupuytren disease has *not* been associated with which of the following?

A. Tobacco use

B. Epilepsy

C. Chronic pulmonary disease

D. Human immunodeficiency virus

E. Occupation

ANSWER 40: **E**

41. What is the predominant cell type found histologically in contracted Dupuytren fascia?

A. Neutrophil

B. Myofibroblast

C. Fibroblast

D. Chondrocyte

E. Osteoblast

ANSWER 41: **B**

42. What is the most common complication after partial palmar fasciectomy?

A. Infection

B. Complex regional pain syndrome (CRPS)

C. Hematoma formation

D. Recurrence

E. Digital neurovascular injury

ANSWER 42: **D**

Hand Tumors

43. What is the second most common soft tissue tumor of the hand?

A. Ganglion cyst

B. Mucous cyst

C. Giant cell tumor of tendon sheath

D. Schwannoma

E. Epidermal inclusion cyst

ANSWER 43: **C**

44. A 40-year-old woman presents to the office with the insidious onset of wrist pain and swelling over a period of 2 months. Imaging reveals an eccentric lytic lesion in the metaphysis and epiphysis of the distal radius, which is consistent with a benign aggressive pathology. Biopsy is performed that demonstrates numerous osteoclast-like multinucleated giant cells. What are the likely diagnosis and preferred treatment for this lesion?

A. Squamous cell carcinoma—amputation above level of the wrist

B. Giant cell tumor—wide excision with curettage and bone grafting

C. Unicameral bone cyst—observation with repeat radiographs in 2 months

D. Lung cancer metastasis—wide excision with curettage and bone grafting

E. Enchondroma—observation with repeat radiographs in 2 months

ANSWER 44: **B**

45. What is the most common sarcoma of the hand?

A. Chondrosarcoma

B. Epithelioid sarcoma

C. Osteosarcoma

D. Liposarcoma

E. Malignant fibrous histiocytoma

ANSWER 45: **B**

Hand Infections

46. What is the most common organism isolated in cases of chronic paronychia infections?

A. *Staphylococcus aureus*

B. *Candida albicans*

C. *Eikenella corrodens*

D. *Streptococcus spp.*

E. *Pasteurella multocida*

ANSWER 46: **B**

47. All of the following are classic signs of septic flexor tenosynovitis except:

A. Flexed resting posture of digit

B. Fusiform swelling of digit

C. Pain with passive digit flexion

D. Tenderness of flexor tendon sheath

E. Pain with passive digit extension

ANSWER 47: **C**

48. Mortality following the onset of necrotizing fasciitis has been clearly correlated with:

A. Age of patient

B. Virulence of the causative organism

C. Time from presentation to initiation of treatment

D. Immune system status

E. Proximity of involved area to the chest wall

ANSWER 48: **C**

Congenital Hand Differences

49. Madelung deformity has been hypothesized to be linked to a genetic disorder that demonstrates which pattern of inheritance?

A. Autosomal recessive

B. X-linked dominant

C. Autosomal dominant

D. X-linked recessive

E. Sporadic mutation

ANSWER 49: **B**

50. What is the most common congenital hand difference?

A. Camptodactyly

B. Thumb hypoplasia

C. Postaxial polydactyly

D. Clinodactyly

E. Syndactyly

ANSWER 50: **E**

51. An 8-month-old girl is presented to the office with bilateral type III radial dysplasia. The parents want to explore possible surgical options that could correct the deformity. Which of the following is a strong contraindication to centralization of the carpus on the distal ulna?

A. Inadequate elbow ROM

B. Associated VACTERL syndrome

C. Small stature

D. Absence of the thumb

E. Decreased wrist ROM

ANSWER 51: **A**

Elbow

52. Which of the following structures is the primary restraint to valgus stress within functional elbow ROM?

A. Transverse bundle of the medial (ulnar) collateral ligament

B. Radial head

C. Lateral ulnar collateral ligament

D. Ulnohumeral articulation

E. Anterior bundle of the medial (ulnar) collateral ligament

ANSWER 52: **E**

53. What is the structure most commonly implicated in lateral epicondylitis?

A. Lateral ulnar collateral ligament

B. Extensor carpi radialis longus

C. Origin of brachioradialis

D. Extensor digitorum communis

E. Extensor carpi radialis brevis

ANSWER 53: **E**

54. What nerve is at most risk during a single-incision approach to repair of a distal biceps tendon rupture?

A. Lateral antebrachial cutaneous nerve

B. Medial antebrachial cutaneous nerve

C. Anterior interosseous nerve

D. Median nerve

E. Radial nerve

ANSWER 54: **A**

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CHAPTER 8

Spine

Francis H. Shen, and Adam Shimer

Introduction

- **History (** Table 8.1)
    - Localized pain (tumor, infection), especially pain radiating to the extremity (radicular symptoms)
    - Mechanical pain (instability, discogenic disease)
    - Radicular pain (herniated nucleus pulposus [HNP], stenosis), night pain (tumor)
    - Systemic symptoms such as fever and unexplained weight loss (infection, tumor)
    - History of an acute injury or precipitating event should be investigated (trauma).
    - Complete review of symptoms (including psychiatric history)

- The finding of an "inverted V" triad of hysteria, hypochondriasis, and depression on the Minnesota Multiphasic Personality Inventory has been identified as a significant adverse risk factor for lumbar disc surgery.
- Psychosocial evaluation, pain drawings, and psychological testing are helpful in some cases.

□ Social history

- Occupational risks: jobs requiring prolonged sitting and repetitive lifting
- Smoking may increase disc degeneration.

□ Physical examination (Fig. 8.1; Tables 8.2 and 8.3)

□ Observation for muscle atrophy (rare), postural changes, gait, hair distribution, and so forth.

□ Palpation of posterior spine (spasm, localized tenderness)

□ Motor examination, motor grading (Table 8.4)

□ Sensory examination

□ Reflexes

□ Rectal examination

- Motor: rectal tone and volitional contraction
- Sensory: perianal sensation
- **Reflex: presence or absence of bulbocavernosus reflex (BCR)**
  - **Test for presence of spinal shock** is performed by monitoring for anal sphincter contraction in response to squeezing the glans penis or clitoris or by tugging on an indwelling Foley catheter.
  - Presence of anal sphincter contraction is a normal or present BCR, whereas absence of anal sphincter contraction in the 24- to 48-hour period after a spinal cord injury is abnormal and implies the presence of spinal shock.

Table 8.1

Examination of Patients With Disorders of the Spine

Component	Features
Inspection	Overall alignment in sagittal and coronal planes (sciatic scoliosis)
Gait	Wide-based (myelopathy), forward-leaning (stenosis), antalgic
Palpation	Localized posterior swelling (trauma), acute gibbus deformity, tenderness
Range of motion	Flexion/extension, lateral bend, full versus limited
Neurologic function	Motor, sensory, reflexes, assessment of long-tract signs (see Table 8.3)
Special tests	Straight-leg raise, Spurling test, Waddell signs of inorganic pathology

- Assessment of surrounding joints and associated neurovascular structures.
  - Localized hip and shoulder pathology may simulate spine disease and must also be evaluated.
  - Vascular evaluation (distal pulses)
  - Abdominal (bruits and pulsatile masses) and rectal examinations

- **Imaging**
  - Plain radiographs
    - Should be obtained 4–6 weeks after onset of symptoms
    - “Red flag” symptoms warrant immediate radiographs.
    - **Upright x-rays may simulate spinal alignment and identify subtle instability better than supine films and should be obtained whenever possible.**
    - **Upright flexion-extension radiographs for suspected instability**
    - Standing upright 36-inch scoliosis films can help provide assessment of sagittal and coronal alignment.
    - Low specificity of plain radiographic findings. By age 65, 95% of men and 70% of women have degenerative changes.
  - MRI
    - Excellent for further imaging of HNP, stenosis, soft tissue, tumor, and infection (Fig. 8.2)

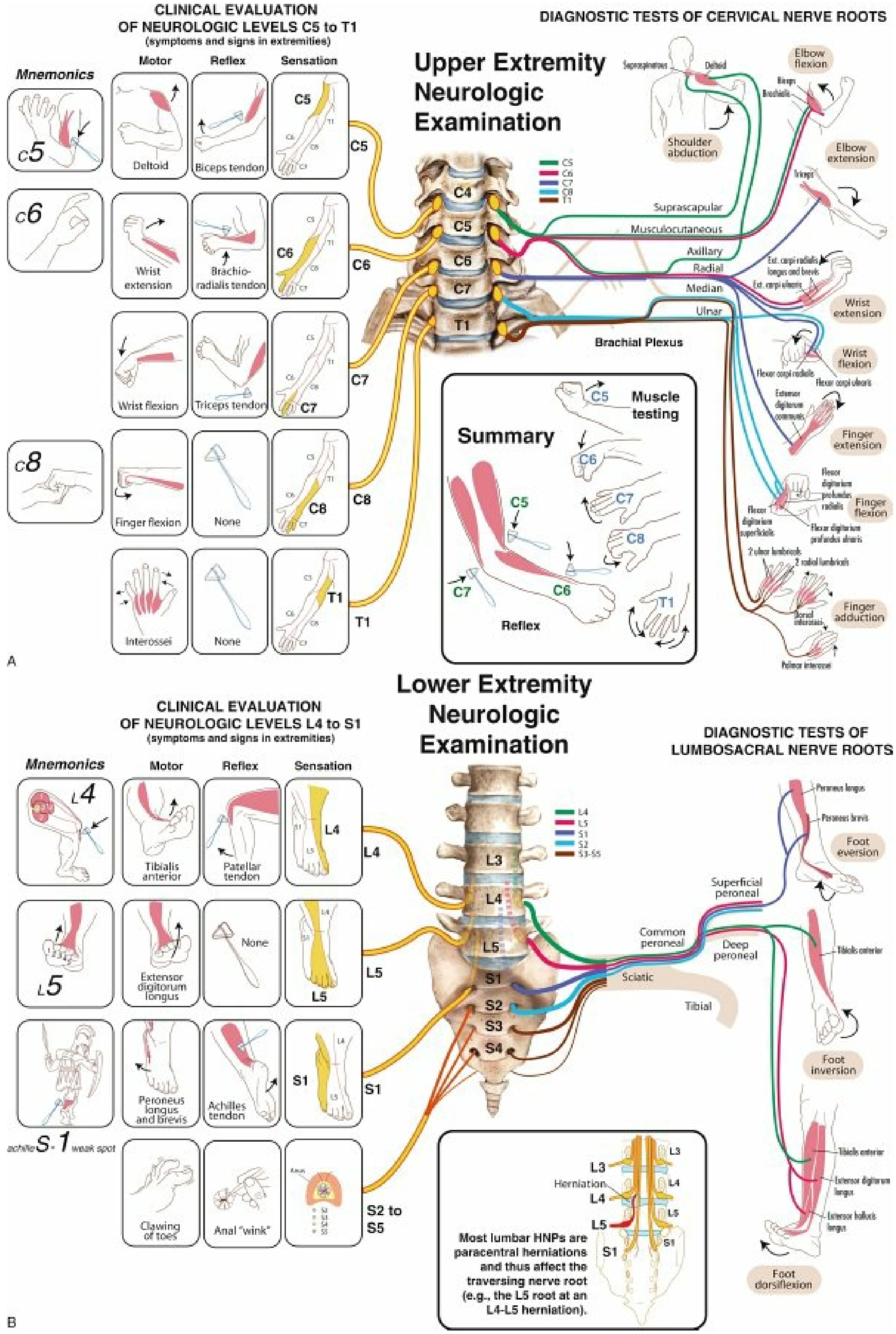

FIG. 8.1 Neurologic examination of the upper and lower extremities.

Table 8.2

Findings in Cervical Nerve Root Compression

Level	Root	Muscles Affected	Sensory Loss	Reflex
C3–4	C4	Scapular	Lateral neck, shoulder	None
C4–5	C5	Deltoid, biceps	Lateral arm	Biceps
C5–6 [a]	C6	Wrist extensors, biceps, triceps (supination)	Radial forearm, thumb, index finger	Brachioradialis
C6–7	C7	Triceps, wrist flexors (pronation)	Middle finger	Triceps
C7–T1	C8	Finger flexors, interossei	Ulnar hand, ring, and small finger	None
T1–2	T1	Interossei	Ulnar forearm	None

[a] Most common level.

Table 8.3

Findings in Lumbar Nerve Root Compression

Level	Nerve Root	Sensory Loss	Motor Loss	Reflex Loss
L1–3	L2, L3	Anterior thigh	Hip flexors	None
L3–4	L4	Medial calf	Quadriceps, tibialis anterior	Knee jerk
L4–5	L5	Lateral calf, dorsal foot	EDL, EHL	None
L5–S1	S1	Posterior calf, plantar foot	Gastrocnemius/soleus	Ankle jerk
S2–4	S2, S3, S4	Perianal	Bowel/bladder	Cremasteric

EDL, Extensor digitorum longus; *EHL*, extensor hallucis longus.

Table 8.4

Motor Grading

Grade	Description
0	No movement, no contractions
1	Flicker; contraction without movement
2	Movement with gravity removed
3	Movement against gravity
4	Movement against gravity and against some resistance
5	Full motor strength against resistance

- MRI with gadolinium enhancement is the best study for a recurrent HNP, infection, and spinal tumors
- **False-positive MRI results are common**
  - On cervical MRI, 25% of asymptomatic patients older than age 40 have findings of either HNP or foraminal stenosis.
  - **Correlation with history and physical examination is critical.**
- MRI is also useful for detecting intrinsic changes in the spinal cord and disc degeneration.
  - Differential diagnosis for high-intensity signal on T2-weighted imaging includes spinal cord edema, myelomalacia (Fig. 8.3), syrinx, enlarged central canal, demyelinating disease, transverse myelitis, and spinal cord infarct.

□ CT using fine cuts with or without myelographic dye is used to examine bony anatomy after previous surgery and to determine the quality of fusion. Because CT myelograms can be reformatted in multiple planes they can also be helpful in patients with sagittal or coronal plane deformity to better define the areas of stenosis.

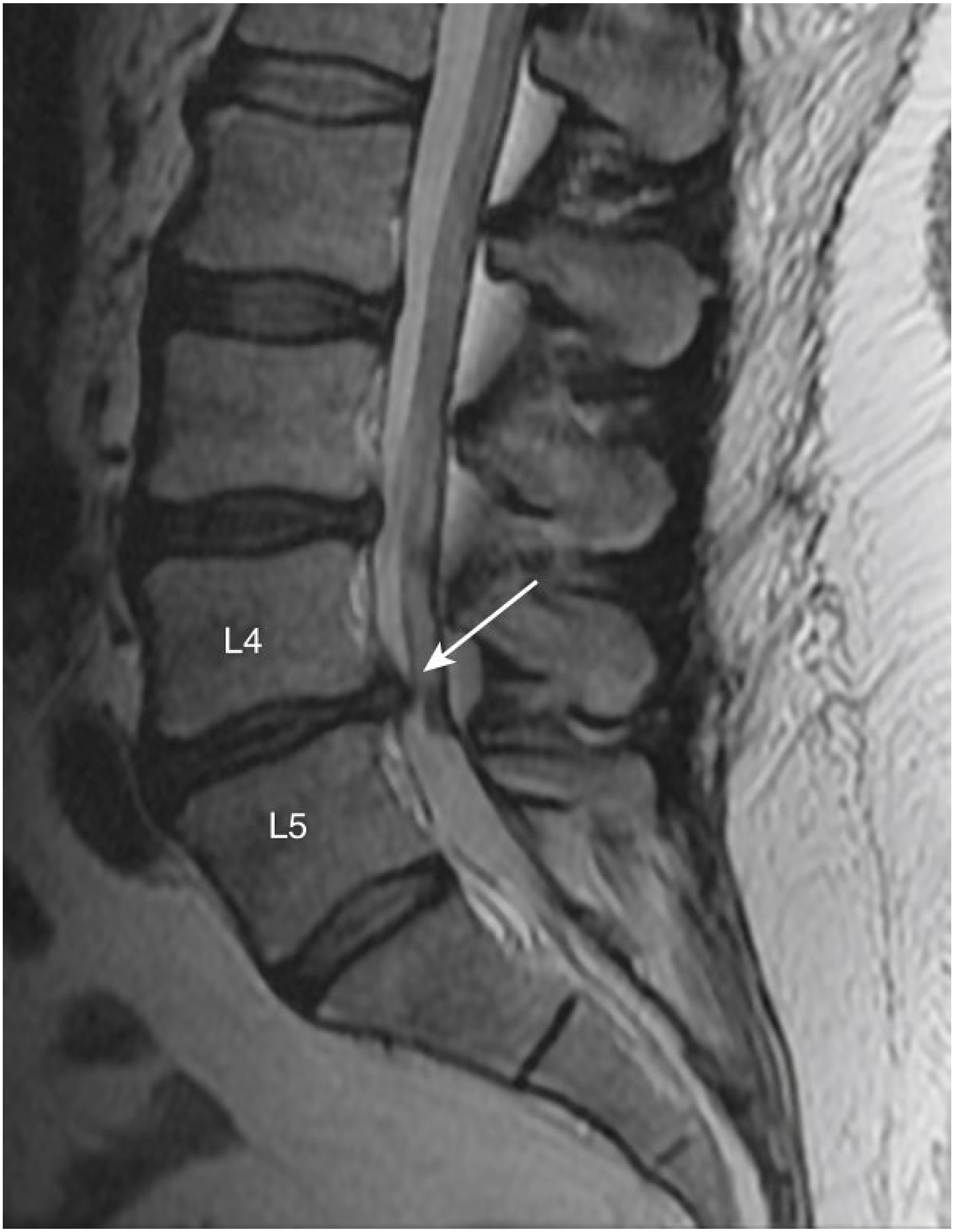

FIG. 8.2 Sagittal T2-weighted lumbar MR image demonstrating herniated disc *(arrow)* at L4–5.

- Bone scanning is helpful in evaluating metastatic disease and may be negative with multiple myeloma.
- **Laboratory evaluation**
  - CRP and erythrocyte sedimentation rate (ESR) for infection
  - Metabolic screening, serum/urine protein electrophoresis for myeloma
  - Complete blood cell count (often a high-normal WBC count with infection or anemia with myeloma).
- **EMG and nerve conduction studies (NCSs)**

- Frequently performed together as EMG/NCS
  - EMG can help assess for diseases that damage muscle tissue, nerves, or the junction between the two; measures electrical activity of muscles at rest and during contraction.
  - NCS helps identify injury to peripheral nervous system; measures how well and how fast nerves can send electrical signals
- Can be useful for differentiating peripheral nerve compression from radiculopathy and for detecting systemic neurologic disorders such as amyotrophic lateral sclerosis.
- Evaluation of spine for presence of nerve root pathology should include evaluation of paraspinous muscles.
- Have a high false-negative rate; therefore correlation of results with history, clinical examination, and imaging important

- **Differential diagnosis—physical examination, imaging studies, and laboratory tests assist with differential diagnosis (** Table 8.5).

Cervical Spine

- **Cervical degenerative disc disease (also known as cervical spondylosis)—chronic disc degeneration and associated facet arthropathy that can result in four clinical entities**
  - Discogenic neck pain (axial pain)
  - Radiculopathy (root compromise)

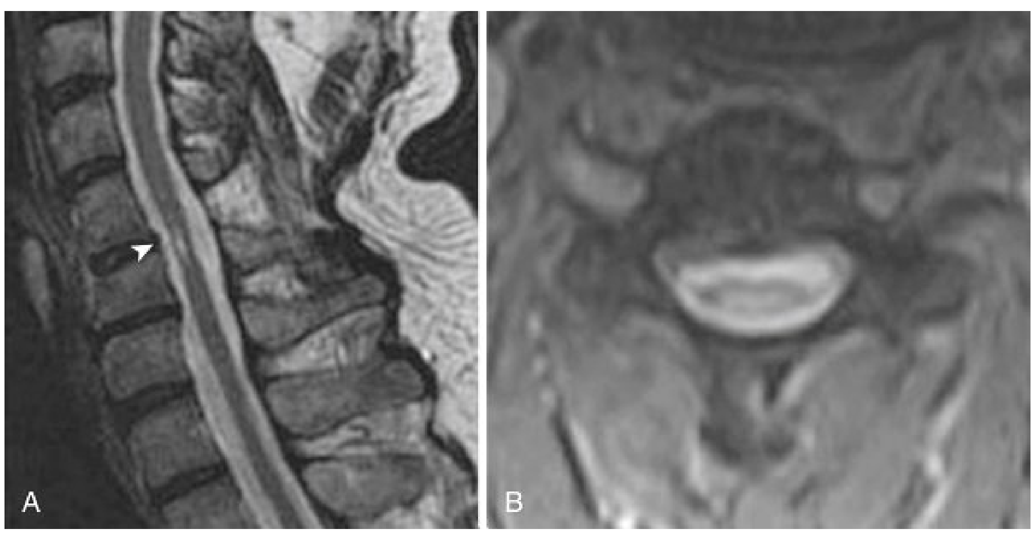

FIG. 8.3 Myelomalacia. Sagittal (A) and axial (B) T2-weighted cervical MR images months after a spinal cord contusion. Notice there is focal thinning and volume loss of the spinal cord and a central small myelomalacic area in the spinal cord, displaying well-defined high T2 cerebrospinal fluid–like signal *(arrowhead).*

From Cianfoni A, Colosimo C: Imaging of spine trauma. In Law M et al, editors: *Problem solving in neuroradiology,* Philadelphia, 2011, Elsevier, p 494.

Table 8.5

Differential Diagnosis in Disorders of the Spine;

Parameter	Disorder			
	HNP	Spinal Stenosis	Spondylolisthesis/Instability	Tum
Predominant pain (leg vs. back)	Leg	Leg	Back	Back
Constitutional symptoms				+
Tension sign	+			
Neurologic findings		+	+ After stress	
Plain radiographic findings		+	+	±
Lateral motion radiographic findings				+
CT findings	+	+		+
Myelogram findings	+	+		
Bone scan findings				+
ESR elevation				+
Calcium/phosphorus/alkaline phosphatase elevations				+

+, Present; ±, present or absent.

Modified from Weinstein JN, Wiesel SW: *The lumbar spine,* Philadelphia, 1990, Saunders, 1990, p 360.

- Myelopathy (cord compression)
- Myeoloradiculopathy (combinations of spinal cord and root compromise)

▪ **Epidemiology**
- Peaks between age 40 and 50 years
- Men affected more than women
- C5–6 level most frequently involved, followed by C6–7
- Risk factors
  - Frequent lifting
  - Cigarette smoking
  - History of excessive driving

▪ **Pathoanatomy**
- Degenerative spinal cascade
  - First described in 1970s by Kirkaldy-Willis; emphasis on interdependence of intervertebral disc and two facet joints in the thoracolumbar spine

    - In cervical spine, is the result of interplay of intervertebral disc and four other articulations (Fig. 8.4)
        - Two uncovertebral joints (of Luschka)
        - Two facet joints—facet joint capsules known to have sensory receptors that may play a role in pain and proprioceptive sensation in cervical spine
    - Progressive collapse of cervical discs, resulting in loss of normal lordosis of cervical spine and chronic anterior cord compression across the kyphotic spine/anterior chondroosseous/discoosteophytic spurs
    - Subsequent loading of facet and uncovertebral joint, resulting in spondylotic changes in foramina that may restrict motion and lead to spinal cord and/or nerve root compression
- Clinical relevance
    - "Soft" disc herniation
        - Nonspecific terminology often used to describe herniation of nucleus pulposus of intervertebral disc without bony osteophytes
        - Usually posterolateral, between the posterior edge of the uncinate process and the lateral edge of the posterior longitudinal ligament, it may result in acute radiculopathy.

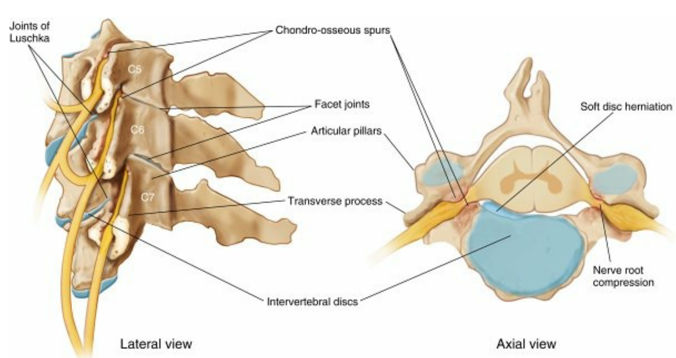

FIG. 8.4 Cervical root impingement due to cervical spondylosis.

        - Anterior herniation may cause dysphagia (rare).

        - Myelopathy may be seen with large central herniation or spondylotic bars with a congenitally narrow canal.
    - "Hard" disc herniation
        - Nonspecific terminology often used to describe HNP with associated discoosteophytic spur
        - Can result in symptomatology similar to that of soft disc herniation, including spinal cord and/or nerve root compression; rarely dysphagia with anterior osteophytes
- Cord compromise as canal diameter decreases
    - Congenital versus acquired (traumatic, degenerative)
    - **Diameter measured on plain lateral radiograph from posterior aspect of vertebral body to spinolaminar line (Fig. 8.5); diameter less than 14 mm is cause for concern.**
    - Normal 14 mm or greater
    - Relative stenosis: less than 14 mm (10–13 mm)
    - Absolute stenosis: less than 10 mm
    - Pavlov (Torg) ratio (canal/vertebral body width)
        - Clinical significance debated
        - Normal ratio should be 1.0.
        - Ratio less than 0.8 considered abnormal and may be a risk factor for later neurologic involvement (debated).
    - Dynamic compression
        - Neck extension—cord is compressed between degenerative disc and spondylotic bar anteriorly and the hypertrophic facets and infolded ligamentum flavum posteriorly.
        - Neck flexion results in slight increase in canal diameter and relief of cord compression.

▪ **Discogenic neck pain**
- □ Secondary to intervertebral disc degeneration without other pathologic entities, such as spinal instability, fractures, dislocations, and neural compression
- □ Symptoms

- May manifest as insidious onset of neck pain without neurologic signs or symptoms, exacerbated by excess vertebral motion

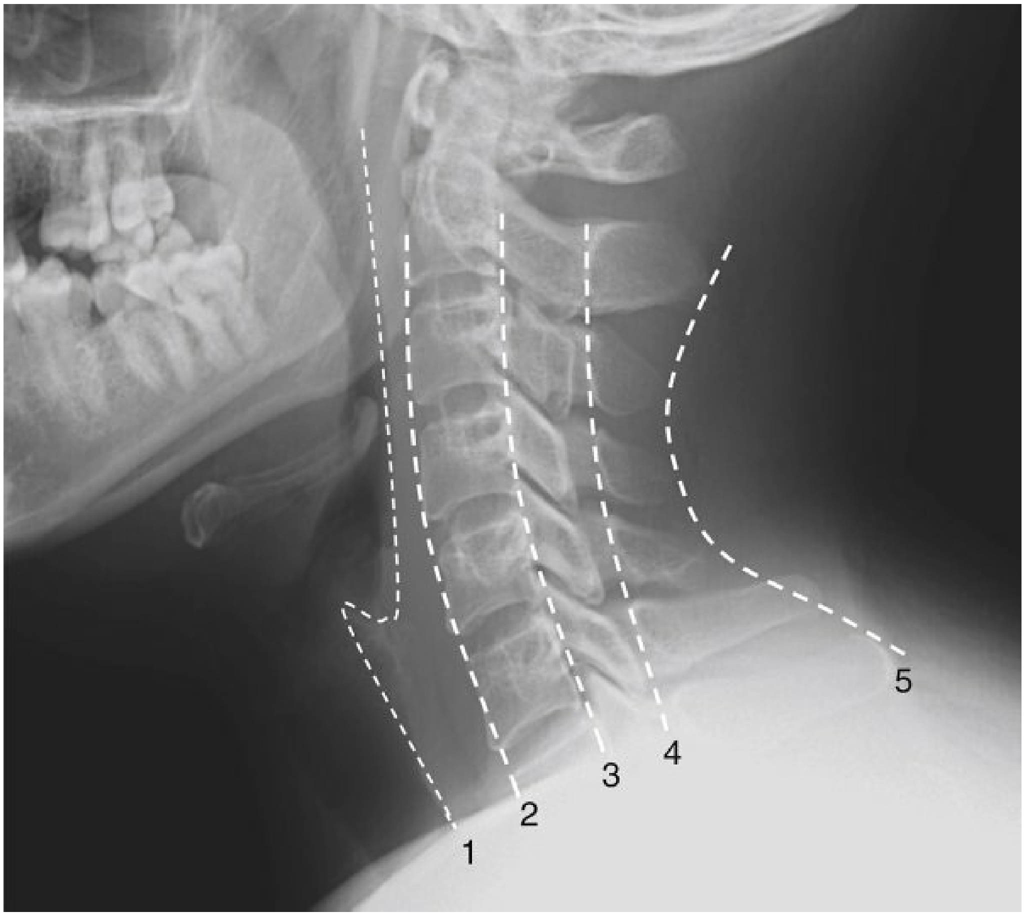

FIG. 8.5 Five vertebral lines of the lateral cervical radiograph. *1,* Prevertebral soft tissue line. *2,* Anterior vertebral line. *3,* Posterior vertebral line. *4,* Spinolaminar line. *5,* Spinous process line. Diameter of the spinal canal can be determined by measuring the distance between lines *3* and *4*.

Adapted from Shen FH: Spine. In Miller MD et al, editors: *Orthopaedic surgical approaches,* ed 2, Philadelphia, 2015, Elsevier, p 166.

- Occipital headache common but not necessary to diagnosis

□ Examination findings

- Typically benign; normal motor and sensory findings, normal reflexes
- Cervical range of motion may be decreased secondary to pain but without pathologic evidence of mechanical instability

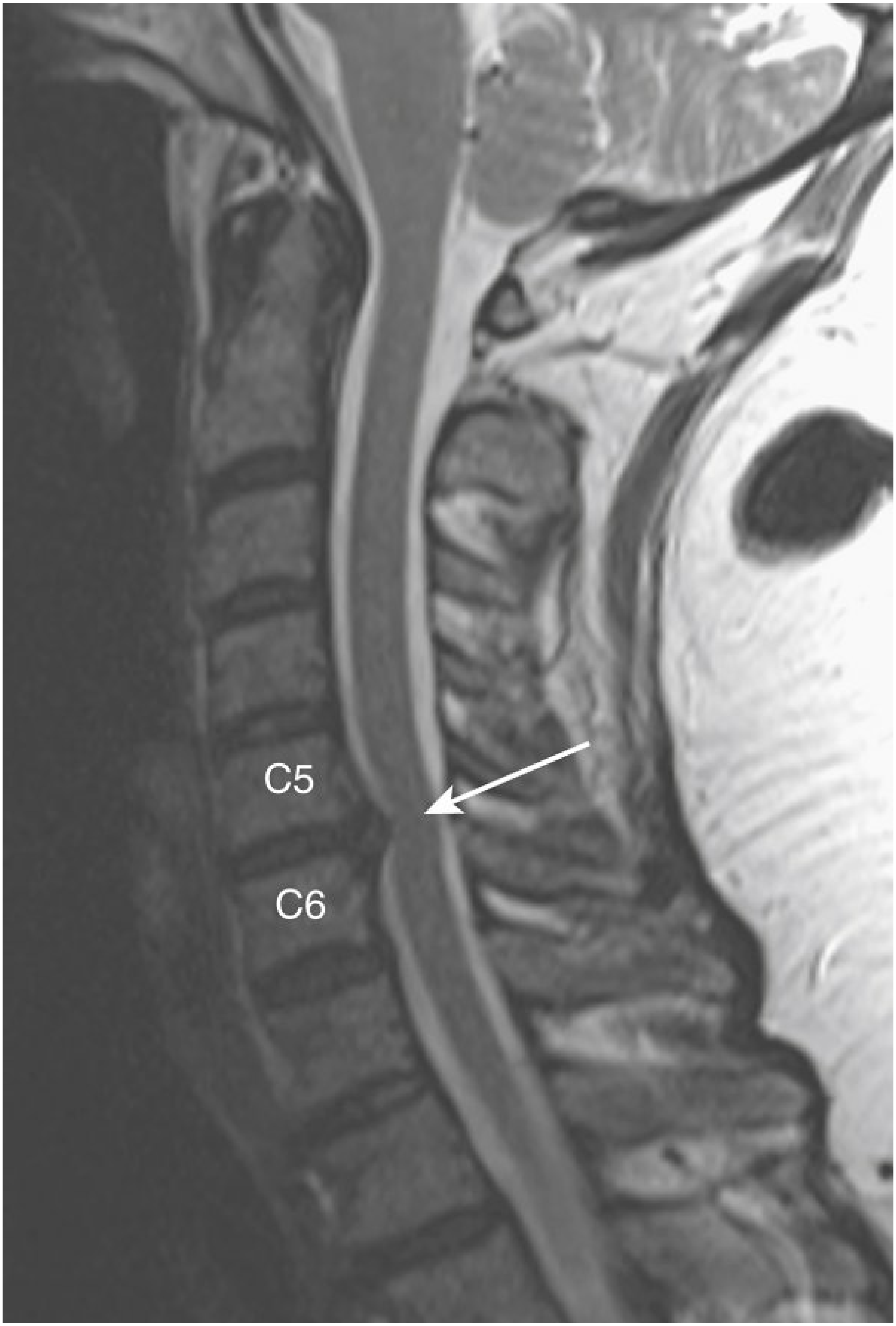
C5
C6

FIG. 8.6 Sagittal T2-weighted cervical MR image demonstrating a C5–6 herniated disc *(arrow)* that results in C6 nerve root compression.

- □ Imaging
  - Radiographs—typically normal results without evidence of instability; may demonstrate disc space narrowing
  - MRI usually demonstrates intervertebral disc degeneration; decreased signal in the disc on T2-weighted imaging (dark disc), with or without anular tear or high-intensity zone (HIZ).
- □ **Treatment**
  - **Nonoperative therapy: antiinflammatories, symptomatic care**
  - **Patient education emphasizing the self-limiting nature of symptoms is important.**
  - **Surgical options for discogenic neck pain are limited and should be avoided.**

▪ **Cervical radiculopathy**

- □ Nerve root compromise without reference to specific pathologic entity
  - Can be due to herniated disc, discoosteophytic complex, facet arthropathy, thickened ligamentum flavum, uncovertebral osteophyte, and other problems
  - Can involve one or multiple roots (polyradiculopathy)
  - Commonly shoulder and arm pain, paresthesias, and numbness
  - Overlapping findings because of intraneural intersegmental connections of sensory nerve roots
- □ Caudal nerve root at a given level is usually affected (see Table 8.2)
  - Cervical nerve roots exit above their corresponding vertebrae (e.g., C5 exits at the C4–5 neural foramen).
    - Consequently, disc herniation at C5–6 involves the C6 nerve root (Fig. 8.6).
    - Disc herniation at C7–T1 involves the C8 root.
- □ Symptoms
  - May initially manifest as neck pain; then radicular symptoms develop
  - Pain, numbness, paresthesia in a dermatomal distribution to upper extremity
- □ Physical examination
  - Motor—weakness uncommon but, when present, is

associated with the myotome

- Sensory—pain, numbness, or dysesthesias along dermatomal distribution is common.
- Reflexes—typically normal or below normal (hyporeflexia)
- **Spurling test**—rotation and lateral bend of the neck, with vertical compression on the head; the occurrence of radicular symptoms during this test suggests nerve root pain.
- **Shoulder abduction sign**—relief of radicular pain with shoulder abduction (examiner places hand on top of patient's head) is suggestive of a cervical etiology.

□ Treatment

- Nonsurgical treatment—NSAIDs, cervical epidural injections, isometric exercises, traction, and, occasionally, temporary collar immobilization
- Surgical indications—progressive motor weakness, persistent disabling pain despite conservative measures
- Procedures
    - Anterior cervical discectomy and fusion (ACDF)—removal of herniated disc with excision of associated osteophytes followed by strut graft fusion with or without instrumentation; ACDF can be single-level or multilevel.
    - Anterior cervical corpectomy and fusion (ACCF)—if neural compression is due to pathology behind the vertebral body, removal of vertebral body (corpectomy) may be necessary, with subsequent bony fusion with or without instrumentation.
    - Application of anterior plating may increase the fusion rate in multilevel discectomies with fusion and will protect a strut graft in multilevel corpectomies.
    - Cervical total disc replacement (TDR)—removal of herniated disc with excision of associated osteophytes followed by motion-preserving disc arthroplasty device. Care should be taken to avoid excessive resection of uncovertebral joints. Presence of spinal deformity, segmental spinal instability, facet arthropathy, and inability to adequately visualize the implant intraoperatively on radiography are contraindications to cervical TDR placement, and ACDF should be considered instead.

- Posterior keyhole laminoforaminotomy—less commonly performed, but option for radiculopathy secondary to posterior compression (facet hypertrophy) or for lateral soft disc herniations. Central disc herniations are contraindication to posterior keyhole laminoforaminotomy because of the inability to safely access the herniation.

- **Cervical myelopathy (** Fig. 8.7)
  - Spinal cord compromise without reference to specific pathologic entity
  - Presenting symptoms can be subtle
    - Finger clumsiness, deterioration of handwriting, difficulty in fine motor control of hands, weakness of pinch

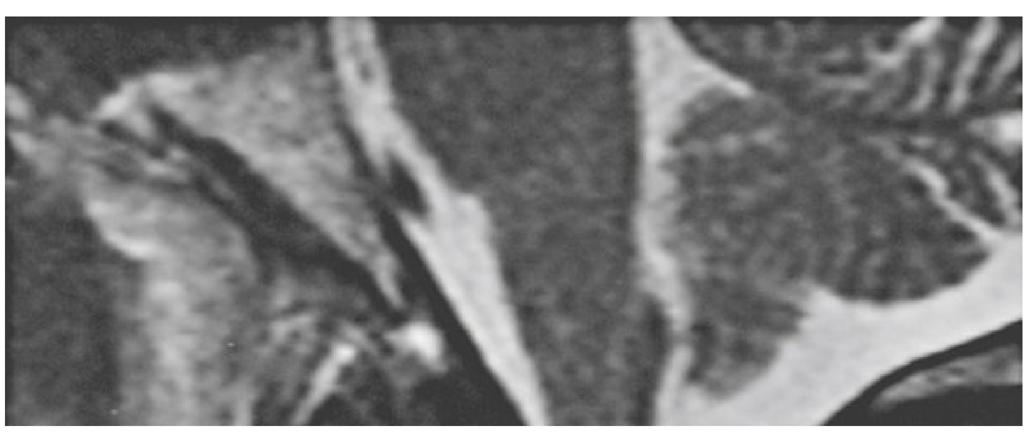

FIG. 8.7 Disc-related myelopathy. Fast T2-weighted sagittal MR image of the cervical spine. The C3–4 disc is protruding into the spinal canal, and there is compression of the cord that has high signal within it *(arrowhead).* The cord abnormality is the result of cord ischemia with myelomalacia. The discs are protruding to a lesser extent at lower levels, causing multilevel canal stenosis.

- Ataxia with wide-based gait, leg heaviness, and inability to perform tandem walk
- Urinary retention, urgency, or frequency
- Lower extremity weakness (corticospinal tracts) can be associated with worse prognosis.

□ Natural history of cervical spondylotic myelopathy is characterized by one of three presentations:

- Stepwise deterioration in symptomatology followed by a period of stability (most common, 65%–80%)

        - Slowly progressive decline (over months to years, 20%–25%)
        - Rapidly progressive decline (over days to weeks, 3%–5%)
    - Physical examination
        - Upper motor neuron findings in myelopathy
        - Myelopathy hand and the finger escape sign (small finger spontaneously abducts because of weak intrinsic muscles)
        - **Hyperreflexia, Hoffmann sign, clonus, or Babinski sign**
        - **Inverted radial reflex** (ipsilateral finger flexion when brachioradialis reflex being elicited)
        - **Funicular pain**—central burning and stinging with or without L'hermitte sign (radiating lightning-like sensations down the back with neck flexion)
        - Upper motor neuron findings not always present in all patients
        - Upper extremities may have radicular (lower motor neuron) signs along with evidence of distal myelopathy.
    - Treatment
        - Nonsurgical treatment—NSAIDs, cervical epidural injections, isometric exercises, traction, and occasionally temporary collar immobilization
        - **Surgical indications—natural history of myelopathy is typically progressive; therefore surgical decompression is frequently indicated.**
        - Procedures
            - Anterior procedures include ACDF versus ACCF or combination (hybrid). Anterior-based procedures are options for patients with either kyphotic or lordotic cervical sagittal alignment.
            - Posterior options include laminectomy and fusion versus laminoplasty. Posterior-based options are contraindicated in patients with fixed cervical kyphosis owing to the surgical inability to indirectly decompress the spinal cord.
            - Combined anterior and posterior procedures (circumferential surgery). Considered for patients requiring multilevel corpectomy resection with strut reconstructions (highly unstable spine).
- **Rheumatoid spondylitis**
    - Overview
        - **Less common owing to improvement and increased use of disease-modifying antirheumatic drugs (DMARDs)**
        - Patients with rheumatoid arthritis (RA) should undergo flexion/extension radiography before elective surgery.

- **When spine is involved, cervical spine, more specifically occipitoatlantoaxial joint (O–C2), is site most commonly affected.**
    - **Atlantoaxial subluxation (AAS)**—typically the first manifestation of cervical instability in rheumatoid patient
    - **Atlantoaxial invagination (AAI)**—typically occurs next, after AAS
    - **Subaxial subluxation (SAS)**—usually occurs after AAS and AAI
- Occurs in up to 90% of patients with RA and is more common with long-standing disease and with multiple joint involvement

□ Presenting complaints

- Axial neck pain
- Stiffness
- Occipital headaches
    - Due to erosion of the C1–2 joint, with subsequent compression of greater occipital branch of C2 nerve
    - Results more specifically in pain in posterior aspect of base of skull that is typically relieved with manual traction
- Myelopathy, radiculopathy, or myeloradiculopathy, depending on neurologic structures at risk

□ Physical examination

- Subtle signs of neurologic involvement should be sought.
- Neurologic impairment (weakness, decreased sensation, hyperreflexia) in patients with RA usually occurs gradually and is often overlooked or attributed to other joint disease.
- Neurologic impairment with RA has been classified by **Ranawat** (Table 8.6).

□ Imaging

- Radiographic markers are assessed for indications of impending neural compression (Fig. 8.8).
    - **Anterior atlantodens interval (AADI), frequently referred to simply as atlantodens interval (ADI)**
    - **Posterior ADI (PADI), sometimes also referred to as space available for the cord (SAC)**
- MRI
    - **Cervicomedullary angle (CMA)** (Fig. 8.9) is measured by drawing a line along anterior aspect of cervical spinal cord and the medulla.

- Normal: 135–175 degrees
    - In patients with progressive superior migration of the odontoid, the CMA decreases owing to draping of the brainstem over the odontoid.

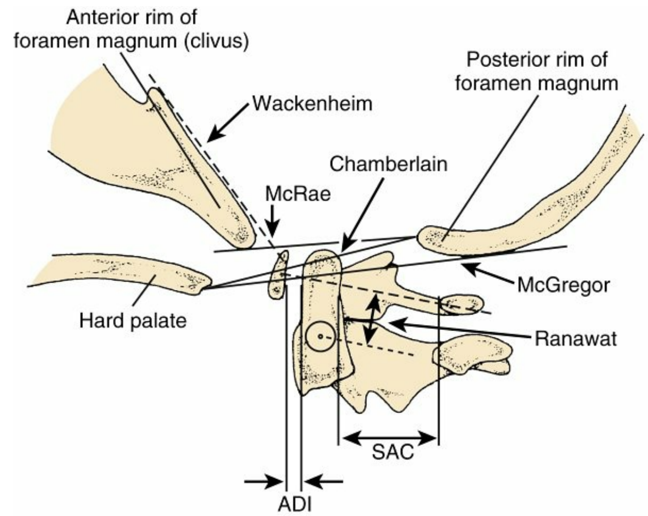

FIG. 8.8 Common measurements in C1–2 disorders.

Table 8.6

Ranawat Classification of Neurologic Impairment in Rheumatoid Arthritis

Grade	Characteristics
I	Subjective paresthesias, pain
II	Subjective weakness; upper motor neuron findings
III	Objective weakness; upper motor neuron findings
IIIA	Ambulatory
IIIB	Nonambulatory

- Reduced CMA has an increased association with respiratory dysfunction and sudden death.

□ Atlantoaxial subluxation (AAS)
- Typically first stage of cervical spine involvement in the rheumatoid patient
    - **Occurs in 50%–80% of patients with RA**
    - Often the result of pannus formation at synovial joints between the dens and ring of C1, resulting in destruction of transverse ligament, dens, or both

        - Leads to instability between C1 and C2, with subsequent subluxation
- Diagnosis
    - Anterior subluxation of C1 on C2 is the most common finding, but posterior and lateral subluxation can also occur.
    - Findings on examination may include limitation of motion, upper motor neuron signs, and weakness.
    - Plain radiographs that include patient-controlled flexion and extension views are evaluated to determine AADI as well as PADI.
    - Instability is suggested by AADI motion of more than 3.5 mm on flexion and extension views, although radiographic instability in RA is common and not necessarily an indication for surgery.
    - **PADI less than 14 mm may be more sensitive than AADI measurement for spinal cord compression in patients with RA.**
- Surgical indications
    - Intractable pain
    - Progressive neurologic instability, cervical myelopathy
        - Can be due to mechanical instability
        - Direct compression by pannus of C2

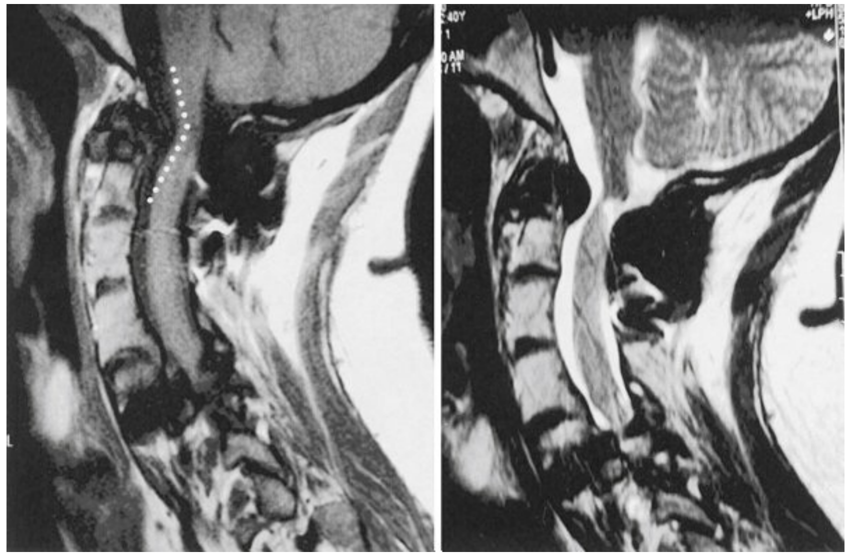

FIG. 8.9 Cervicomedullary angle (CMA). MR images of a patient with myelopathic rheumatoid with a CMA measuring 130 degrees *(dotted white line).* Notice the effect of progressive cranial settling combined with an increasing retrodental pannus on the craniocervical junction.
From Shen FH et al: Rheumatoid arthritis: evaluation and surgical management of the cervical spine, *Spine J* 4:689–700, 2004.

- Mechanical instability; evaluation of C1–2 motion/relationship
    - **AADI greater than 9–10 mm**
    - **PADI less than 14 mm**
        - PADI may be more sensitive for identifying patients at increased risk of neurologic injury
        - PADI less than 14 mm usually requires surgical treatment.
        - Surgery is less successful in patients with Ranawat grade IIIB neurologic impairment but should still be considered.
- Treatment
    - Surgical fixation
        - Gallie fusion—mostly of historical significance
        - Brooks fusion—mostly of historical significance and rarely used alone
        - C1–2 transarticular screw fixation (Magerl)

- Still used but less commonly since advent of C1–2 Harms construct (see later)
- Requires preoperative CT to evaluate position of vertebral arteries
- Requires reduction of C1–2 joint
- Poses increased risk for vertebral artery and C2 nerve injury
- **C1 lateral mass—C2 pedicle/pars fixation (Harms construct)**
  - Lower rate of vertebral artery and C2 nerve injury
  - **Biomechanically strongest construct of C1–2 fixation techniques**
  - Does not require reduction of C1–2 joint
- Odontoidectomy
  - Should be reserved as a secondary procedure
  - Anterior cord compression by pannus often resolves after posterior spinal fusion.

□ AAI

- Also known as cranial settling, basilar invagination, cranial invagination, and other names.
  - Second most common manifestation of RA in cervical spine
  - Occurs in 40% of patients with RA
  - **Results in cranial migration of the dens from erosion and bone loss between the occiput and C1–2**
  - Often seen in combination with fixed atlantoaxial subluxation
  - Measurements are shown in Fig. 8.8.
    - Landmarks may be difficult to

identify.
      - Ranawat line is most reproducible.
  - Diagnosis
    - Progressive cranial migration of dens
    - Findings on examination may include limitation of motion, upper motor neuron signs, weakness, and, in severe cases, bulbar symptoms.
  - Surgical indications
    - Intractable pain
    - Progressive cranial migration or neurologic compromise may require operative intervention (occiput–C2 fusion).
    - **Cervicomedullary angle less than 135 degrees (on MRI) suggests impending neurologic impairment.**
  - Treatment
    - Occipitocervical fusion
      - Typically from occiput to C2
      - Gentle traction to help bring odontoid process out of foramen magnum
    - Transoral or retropharyngeal odontoid resection for persistent brainstem compression after occiput–C2 fusion.
- □ SAS
  - Occurs in 20% of cases of RA
  - Seen in combination with upper cervical spine instability
  - Pathoanatomy
    - Pannus formation in uncovertebral joints (joints of Luschka) and facet joints. Subluxation may occur at multiple levels.
    - Radiographic markers of instability
      - Subaxial subluxation of greater than 4 mm or more than 20% of the body is indicative of cord compression.
      - **A cervical height index (cervical body height/width) of less than 2.00 approaches 100% sensitivity and specificity in predicting neurologic compromise.**
  - Surgical indications
    - Intractable pain
    - Progressive neurologic compromise, cervical

myelopathy
    - Mechanical instability—subluxation greater than 4 mm
  - Procedure
    - Posterior spinal fusion with or without decompression
      - **Fusion to the most distal unstable level.**
      - **Occiput and/or C1–2 joint included if AAI or AAS exists.**
    - **Anterior spinal fusion**
      - May be required to restore sagittal alignment
      - May be necessary to increase likelihood of fusion on multilevel posterior spinal fusion
  - **Surgery may not reverse significant neurologic deterioration, especially if a tight spinal canal is present, but can stabilize it.**
- ▫ Ankylosing spondylitis (AS)
  - Introduction
    - Chronic inflammation; part of group of conditions known as *spondyloarthropathies.*
    - Etiology unknown; association with HLA-B27. However, not all patients with HLA-B27 experience AS.
  - Presentation and assessment
    - Symptoms most frequently start in sacroiliac joint (sacroiliitis) or lumbar spine
    - **Patients with AS who present with complaint of spine pain, with or without a history of trauma, must be carefully evaluated for occult fracture.**
      - In particular, patients with AS and neck pain have a presumed fracture unless proven otherwise.
      - Concerns for pseudarthrosis and progressive kyphotic deformity
      - **Undiagnosed cervical fractures in patient with AS pose high risk for neurologic compromise.**
  - Plain x-rays
    - Ossification of intervertebral disc
    - Marginal syndesmophytes

- Bamboo spine
- **Plain radiographs frequently normal or miss occult fractures; in patients with AS, failure to diagnose such fractures can be devastating (Fig. 8.10).**

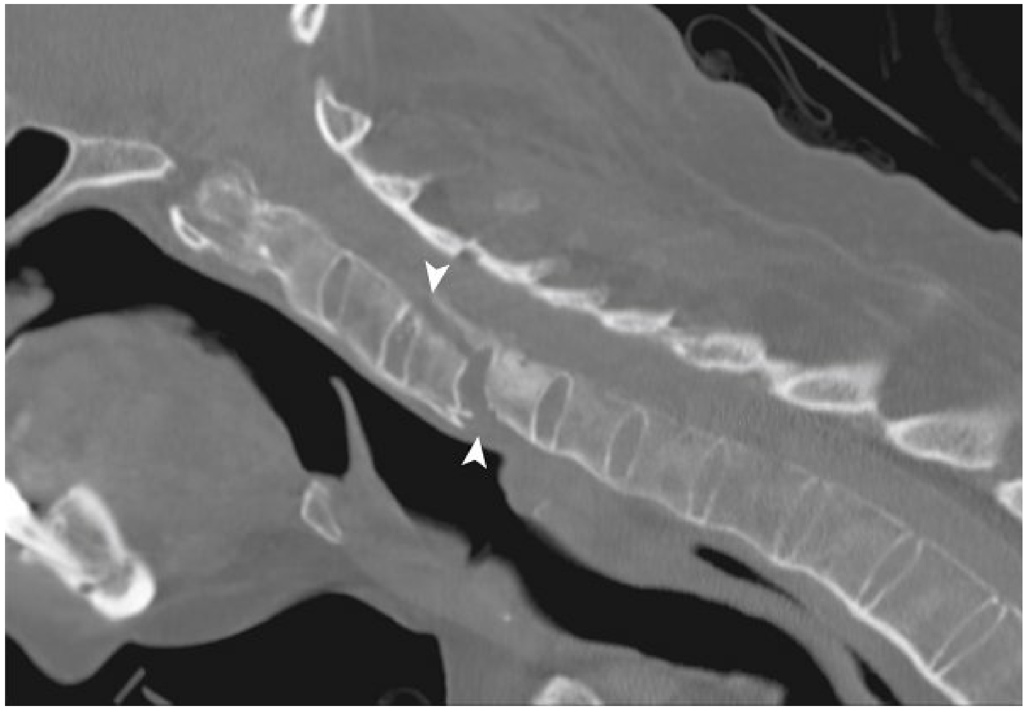

FIG. 8.10 Parasagittal cervical CT reconstruction demonstrating classic changes consistent with ankylosing spondylitis with loss of cervical lordosis and marginal syndesmophytes. An oblique fracture can be seen entering through the ossified C4–5 disc and then extending vertically through the vertebral body of C4 *(arrowheads).*

- Advanced imaging should be strongly considered.
  - CT
  - MRI
- In addition to occult fractures, patients with AS are at risk for development of epidural hematomas.
- Frequently patients with AS can present with loss of horizontal gaze, inability to look straight ahead (see Adult Deformity section, discussion of Kyphotic deformity in ankylosing spondylitis).
  - Chin-on-chest deformity
  - Associated with severe hip flexion contracture
  - Flexion deformity of the lumbar spine
  - Increased cervical, thoracic, and lumbar kyphosis common

□ Treatment

- Nonoperative: reduction of pain, stiffness, and inflammation
- Surgical (see Adult Deformity section, discussion Kyphotic

deformity in ankylosing spondylitis)

- Careful intraoperative positioning
- Ankylosed cervical spine can make intubation and airway management challenging
- **Correction of hip and lumbar disorder is first**
- May require cervicothoracic laminectomy, osteotomy, and fusion for correction of the neck deformity
    - Typically performed at a C7–T1 pedicle subtraction osteotomy
    - C8 nerve root frequently at risk during this procedure
    - May require a staged anterior approach to obtain anterior column support at C7–T1 in patients in whom substantial distraction and opening of the anterior column occur during completion of the osteotomy (osteoclasis)
- Postoperative immobilization may require addition of halo cast/vest.
    - Internal fixation should be as secure as possible in the attempt to avoid halo immobilization.
    - Role of traction with halo immobilization as the primary treatment of cervical spine fractures in AS is controversial, and is being used less and less.
    - Traction with halo immobilization as primary treatment is not well tolerated in AS.

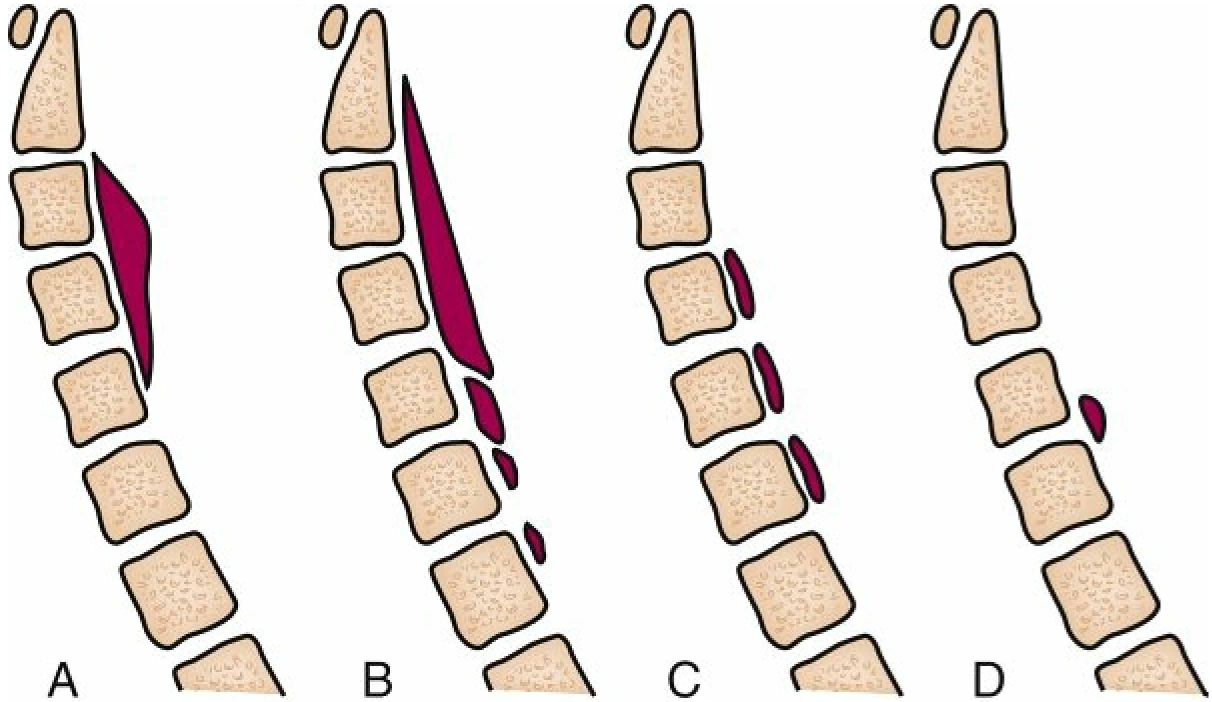

FIG. 8.11 Classification of ossification of posterior longitudinal ligament. (A) Continuous type. (B) Mixed type. (C) Segmental type. (D) Localized type.
From Takeshita K: Ossification of the posterior longitudinal ligament. In Shen FH et al, editors: *Textbook of the cervical spine,* Maryland Heights, MO, 2015, Elsevier, p 157.

- **Ossification of the posterior longitudinal ligament (OPLL)**
  - Introduction
    - Ectopic endochondral ossification of the posterior longitudinal ligament
    - Typically affects cervical spine, followed by thoracic spine, and least frequently affects lumbar spine
    - Common in Asians, particularly Japanese population, but also seen in non-Asians
    - Men-to-women ratio 2:1
    - Associated with other spondyloarthropathies, such as AS and diffuse idiopathic skeletal hyperostosis (DISH)
  - Presentation and assessment
    - Majority of cases can be asymptomatic
    - Symptomatic cases manifest as symptoms of cervical stenosis with myelopathy and/or radiculopathy.
  - Imaging
    - Linear ossification immediately posterior to vertebral body in spinal canal (Fig. 8.11)
    - Classification
    - Continuous—long lesions extending over several vertebrae
    - Mixed—combination of continuous and segmental
    - Segmental—one or several separate lesions
    - Localized (also known as *circumscribed*)—lesions mainly located at the level of the intervertebral disc space

- OPLL can be hard to identify on MRI; can be misidentified as multilevel herniated disc
- **Ossification is better defined on CT scan** (Fig. 8.12).

□ Treatment

- Nonoperative
  - Important to recognize that majority of patients with OPLL are asymptomatic.
  - Prophylactic surgery in the asymptomatic patient is not necessary.
- Operative
  - **Posterior approach**
    - **Relies on indirect decompression of spinal canal**
    - Requires lordotic or neutral sagittal alignment
    - Laminectomy alone not performed as frequently; higher associated rate of post-laminectomy kyphosis
    - Laminectomy and fusion, typically with instrumentation
    - Laminoplasty
      - **Requires neutral to lordotic sagittal alignment**

FIG. 8.12 Sagittal reconstruction CT scan of patient with mixed-type ossification of the posterior longitudinal ligament. From Takeshita K: Ossification of the posterior longitudinal ligament. In Shen FH et al, editors: *Textbook of the cervical spine,* Maryland Heights, MO, 2015, Elsevier, p 160.

- Contraindicated in kyphotic spine

- Anterior approach
  - More directly addresses the pathology
    - ACDF
    - ACCF
    - Hybrid of ACDF and ACCF (combination)
  - **However, OPLL is frequently associated with dural ossification.**
    - Therefore anterior-based approaches may be associated with higher incidence of dural leaks.
  - Anterior floating technique has been described. OPLL is thinned down but not removed. Stenosis is decompressed laterally around the OPLL, allowing it to become "free-

floating."

- **Sports-related cervical spine injuries**
  - Neurapraxia ("burners" and "stingers")
    - Commonly associated with stretching of the upper brachial plexus
      - Bending the neck away from the depressed shoulder
      - Neck extension toward the painful shoulder in the setting of foraminal stenosis
    - Symptoms include burning dysesthesia and weakness in the involved extremity.
      - Typically unilateral
      - Bilateral symptoms or lower extremity symptoms suggestive of spinal cord injury
    - Fracture or acute HNP should be ruled out.
    - The athlete with a neck injury should be further evaluated for cervical pain, tenderness, or persisting neurologic symptoms.
    - **Use of steroids not indicated; neurapraxia due to peripheral nerve lesions**
  - Transient quadriplegia (TQ)
    - Usually seen after axial load injury (spearing) but may also be seen after forced hyperextension or hyperflexion
    - Manifests as bilateral burning paresthesia and weakness or paralysis
    - Risk factors
      - Cervical stenosis
      - Torg ratio
        - Ratio between width of sagittal canal diameter and width of vertebral body
        - Normal 1.0
        - Less than 0.8 indicates stenosis
        - Poor positive predictive value; should not be used as screening tool
      - Preexisting instability
      - HNP
      - Congenital fusions (Klippel-Feil syndrome)
    - Third and fourth cervical levels are the most commonly affected.
    - No definitive association with future permanent neurologic injury
    - Patients with concurrent pathologic conditions, including instability, HNP, degenerative changes, and symptoms that

last more than 36 hours, should be prohibited from participating in contact sports.

Thoracic Spine

- **Thoracic disc disease**
  - Epidemiology
    - **Radiographic evidence of disc degeneration is relatively common; however, symptomatic disc herniation is very uncommon (1% of all surgical HNPs).**
    - Typically involves the middle to lower thoracic levels
      - Most herniations occur at T11–12.
      - 75% occur at T8–12.
  - Diagnosis
    - Manifests as the onset of back or chest pain
    - May include radicular symptoms
      - Bandlike chest or abdominal discomfort, numbness, paresthesias, leg pain
      - Myelopathy may be present.
      - Sensory changes, paraparesis, bowel/bladder/sexual dysfunction
    - Physical findings may be subtle and difficult to elicit
      - Localized tenderness
      - Thoracic radiculopathy—dermatomal sensory changes
      - **Thoracic myelopathy—patient presents with upper motor neuron signs of the lower extremity, with leg hyperreflexia, weakness, and normal upper extremity findings**
      - Abnormal rectal findings (rarely present)
    - Imaging
      - Radiographs may show disc narrowing and calcification or osteophytic lipping.
      - CT myelography or MRI should demonstrate thoracic HNP.
      - MRI is useful for ruling out cord disorder, but there is a high false-positive rate, requiring close correlation with clinical findings.

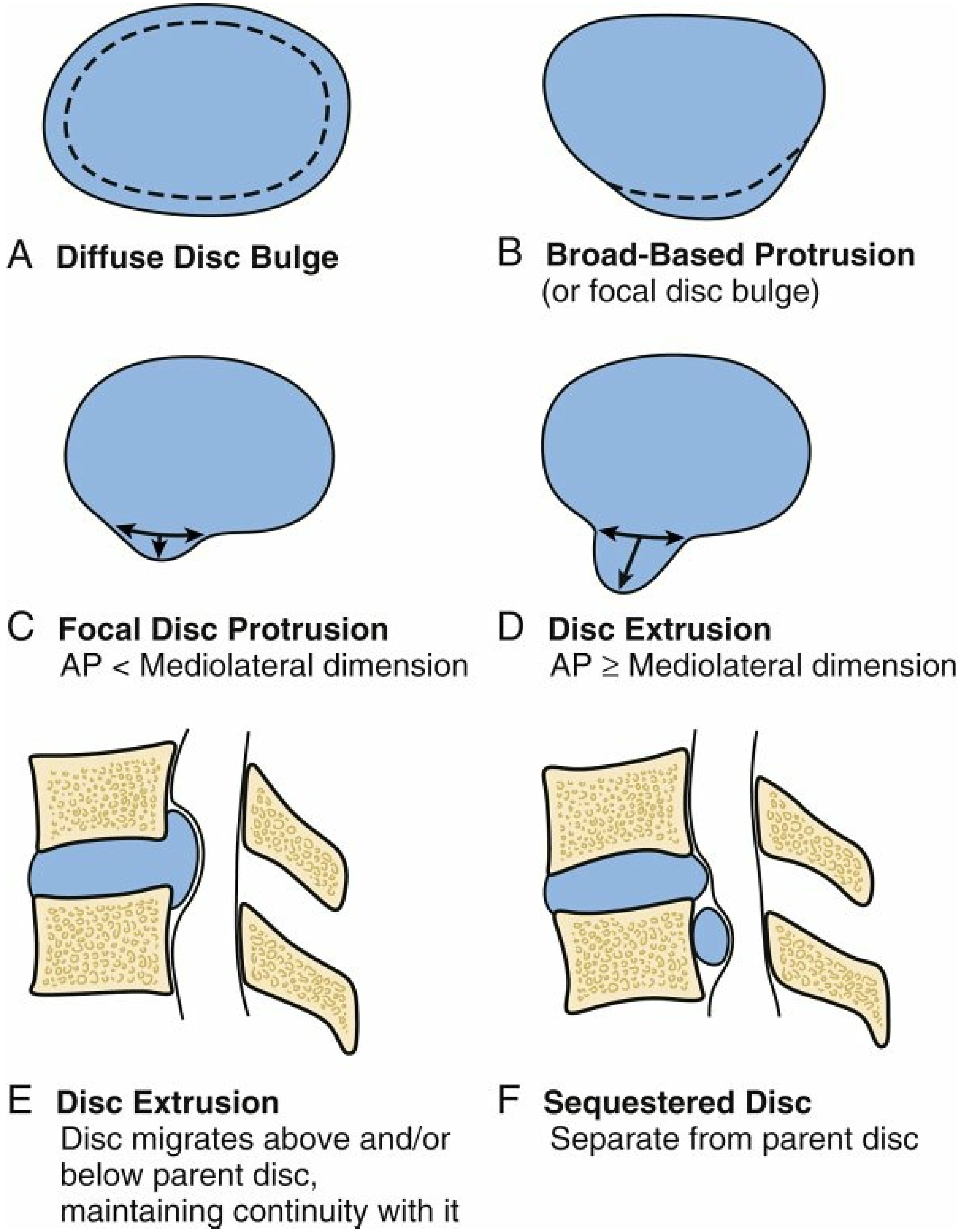

FIG. 8.13 Types of disc herniation.

- **Thoracic HNP**
  - Pathophysiology
    - Disc degeneration
      - Aging results in loss of water content.
      - Tearing of the anulus
      - Myxomatous changes resulting in herniation of nuclear material
    - Thoracic HNP can be divided into central, posterolateral, and lateral herniations.

- Underlying Scheuermann disease may predispose to development of HNP.
- Disc herniation (Fig. 8.13)
  - Discs can protrude (bulging nucleus, intact anulus).
  - Disc extrusion (through anulus but confined by posterior longitudinal ligament)
  - Disc sequestration (disc material free in canal)
- HNP usually a disease of young and middle-aged adults; in older patients the nucleus desiccates and is less likely to herniate.

□ Treatment

- **Nonsurgical**
  - **Most thoracic disc herniations resulting in radiculopathy are managed symptomatically and nonoperatively.**
  - Immobilization, analgesics, and nerve blocks are sometimes helpful for radiculopathy.
- Surgical indications
  - Progressive thoracic myelopathy (worsening gait instability, ataxia, bowel or bladder dysfunction, etc.)
  - Persistent unremitting radicular pain (uncommon)
- Procedures
  - Anterior transthoracic approach—typically for midline or central HNP; anterior discectomy (hemicorpectomy as needed) and fusion with or without instrumentation
  - **Posterior transpedicular/lateral extracavitary approach—for lateral HNP**
    - Used for central disc herniations as well but can be more technically challenging
    - Depending on the degree of bony facet resection, typically requires fusion with or without instrumentation
  - Thoracoscopic discectomy can also be employed; can be technically challenging.
  - Laminectomy—contraindicated
    - Listed mostly for historical interest
    - Associated with high rate of

neurologic injury
- Laminectomy does not allow safe access to the HNP without spinal cord retraction and manipulation.

Lumbar Spine

- **Lumbar disc disease (also known as** *lumbar spondylosis*)
  - Major cause of morbidity, with a major financial impact in the United States
    - Spectrum of symptoms that can result in several clinical entities, including discogenic back pain, lumbar disc herniations, spondylolisthesis, and lumbar spinal stenosis
    - Usually involves the L4–5 disc (the "backache disc"), followed closely by L5–S1
  - Pathoanatomy—degenerative spinal cascade
    - First described in 1970s by **Kirkaldy-Willis**; emphasis on interdependence of intervertebral disc and two facet joints in the thoracolumbar spine.
    - Progressive collapse of the lumbar intervertebral disc, resulting in loss of normal lordosis of the lumbar spine and chronic anterior cord compression, in turn leading to anterior chondroosseous/discoosteophytic spurs
    - Subsequent loading of facet joint causing spondylotic changes in the foramina
    - Can result in segmental instability (spondylolisthesis) owing to collapse of the disc and incompetence of the facet joint
- **Discogenic back pain**
  - Secondary to intervertebral disc degeneration without other pathologic entities, such as spinal instability, fractures, dislocations, and neural compression
  - Diagnosis
    - Examination
      - Paucity of physical findings
      - Back pain greater than leg pain
      - No radiculopathy—absence of tension signs
    - Imaging
      - Radiographs are negative for instability but may show disc space narrowing or other stigmata of spondylosis.
      - MRI typically reveals decreased signal intensity in the disc space on T2-weighted imaging (dark

disc), with or without annular tear or HIZ (Fig. 8.14).

- Discography
  - Controversial study
  - Designed as a preoperative study to correlate MRI findings with a clinically significant pain generator
    - Needle placed into intervertebral disc space and contrast dye injected

FIG. 8.14 Sagittal T2-weighted lumbar MR image demonstrating a degenerative dark disc *(white arrowhead)* with associated annular tear *(black arrow)*, also known as a *high-intensity zone*.

    - Extra fluid in disc increases pressure in the disc. For the result to be considered reliably positive, the procedure should elicit pain after injection similar to that usually described by the patient (concordant pain).

- The study should involve at least one minimally painful, nonconcordant level.
- Study should be performed at multiple levels to include all abnormal levels and one or more normal levels as identified on MRI.
- Evidence suggests that anular tears created by the needle during discography may accelerate the rate of symptomatic disc degeneration; as a result, discography is falling out of favor.

▫ Treatment

- **Almost always conservative treatment**
    - More than half of patients who seek treatment for low back pain recover in 1 week, and 90% recover within 1–3 months.
    - NSAIDs, physical therapy, and conditioning
    - Patient education about the self-limiting nature of discogenic back pain is important.
- Surgical interventions
    - Controversial; surgery should be avoided whenever possible for discogenic back pain.
        - Conservative measures should be exhausted before any consideration is given to surgical intervention.
    - Currently no good surgical option available that reliably reduces symptoms of discogenic back pain
    - Options available include:
        - Interbody fusion
            - Anterior retroperitoneal approach, or direct lateral, or through a posterior midline lumbar, or posterior transforaminal lumbar interbody fusion approach

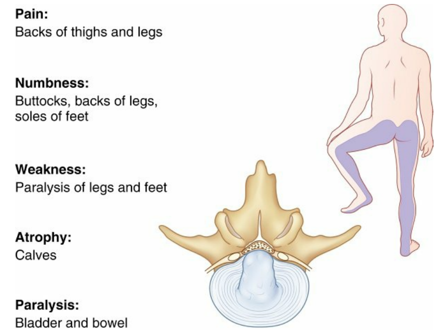

FIG. 8.15 Cauda equina syndrome.

- Fusion is performed with structural constructs (femoral ring allografts or interbody fusion cages) in the disc space.
- Intradiscal electrothermy—involves percutaneously heating the fibers of the anulus fibrosus to reconfigure the collagen fibers, thus restoring the mechanical integrity of the disc.
  - This procedure may be effective in early conditions (<50% loss of disc height) but not in more advanced disease.
  - Long-term follow-up suggests that symptomatic improvement often lasts less than 1 year, and this procedure has been largely abandoned.
- Total disc arthroplasty
  - Another surgical option for patients with degenerative disc disease at a single level (L4–5 or L5–S1) in the lumbar spine with the absence of spondylolisthesis and no relief from 6 months

of nonoperative therapy
- In direct comparison with anterior interbody fusion, total disc arthroplasty showed equivalent clinical results and no catastrophic failures at 2-year follow-up.
- Significant concerns include long-term results, design issues, cost, and the safety of revision procedures.

- **Lumbar herniated disc**
  - Pathophysiology
    - Most herniations are posterolateral (where the posterior longitudinal ligament is the weakest) and may manifest as back pain and nerve root pain/sciatica involving the lower nerve root at that level (L5 nerve at the L4–5 level).
    - Herniations lateral to the neural foramen (also called “far lateral” disc herniations) involve the upper nerve root (L4 nerve at the L4–5 level).
    - Central herniations are often associated with back pain only; however, acute insults may precipitate cauda equina compression syndrome (Fig. 8.15).
  - Diagnosis (see Introduction)
    - History
      - Typically manifests initially as back pain with or without history of trauma
      - Subsequent development of leg pain that is worse with sitting and better with standing and lying
      - Pain or numbness radiating beyond the knee, typically in a dermatomal distribution
      - Weakness and bowel and bladder dysfunction less common but should be asked about during history.
      - Red flags (fever, chills, nausea, vomiting, weight loss, night sweats, etc.) typically absent
    - Examination (see Table 8.3)
      - Motor findings—typically normal but weakness may be present depending on nerve root involved
      - Sensory findings—Patient typically presents with

pain, numbness, and/or dysesthesia radiating down leg in a dermatomal pattern.

- Reflexes—typically normal but there may be hyporeflexia at level of involved nerve root
- **Provocative maneuvers**
    - Supine straight-leg test—patient supine and raising leg with knee straight; result is positive if movement of leg between 30 and 70 degrees reproduces and/or exaggerates symptoms radiating down leg. This finding is sensitive for L4, L5, and S1 nerve root irritation but is not very specific.
    - Seated straight-leg test—variation of supine straight-leg raise, performed while patient in seated position. In positive result, hip flexion with knee extension reproduces and/or exaggerates symptoms radiating down leg. Less sensitive than supine straight-leg raise.
    - Contralateral straight leg test—if raising contralateral asymptomatic leg with knee straight causes pain radiating down the symptomatic leg, result is positive. More specific for an axillary disc herniation.
    - Lasègue sign—relief of radiating leg symptoms with knee flexion while hip is flexed.
    - Femoral tension sign—with patient prone and hip extended, the examiner passively flexes the knee. Sign is present if this movement reproduces and/or exaggerates symptoms radiating down anterior thigh. Sensitive for L2, L3, and L4 nerve root irritation but not very specific.

- Imaging
    - Plain radiographs
        - Upright x-rays may simulate spinal

alignment and identify subtle instability better than supine films and should be obtained whenever possible.
            - Flexion-extension radiographs should be obtained, assessing for instability, particularly if surgical intervention is considered.
        - MRI
            - **False-positive MRI results are very common**; clinical correlation among history, examination, and imaging findings is vital to achieve a successful surgical outcome.
            - MRI with gadolinium enhancement is the best study for recurrent disc herniations.
        - CT myelogram can be obtained if MRI contraindicated; useful in patients with previous surgery to better define bony anatomy.
- □ Treatment
    - Nonsurgical treatment—physical therapy, NSAIDs, activity modification, and spinal steroid injections
    - Surgical indications—progressive motor weakness, persistent disabling pain despite conservative measures
    - Procedures
        - Surgical discectomy
            - Patients with positive study results, neurologic findings, tension signs, and predominantly sciatic symptoms without mitigating psychosocial factors are the best candidates for surgical discectomy.
            - Open, limited open, microscope-assisted, and endoscopic approaches are all equally effective. Visualization and localization of herniated disc and neural structures remains the most important aspect of the surgical approach.
                - Hemilaminotomy and discectomy are the most commonly performed

        - surgical procedures.
        - Total laminectomy may be necessary to access large central herniations and allow for adequate safe retraction of the common dural sac.
        - Paramedian/muscle splitting (Wiltse) approach may be necessary for far-lateral disc herniations.
    - Operative positioning requires the abdomen to be free to decrease pressure on the inferior vena cava and consequently on the epidural veins.
- Fusion with or without instrumentation
    - Typically *not* required for surgical decompression of a herniated disc
    - Performed in presence of instability in conjunction with surgical decompression, not instead of it
    - Indications for fusion
        - Preoperative evidence of segmental spinal instability at level of disc herniation, such as spondylolisthesis and/or increased translational or angular mobility on flexion/extension films
        - **Intraoperative iatrogenic instability secondary to resection of greater than 50% of bilateral facet, resection of 100% of unilateral facet joint, or excessive resection of pars intraarticularis**

- **Spinal stenosis (** Fig. 8.16)
  - Introduction
    - *Spinal stenosis* is narrowing of the spinal canal or neural foramina, which produces nerve root compression, root ischemia, and a variable syndrome of back and leg pain.
    - **Classification**
      - Central stenosis
      - Lateral recess stenosis/subarticular stenosis/entry zone stenosis
      - Foraminal stenosis
    - Stenosis is not usually symptomatic until patients reach late middle age; men are affected somewhat more often than women.
    - **Tandem stenosis** is the occurrence of both cervical and lumbar stenosis and can manifest as neurogenic claudication, radiculopathy, and myelopathy.
  - Central stenosis—thecal sac compression
    - Introduction
      - The *central canal* is defined as the space posterior to the posterior longitudinal ligament, anterior to the ligamentum flavum and laminae, and bordered laterally by the medial border of the superior articular process.
      - Soft tissue structures, including the hypertrophied ligamentum flavum, facet capsule, and bulging disc, may contribute as much as 40% to thecal sac compression.
      - ***Absolute stenosis*** **is defined as a cross-sectional area of less than 100 mm ^{2} or less than 10 mm of anteroposterior diameter as seen on CT cross section.**

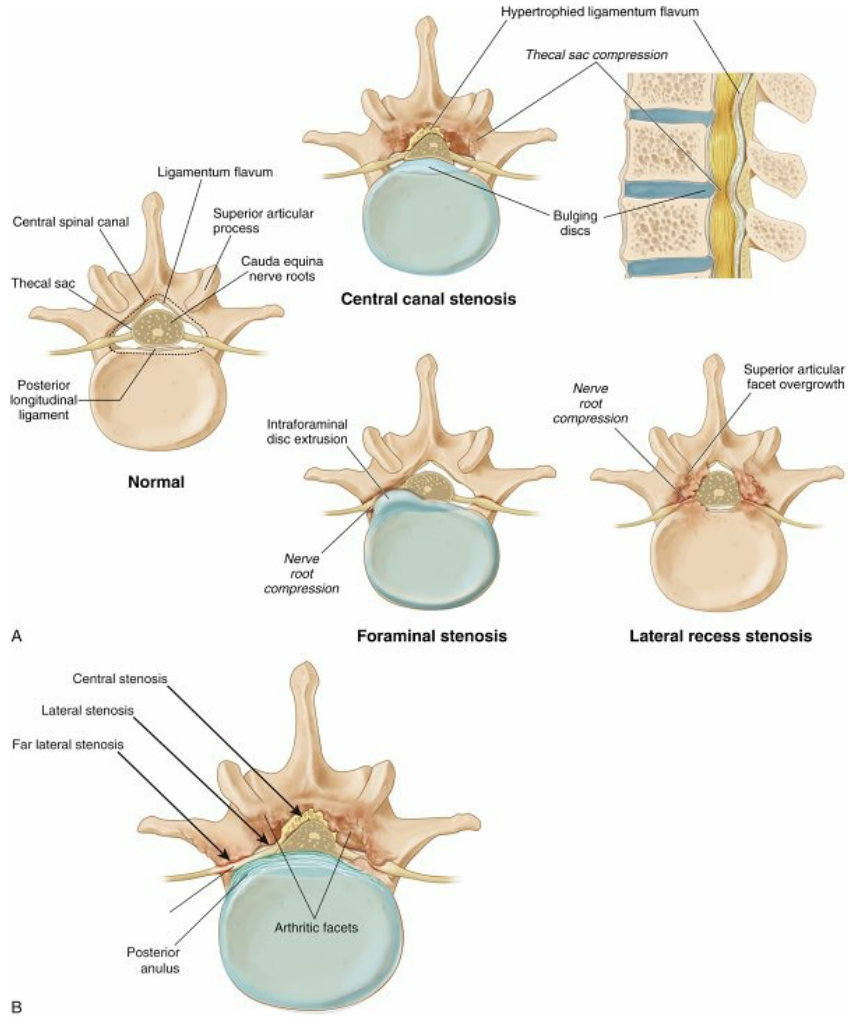

FIG. 8.16 Pathoanatomy of spinal stenosis. (A and B) Comparison of central, lateral/foraminal, and far lateral/lateral recess stenosis.

- Central stenosis is more common in men, in whom the spinal canal is smaller at the L3–5 level than in women.
- Affects an older population more than lateral recess stenosis does

- Etiology—congenital versus acquired
  - Congenital (idiopathic or developmental in achondroplastic dwarfism)
  - Acquired stenosis (most common) is usually:
    - Degenerative secondary to enlargement of osteoarthritic facets with medial encroachment
    - Degenerative secondary to spondylolisthesis
    - Posttraumatic
    - Iatrogenic (postsurgical)
    - Secondary to systemic disease processes such as Paget disease, AS, acromegaly, and fluorosis

- History
- Symptoms include insidious pain and paresthesias with ambulation and are relieved by sitting or flexion of the spine.
- Patients commonly complain of lower extremity pain, usually in the buttock and thigh, with numbness or “giving way.”
- History of radiating leg pain in a true dermatomal distribution is relatively uncommon in those with spinal stenosis.
- **Neurogenic claudication**
    - Differentiated from vascular claudication
    - Pain starts proximal (buttock) and extends distal.
    - Pain relieved only when sitting, not with standing
    - Normal vascular examination
- Physical examination
    - Few abnormal neurologic findings (present in <50% of cases). Tension signs are rarely present.
    - Primary finding is typically limited extension, which may exacerbate pain.
    - Normal extremity perfusion and pulses
    - Standing treadmill test can be a sensitive (>90%) provocative evaluation of neurogenic claudication (Table 8.7).
- Diagnostic studies—further workup may include:
    - Plain radiographs
        - Interspace narrowing due to disc degeneration
        - Medially placed facets
        - Flattening of the lordotic curve
        - Subluxation and degenerative changes of the facet joints may also be seen.
    - CT myelogram
        - Osteophyte formation
        - Axial CT of axial canal morphology may demonstrate trefoil canal.
    - MRI—study of choice (Fig. 8.17)
        - Hypertrophy of ligamentum flavum
        - Foraminal stenosis and nerve root entrapment
        - Evaluation for malignancy
    - EMG/nerve conduction velocity testing may be used.
        - Sensitivity is variable and depends on

the examiner.

- Nerve conduction velocity testing is sometimes helpful in differentiating radiculopathy from peripheral neuropathy.

FIG. 8.17 Spinal stenosis. Sagittal (A) and axial (B) T2-weighted MR images demonstrating central stenosis (particularly at L2–3) due to a combination of anterolisthesis, disc herniation, thickened ligamentum flavum, and facet hypertrophy. Note the classic appearance of curly nerve roots above the stenosis, known as *redundant nerve roots*.
From Van Goethem JWM et al: Spine and lower back pain. In Law M et al, editors: *Problem solving in neuroradiology,* Philadelphia, 2011, Elsevier, p 610.

Table 8.7

Findings on Treadmill Tests in Neurogenic Claudication

	Finding	
Activity	Vascular CLAUDICATION	Neurogenic Claudication
Walking	Distal–proximal pain, calf pain	Proximal–distal thigh pain
Uphill walking	Symptoms develop sooner	Symptoms develop later
Rest	Relief with sitting or bending	
Bicycling	Symptoms develop	Symptoms do not develop
Lying flat	Relief	May exacerbate symptoms

- Treatment

- Nonoperative
    - Rest, Williams flexion exercises, NSAIDs, weight reduction
    - Lumbar epidural steroids may be helpful for short-term relief but have shown variable results in controlled studies.
    - Transforaminal nerve block can be effective when the involved roots can be identified.
- Surgical indications
    - Positive study results and a persistent, unacceptably impaired quality of life
    - Progressive motor weakness and/or bowel and bladder dysfunction (uncommon)
- Surgical techniques
    - **Adequate decompression of the identified disorder typically includes laminectomy and partial medial facetectomy, which can usually be done without destabilizing the spine, thus avoiding fusion.**
    - Residual foraminal stenosis is a common reason for persistent radicular pain after laminectomy.
    - **Indications for fusion**
        - Surgical instability (removal of 100% of one facet or greater than 50% of both facets)
        - Pars defects (including those that are postsurgical) with disc disease
        - Symptomatic radiographic instability
        - Degenerative or isthmic spondylolisthesis
        - Degenerative scoliosis
- **Outcomes—Spine Patient Outcomes Research Trial (SPORT)**

- At 4-year follow-up, primary outcome measures (SF-36 Bodily Pain and Physical Function, Oswestry Disability Index) are significantly better for operative than for nonoperative groups.
- Both operative and nonoperative groups experienced improvement from baseline.

□ **Lateral recess stenosis—nerve root compression**

- Introduction
  - **Lateral recess stenosis is also known as *subarticular stenosis* or *entry zone stenosis*.**
  - The lateral recess is defined by the superior articular facet posteriorly, the thecal sac medially, the pedicle laterally, and the posterolateral vertebral body anteriorly.
  - Compression of individual nerve roots by medial overgrowth of the superior articular facet at a given facet joint
- Etiology
  - Impingement of nerve roots lateral to thecal sac as they pass through the lateral recess and into the neural foramen
  - Associated with facet joint arthropathy (superior articular process enlargement) and disc disease (see Fig. 8.16B)
  - Subarticular compression—compression between medial aspect of a hypertrophic superior articular facet and posterior aspect of vertebral body and disc
  - Hypertrophy of the ligamentum flavum and/or ventral facet joint capsule and vertebral body osteophyte/disc exacerbates the stenosis.
  - **Affects the traversing (lower) nerve root (L5 root at L4–5)**
- Treatment
  - After failure of nonoperative treatment, decompression of the hypertrophied lamina and ligamentum flavum and partial facetectomy are usually successful.
  - Nerve root compression can occur at more than one level and must be completely decompressed

to relieve the symptoms.
- Fusion may be necessary if instability is present or created by surgery.

□ **Foraminal stenosis—nerve root compression**

- Introduction
  - The intervertebral foramen is bordered superiorly and inferiorly by the adjacent level pedicles, posteriorly by the facet joint and lateral extensions of the ligamentum flavum, and anteriorly by the adjacent vertebral bodies and disc.
  - Normal foraminal height is 20–30 mm; superior width is 8–10 mm.
- Etiology
  - Intraforaminal disc protrusion
  - Impingement of the tip of the superior facet
  - Lower lumbar areas (L4–5 and L5–S1) are usually involved because the foramina decrease in size as the nerve root increases in size.
  - Foraminal stenosis affects the exiting (upper) root (L4 at L4–5) at a motion segment.
  - Pain may be the result of intraneural edema and demyelination.
- History and physical examination
  - More consistent with nerve root compression, as with radiculopathy from herniated disc
  - Pain, numbness, and/or dysesthesia typically follow a dermatomal distribution.
  - Motor and reflex findings typically normal but in the presence of weakness will follow myotome; typically has normal reflexes or is hyporeflexic.
  - Tension signs can be present.
- Imaging studies are analogous to those for other lumbar conditions.
- **Treatment**
  - **Nonoperative treatment should be the mainstay of management.**
  - **Surgical indications**
    - **Positive study results and a persistent, unacceptably impaired quality of life**
    - **Progressive motor weakness and/or bowel and bladder dysfunction**

(uncommon)

- Surgical techniques
  - Identification of the area and source of stenosis.
  - Typically, partial medial facetectomy and resection of medial process of superior articular process
  - Care should be taken to **preserve more than 50% of facet joint and pars intraarticularis** to preserve stability.
  - Fusion and stabilization should be considered if preoperative evidence of instability or iatrogenic intraoperative instability

- **Spondylolysis and spondylolisthesis**
  - Spondylolysis—defect in the pars interarticularis
    - One of the most common causes of low back pain in children and adolescents
      - Typically symptoms aggravated with extension
        - Improved with flexion

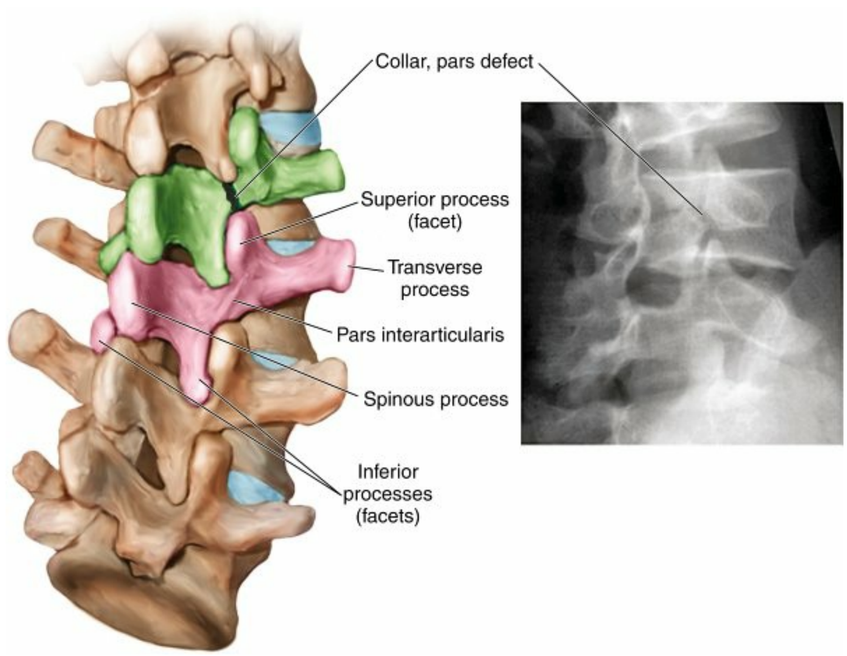

FIG. 8.18 Spondylolysis. Note disruption of the neck of the "Scottie dog."

- May or may not be associated with radicular symptoms and nerve root irritation
- Fatigue fracture from repetitive hyperextension stresses
  - Most common in gymnasts and football linemen
  - Probable hereditary predisposition

- Imaging
    - Plain lateral radiographs demonstrate 80% of the lesions.
    - Another 15% are visible on oblique radiographs, which show a defect in the neck of the Scottie dog of the lumbar spine.
    - CT, bone scanning, and **single-photon emission computed tomography (SPECT) may be helpful in identifying subtle defects.**
    - Increased uptake on SPECT is more compatible with acute lesions that have the potential to heal.
    - MRI can also identify pars defect, which is not always evident. Can also demonstrate "stress reaction" as bony edema without true lysis. Also can help show the fibrocartilaginous reparative process (Gill nodule).
- Treatment
    - Usually aimed at symptomatic relief rather than fracture healing in spondylolysis without spondylolisthesis
        - Activity restriction
        - Flexion exercises
        - Bracing
    - Nonunion is common and may not show on scans.
    - Prognosis—unilateral defects rarely have progression of the slippage (-olisthesis).

□ Spondylolisthesis—forward slippage of one vertebra on another (-olisthesis)

- Classification—six types (Newman, Wiltse, McNab) (Figs. 8.18 and 8.19; Table 8.8)

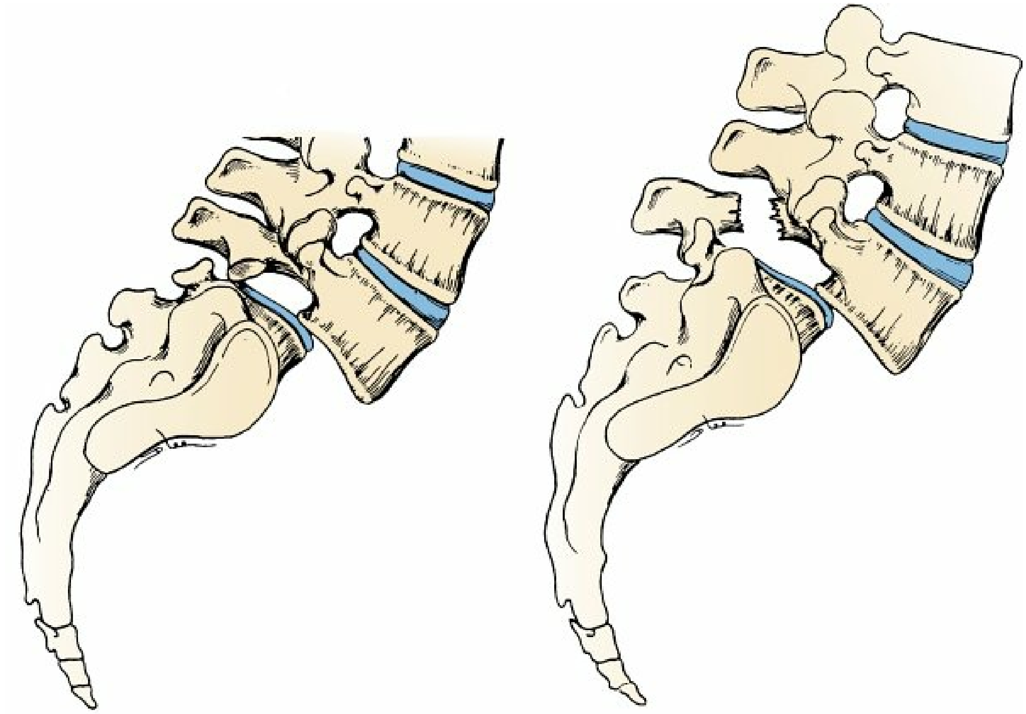

FIG. 8.19 Comparison of dysplastic and isthmic spondylolisthesis. Adapted from Rothman RH, Simeone FA: *The spine,* ed 2, Philadelphia, 1982, Saunders, p 264.

- Grading—five grades according to severity (Meyerding); severity of the slip based on amount or degree (compared with S1 width) (Fig. 8.20)
  - Grade I: 0%–25%
  - Grade II: 25%–50%
  - Grade III: 50%–75%
  - Grade IV: greater than 75%
  - Grade V: greater than 100% (spondyloptosis)
- Other relevant measurements (see Fig. 8.20)
  - Sacral inclination (normally >30 degrees)
  - Slip angle (normally <0 degrees, signifying lordosis at the L5–S1 disc)
    - Means of quantifying lumbopelvic deformity
    - Predicts intervention and affects cosmesis as well as prognosis

Table 8.8

Types of Spondylolisthesis

Type	Age	Pathology/Other
I—Dysplastic	Child	Congenital dysplasia of S1 superior facet
II—Isthmic [a]	5–50 yr	Predisposition leading to elongation/fracture of pars (L5–S1)
III—Degenerative	>40 yr	Facet arthrosis leading to subluxation (L4–5)
IV—Traumatic	Any age	Acute fracture other than pars
V—Pathologic	Any age	Incompetence of bony elements
VI—Postsurgical	Adult	Excessive resection of neural arches/facets

[a] Most common type.

- **Pelvic incidence (PI) (normally 50 degrees)**
  - The natural history of the disorder is that unilateral pars defects almost never slip and that the progression of spondylolisthesis slows over time.
  - **However, in adulthood, degeneration and narrowing of the disc (usually L5–S1) are common and lead to narrowing of the neural foramen and compression of the exiting (L5) root that causes the radicular symptoms.**

□ Pediatric/adolescent considerations

- Presentation
  - Typically back pain (instability), hamstring tightness, palpable step-off, alteration in gait (“pelvic waddle”)
  - Although symptoms may begin at any time in life, screening studies identify the slippage as occurring most commonly at age 4–6 years.
  - Severe slips are rare and may be associated with radicular findings (L5), cauda equina dysfunction, kyphosis of the lumbosacral junction, and “heart-

shaped" buttocks.

- Epidemiology
    - **Usually at L5–S1 and typically grade II**
    - Occurs most often in whites, boys, and children who participate in hyperextension activities
    - Remarkably common in some Eskimo tribes (>50%)
- Etiology
    - Thought to result from shear stress at the pars interarticularis and to be associated with repetitive hyperextension
    - Patients with type I or dysplastic spondylolisthesis are at a higher risk for slip progression and the development of cauda equina dysfunction because the neural arch is intact.
    - Spina bifida occulta, thoracic hyperkyphosis, and Scheuermann disease have been associated with spondylolisthesis.
- **Treatment**
    - **Nonoperative**
        - Most cases treated conservatively with symptomatic care
            - Usually responds to nonoperative treatment consisting of activity modification and exercise
            - Adolescents with a grade I slip may return to normal activities, including contact sports, once asymptomatic.
            - Those with asymptomatic grade II spondylolisthesis are restricted from activities such as gymnastics and football.
            - Careful observation must be maintained to

assess for progression of slip in the pediatric and adolescent patient.

- Risk factors for progression: young age at presentation, female sex, slip angle greater than 10 degrees, high-grade slip
- **Dysplastic types include dome-shaped or significantly inclined sacrum (>30 degrees beyond vertical position), trapezoid-shaped L5, sagittal shape, or dysplasia of facets of S1.**

- Surgical indications
  - Progression of slip
  - Weakness (uncommon), persistent severe back or leg pain despite conservative measures
- Operative treatment
  - Low-grade spondylolisthesis (grades I and II)
    - Surgery for patients with a low-grade slip generally consists of L5–S1 posterolateral fusion in situ and is usually reserved for those with intractable pain in whom nonoperative treatment has failed or those demonstrating progressive slippage.
    - Wiltse has popularized a paraspinal muscle–splitting approach to the lumbar transverse process and sacral alae that is frequently used in this setting.
    - L5 radiculopathy is uncommon in children with low-grade slips

and rarely if ever requires decompression.
    - Repair of the pars defect with the use of a lag screw (Buck) or tension band wiring (Bradford) with bone grafting has been reported. Indicated in young patients with slippage less than 10% and a pars defect at L4 or above.
- High-grade disease (grades III through V)
    - Commonly cause neurologic abnormalities
    - L5–S1 isthmic spondylolisthesis causes an L5 radiculopathy (in contrast to S1 radiculopathy in L5–S1 HNP).
    - Prophylactic fusion is recommended in growing children with slippage of more than 50% (grades III, IV, V).
    - Often requires in situ bilateral posterolateral fusion, usually at L4–S1 (L5 is too far anterior to effect L5–S1 fusion), with or without instrumentation
    - Nerve root exploration is controversial but usually limited to children with clear-cut radicular pain or

significant weakness.
- Other surgical procedures described include posterior decompression, fibular interbody fusion, and posterolateral fusion without reduction, with excellent long-term results (Bohlman), as well as L5 vertebrectomy and fusion for spondyloptosis (Gaines resection).

- **Considerations for reduction of spondylolisthesis**
  - Reduction of spondylolisthesis has been associated with a 20%–30% incidence of L5 root injuries (most are transient) and should be used cautiously.
  - The most commonly cited indications are a cosmetically unacceptable deformity and L5–S1 kyphosis so severe that the posterior fusion mass from L4 to the sacrum would be under tension without reversal of the kyphosis.

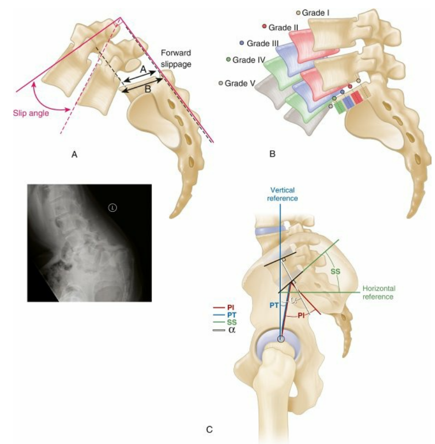

FIG. 8.20 Spondylolisthesis. (A) Slip angle and percentage of forward slippage. The slip angle is measured from the superior border of L5 and a perpendicular line from the posterior edge of the sacrum. (B) Meyerding grades I to V. The grade of spondylolisthesis is determined by dividing the sacral body into four segments, with grade V as spondyloptosis. (C) *Pelvic incidence (PI):* A line perpendicular to the midpoint of the sacral end plate is drawn. A second line connecting the same sacral midpoint and the center of the femoral heads is drawn. The angle subtended by these lines is the pelvic incidence. Should the femoral heads not be superimposed, the center of each femoral head is marked and the point halfway between the two centers serves as the femoral head center. *Pelvic tilt (PT):* A line from the midpoint of the sacral end plate is drawn to the center of the femoral heads.

The angle subtended between this line and the vertical reference line is the pelvic tilt.
Sacral slope (SS): A line parallel to the sacral end plate is drawn. The angle subtended between this line and the horizontal reference line is the sacral slope.
α Angle–L5 incidence: A line from the midpoint of the upper end plate of L5 is connected to the center of the femoral heads. A second line perpendicular to the upper L5 end plate is drawn from the midpoint of the end plate. The angle subtended by these two lines (α) is the L5 incidence.
Modified from Herring J: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2007, Elsevier.

- In situ fusion leaves a patient with a high-grade slip and lumbosacral kyphosis with such severe compensatory hyperlordosis above the fusion that long-term problems frequently ensue.
- Reduction in this setting is gaining widespread acceptance.
- Close neurologic monitoring is needed during the procedure and for several days afterward to detect postoperative

neuropathy.

- Degenerative spondylolisthesis considerations
  - Epidemiology
    - More common in African Americans, persons with diabetes, and women older than 40 years
    - **Most common at the L4–5 level**
    - Reported to be more common in patients with transitional (sacralized) L5 vertebrae and sagittally oriented facet joints
  - Presentation
    - Central stenosis results in neurogenic claudication.
      - Decreased ambulatory status
      - Leg heaviness and cramping
      - Improved with flexion, exacerbated with extension (shopping cart sign)
      - Bowel and bladder dysfunction (uncommon)
    - Lateral recess stenosis results in nerve root compression.
      - **Typically traversing nerve root compression**
      - Due to compression between the hypertrophic and subluxated inferior facet of superior vertebra and the posterosuperior body of inferior vertebra
      - L4–5 degenerative spondylolisthesis typically compresses the L5 (traversing) nerve root.
  - Treatment
    - Nonoperative—same as for stenosis
    - Operative—decompression of the nerve roots and stabilization by fusion (traditionally posterolateral), with or without instrumentation
    - Outcomes (SPORT trial)
      - At 4-year follow-up, primary outcome measures (SF-36 Bodily Pain and Physical Function, Oswestry Disability Index) are significantly better for operative than for nonoperative groups.
      - Both operative and nonoperative

groups experienced improvement from baseline.

- **Adult isthmic spondylolisthesis considerations**
  - Introduction
    - Familial association
    - Associated increased PI
      - As PI increases, so does sacral slope, necessitating an increase in lumbar lordosis to maintain sagittal balance.
      - Normal individuals have a PI of 50–55 degrees, whereas patients with spondylolisthesis have a PI of 70–80 degrees.
    - However, pelvic incidence does not predict progression of listhesis.
    - L5–S1 most common level for isthmic spondylolisthesis
  - Presentation
    - Low back pain—typically aggravated with extension and due to posterior element compression
    - **Radiculopathy—typically exiting nerve root and due to compression from the fibrocartilaginous reparative pars (Gill nodule).**
    - **L5–S1 isthmic spondylolisthesis results in L5 (exiting nerve root) radicular pain.**
  - Treatment
    - Nonoperative—hamstring stretching, core strengthening, lumbar flexion-based exercises, NSAIDs
    - Operative options
      - Foraminal decompression
      - In situ posterolateral L5–S1 fusion for grade I/II slips versus posterolateral L4–S1 fusion for grade III/IV/V slips
      - Reduction controversial—may result in L5 (exiting) nerve root palsy
      - Interbody fusion controversial—may increase fusion rates, improve neuroforaminal height, help restore lumbar lordosis, and avoid fusion to L4 in high-grade slips

- **Cauda equina syndrome**

- Description and diagnosis
  - Secondary to large extruded disc, surgical trauma, and/or hematoma
  - Suspected in patients with postoperative urinary retention
  - Manifests as bilateral buttock and lower extremity pain as well as bowel or bladder dysfunction (usually urinary retention), saddle anesthesia, and varying degrees of loss of lower extremity motor or sensory dysfunction
  - Digital rectal examination is used for the initial diagnosis.
  - Examiner should check for presence of rectal tone, perianal sensation, and volitional control/contraction. In particular, evaluation of perianal sensation is important for immediate diagnosis.
  - **Urgent/emergent MRI can help assess for compression of the cauda equina.**
- **Treatment**
  - **Timing of surgical decompression remains controversial, but in general earliest possible decompression is indicated to arrest progression of neurologic loss.**
  - **Although the prognosis for recovery is guarded in most cases, surgical decompression within the first 48 hours has been reported to lead to best outcomes.**
  - Surgical complications
    - Recurrent herniation (usually acute recurrence of signs/symptoms after a 6- to 12-month pain-free interval)
      - Herniation at another level
      - Unrecognized lateral stenosis (may be the most common)
    - Vascular injury—may occur during attempts at disc removal if curettes or pituitary rongeurs are allowed to penetrate the anterior longitudinal ligament
      - Intraoperative pulsatile bleeding due to deep penetration is treated with rapid wound closure, IV administration of fluids and blood, repositioning of the patient, and a transabdominal approach to find and stop the source of bleeding.
      - Mortality may exceed 50%.
      - Late sequelae of vascular injuries include delayed hemorrhage,

pseudoaneurysm, and arteriovenous fistula formation.

- Nerve root injury—more common with anomalous nerve roots
- Iatrogenic vertebral instability
- Pseudarthrosis—may be reduced with use of instrumentation
- Epidural fibrosis occurs at about 3 months postoperatively and may be associated with back or leg pain.
    - Lysis of adhesion is technically challenging and should be considered only after conservative measures have been maximized; early postoperative nerve root mobilization can help reduce the risk of recurrent nerve root fibrosis.
    - Scarring can be differentiated from recurrent HNP with gadolinium-enhanced MRI.

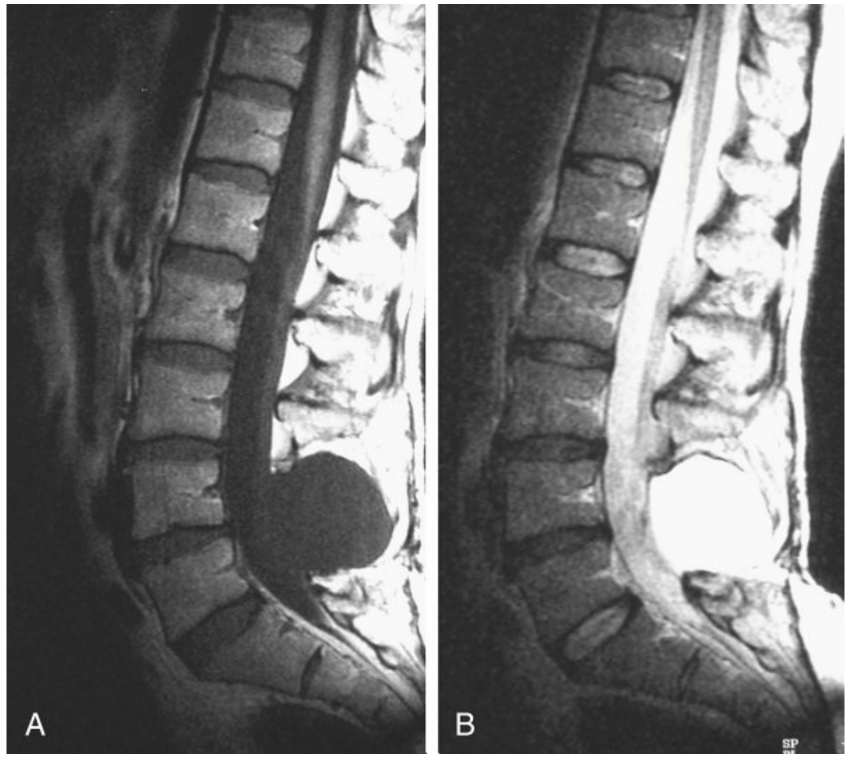

FIG. 8.21 Postoperative pseudomeningocele. Sagittal T1-weighted (A) and T2-weighted (B) MR images demonstrating a large cystic mass that is visible in the laminectomy defect. It has signal intensities identical to those of cerebrospinal fluid and shows no enhancement.
From Van Goethem JWM et al: Spine and lower back pain. In Law M et al, editors: *Problem solving in neuroradiology,* Philadelphia, 2011, Elsevier, p 610.

- **Dural tear—1%–4% incidence**
  - Primary repair necessary to avoid the development of a pseudomeningocele or spinal fluid fistula (Fig. 8.21)
  - **More common during revision surgery (up to 47%)**
  - Fibrin adhesive sealant may be a useful adjunct for effecting dural closure.
  - Bed rest and subarachnoid drain placement are advocated if CSF leak is suspected postoperatively.
  - If tear is adequately repaired, clinical outcomes are generally unaffected.
- Wound infection (≈1% in open discectomy) —increased risk in diabetics
- **Discitis (3–6 weeks postoperatively, with rapid onset of severe back pain).** (Also see Spinal Infections.)

- **MRI with gadolinium is the best diagnostic modality.**
- Needle biopsy followed by empirical use of antibiotics
- Surgery usually not needed

Adult Deformity

- **Adult scoliosis** —coronal plane deformity
  - Usually defined as scoliosis in patients older than 20 years; more symptomatic than its childhood counterpart (see Chapter 3, Pediatric Orthopaedics).
  - Classification
    - Idiopathic—progression of untreated adolescent scoliosis
    - De novo
      - Neuromuscular
      - Degenerative (secondary to degenerative disc disease or osteoporosis)
      - Posttraumatic
      - Iatrogenic
  - Diagnosis
    - Association between pain and scoliosis in the adult is controversial.
    - Progression of symptoms to side of curve convexity indicates poor prognosis.
    - Lumbar stenosis, in particular in the concavity of the curve
    - Cosmetic deformity may be present.
    - Cardiopulmonary problems (thoracic curves >60–65 degrees may alter pulmonary function tests; curves >90 degrees may affect mortality)
    - Myelography with CT or MRI is useful for evaluation of nerve root compression in stenosis.
    - MRI, facet injections, and/or discography may be used to evaluate symptoms in the lumbar spine.
  - Curve progression
    - There is no demonstrated association between curve progression and pregnancy.
    - Progression is unlikely in curves less than 30 degrees.
    - Right thoracic curves more than 50 degrees are at the highest risk for progression (usually 1 degree/yr), followed by right lumbar curves.
  - Treatment

- Nonoperative treatment
    - Uncertain correlation between adult scoliosis and back pain makes conservative management essential.
    - Nonoperative treatment includes NSAIDs, weight reduction, therapy, muscle strengthening, facet joint injections, and orthoses (used with activity).
- **Operative indications**
    - Young adults (<30 years) with curves greater than 50–60 degrees
    - Older patients with refractory pain
    - Sagittal plane imbalance is a strong predictor of disability.
    - **Progressive curves**
    - Cardiopulmonary compromise (worsening pulmonary function test findings in severe curves)
    - Refractory spinal stenosis
- Operative techniques
    - Selective posterior fusions for flexible thoracic curves
    - Combined anterior release and fusion and posterior fusion and instrumentation may be beneficial for large (>70-degree), more rigid curves (as determined on side-bending films) or curves in the lumbar spine.
    - Fusion to L5
        - Associated with development of L5–S1 degenerative disc disease
        - Associated with progressive sagittal imbalance
    - Fusion to sacrum
        - Increases stability of long lumbar fusion
        - Higher incidence of pseudarthrosis and potential for postoperative gait disturbances
    - Fixation to ilium
        - Indicated in lumbosacral fusions involving more than three levels
        - Potential for prominent implants; may be less with use of S2AI screws than with traditional iliac screws

- Anterior interbody fusion
  - Achieves anterior column support
  - Increases stability of long fusions including L5–S1
  - Helps maintain corrections of sagittal and coronal deformities
  - Increased fusion rates
- Outcomes
  - Nonsurgically treated adults with late-onset idiopathic scoliosis are highly productive at 50-year follow-up, with a slightly increased risk of shortness of breath with activity and chief complaints of back pain and poor cosmesis.
  - Operative risk for these patients is high (up to a 25% complication rate in older patients).
- **Complications**
  - **Pseudarthrosis (15% with posterior fusion only; the highest risk at the thoracolumbar junction and at L5–S1)**
  - Urinary tract infection, instrumentation problems, infection (up to 5%), and neurologic deficits
  - Preservation of normal sagittal alignment with fusion is critical to outcomes.

▪ **Kyphosis —**sagittal plane deformity

□ Etiology
- Idiopathic (old Scheuermann disease [since adolescence])
- Posttraumatic (missed posterior ligamentous complex [PLC] injury)
- AS
- Metabolic bone disease
  - Progressive kyphosis secondary to multiple osteoporotic compression fractures
  - Treated with exercise, bracing, and medical management of the underlying bone disease

□ Nontraumatic adult kyphosis
- Severe idiopathic or congenital kyphosis may be a source of back pain in the adult, particularly when it is present in the thoracolumbar or lumbar spine.
- When the symptoms fail to respond to nonoperative management (see preceding discussion on adult scoliosis), posterior instrumentation and fusion of the entire kyphotic segment with a compression implant may be indicated.
- Anterior fusion is considered for curves not correcting to 55

degrees or less on hyperextension lateral radiographs.

- **Kyphotic deformity in AS**
  - Introduction
    - Frequently seen in patients with AS
    - Progressive inflammation and ossification of the spine results in kyphotic deformity of the spine.
    - Results in loss of horizontal gaze
    - Can also be associated with hip flexion contractures
  - Spinal involvement can involve any level of the spine.
    - Frequently direct cervical and cervicothoracic involvement
      - Chin-on-chest deformity
      - Measurements include chin-brow angle.
    - Progressive deformity of the thoracolumbar spine can result in loss of horizontal gaze as well.
  - Nonsurgical management should include prevention with careful exercise and use of medications.
  - Surgical management
    - Should be undertaken only if deformity is debilitating—surgical correction of kyphotic deformity in patients with AS associated with high risk of complications
    - **Careful assessment of location of deformity, including hip and knees**
      - **If present these should be corrected first.**
      - **May eliminate the need for surgical management of the spine**
    - Spinal osteotomies
      - Typically performed at level of greatest deformity
      - Lumbar osteotomies are below the level of the spinal cord and may be safer to perform—traditionally performed at L3.
      - **Cervicothoracic pedicle subtraction osteotomy (PSO) typically performed at C7–T1**
        - Typically, vertebral artery has not entered cervical spine at C7

- PSO performed (described later)
- Careful postoperative examination of C8 root
- Staged anterior procedure may be necessary to achieve anterior column support at C7–T1 if there is a large anterior defect after osteoclasis.

□ Posttraumatic kyphosis

- Present after fractures of the thoracolumbar spine treated without surgery, particularly in setting of PLC injury
- Fractures treated by laminectomy without fusion and also fractures for which fusion has been performed unsuccessfully
- Progressive kyphosis may produce pain at the fracture site, with radiating leg pain and/or neurologic dysfunction if there is associated neural compression.

□ Postlaminectomy deformity

- Progressive deformity (usually kyphosis) resulting from a prior wide laminectomy
- In children this procedure is followed by a high risk (90%) of deformity.
- Consider fusion plus internal fixation prophylactic for young patients who require extensive decompression.
- Fusion using pedicle screw fixation is best for reconstruction in the adult lumbar spine.
- Operative option:
    - Posterior fusion with compression instrumentation for milder deformities
    - Combined anterior and posterior osteotomies, instrumentation, and fusion for more severe deformities
    - Anterior spinal cord or cauda equina decompression combined with posterior instrumentation and fusion for cases involving neurologic dysfunction
    - **Osteotomies**
        - Posterior column osteotomies (PCOs) include both Smith-Petersen osteotomy (SPO) and Ponte

osteotomy—5–10 degrees of sagittal plane correction

- SPO performed through an ankylosed disc space (osteoclasis), whereas Ponte osteotomy is typically closed through intact flexible disc space
  - Excision of superior and inferior articular facet at level of osteotomy
  - Removal of inferior lamina, spinous process, and ligamentum flavum at level of osteotomy (typically chevron-shaped osteotomy)
  - In patients with AS and DISH and in those with ankylosis, osteotomy closure may require aggressive opening of the intervertebral disc anteriorly (known as *osteoclasis*).
    - Osteoclasis is becoming less commonly used, because it is a spinal column–lengthening procedure that can result in traumatic vascular injury of the great

vessels and create a void anteriorly, with loss of anterior column support.

- PSO—30 degrees of sagittal plane correction
    - Wide extensive laminectomy required
    - Pedicles isolated at the level of the osteotomy by resection of superior and inferior articular facets bilaterally
    - Transverse process disarticulated from pedicle
    - Pedicles resected back to the level of the posterior vertebral body
    - Vertebral body decancellated through pedicles with curets
    - Lateral walls of vertebral body carefully isolated with vertebral body retractors
    - Osteotomy completed with removal of wedge-shaped cortical bone of lateral wall
    - Care is taken not to complete the osteotomy through anterior vertebral

body, maneuver that could can result in an extremely unstable spine and parallel collapse of the vertebral body with undercorrection.
- Temporary rods are frequently placed during osteotomy to reduce risk of vertebral body translation.
- Once osteotomy is closed, the dural sac and exiting and traversing nerve roots are checked to ensure excessive compression and dural buckling are not present.

- Vertebral body resection (VBR) —30– 40 degrees of sagittal plane correction
    - Posterior elements removed as during PSO (see first four steps)
    - Vertebral body: removed piecemeal or en bloc
        - En bloc—vertebral retractors are carefully inserted around vertebral body; intervertebral disc is removed above and below vertebral body; vertebral body is carefully rotated around the common dural sac.
        - Piecemeal—vertebral body retractors are carefully inserted around vertebral body;

decancellation of vertebral body with curets through pedicles; vertebral body removed with curets and pituitary rongeurs.

- **Metabolic bone disease**
  - Introduction
    - Osteopenia and osteoporosis remain common causes for vertebral body compression fractures, with subsequent kyphosis and positive sagittal balance.
    - Prevention of compression fractures has been successful with bisphosphonate treatment, with 65% decrease in vertebral fractures at 1 year and 40% at 3 years.
    - An underlying malignancy as a cause of the osteopenia should be considered; evaluation with MRI is sensitive for determining the presence of tumor.
    - Surgical attempts at correction and stabilization are marked by a high complication rate.
  - Cement augmentation—vertebroplasty and kyphoplasty
    - Percutaneous techniques designed to relieve pain typically use polymethylmethacrylate (PMMA).
      - Vertebroplasty uses low-volume, high-pressure, low-viscosity cement.
      - Kyphoplasty has also been proposed to correct deformity (controversial); uses high-volume, low-pressure, higher-viscosity cement.
    - Indications
      - Subacute injuries, although precise indications are poorly defined
      - To respond to either technique, a fracture must still be in the active healing phase, which is best demonstrated on MRI (spin tau inversion recovery [STIR] sequences).
      - A patient with a painful but healed fracture is unlikely to improve.
      - Improvement in pain and quality of life has been questioned in later studies.
    - Complications
      - Hypotensive reaction to cement
      - Extravasation of cement into canal, resulting in compression of neural elements
      - Pulmonary embolization of cement (debated)

Sacropelvis

- **Sacroiliac joint (SIJ) dysfunction**
  - Diagnosis
    - Gaenslen test—performed with patient lying on affected side without support. Direct compression of pelvis reproducing symptoms is considered positive exam finding.
    - FABER test—performed with *f*lexion, *ab*duction, and *e*xternal *r*otation of involved extremity. If maneuver reproduces symptoms, then it is considered positive exam finding.
    - Direct compression with reproduction of symptoms or with flexion, abduction, and external rotation test of involved extremity
  - Treatment
    - Local injections may have diagnostic and therapeutic roles.
    - Orthotic management (trochanteric cinch) can be helpful.
    - Fusion
      - Typically indicated if infection is present
      - Fusion for SIJ dysfunction from degeneration remains controversial; however, evidence suggests that in carefully selected patients in whom extensive conservative measures have failed, consideration of an isolated SIJ fusion may have some benefit
      - Diagnostic injections and/or radiofrequency ablations can help aid in diagnosis and determine efficacy of SIJ fusion.
      - Computer-navigated and/or image-guided SIJ fusions may be associated with lower morbidity and mortality and higher the rate of recovery.
- **Coccygodynia**
  - Diagnosis
    - Pain and point tenderness over coccyx
    - More common in women and may occur after pregnancy or minor trauma or idiopathically
    - Occasionally associated with a fracture
    - Plain radiographs may demonstrate fracture or an increased angular deformity to coccyx but findings can frequently be normal.
  - Treatment
    - Symptoms may last 1–2 years but are almost always self-limiting.
    - Treatment should be conservative and may include use of a

sitting donut, NSAIDs, stretching exercises, and local injection.
- MRI or CT of pelvis and/or spine should be considered if symptoms persist despite conservative measures.
- Surgical resection of the coccyx has a high failure rate and carries significant risk of complications.

▪ **Sacral insufficiency fracture**

□ Diagnosis
- Occurs in older patients with osteopenia
- Often without a history of trauma
- Complaints include low back and groin pain.
- This fracture is diagnosed with a technetium TC 99m bone scan (H-shaped uptake pattern is diagnostic) or with CT.

□ Treatment
- Nonoperative: rest, analgesic medication, and ambulatory aids until symptoms resolve
- Evaluation and management should include an evaluation and workup for osteopenia and osteoporosis.

Spinal Tumors

□ Introduction—spine is a frequent site of metastasis; certain tumors with a predilection for the spine have unique manifestations in vertebrae.
- Tumors of the vertebral body
  - Histiocytosis X
  - Giant cell tumor
  - Chordoma
  - Osteosarcoma
  - Hemangioma
  - Metastatic disease
  - Marrow cell tumors
- Tumors of the posterior elements
  - Aneurysmal bone cysts
  - Osteoblastoma
  - Osteoid osteoma

□ Imaging studies
- Radiographic changes
  - Most tumors are osteolytic and not demonstrated on plain films until greater than 30% of the vertebral body has been destroyed.
  - Absence of a pedicle (winking owl sign on

anteroposterior radiograph)
            - Cortical erosion or expansion
            - Vertebral collapse
        - Bone scans can be helpful in cases of protracted back pain or night pain.
        - **MRI is the diagnostic modality of choice.**
            - Malignant tumors have decreased T1 and increased T2 signal intensities.
            - Sensitivity of MRI is increased with use of gadolinium.
            - Malignant tumors occur more frequently in the lower spinal levels (lumbar > thoracic > cervical) and in the vertebral body.
        - CT scan can provide information on bony involvement and mechanical stability.
            - In cases in which the primary tumor is unknown, CT-guided needle biopsy is often possible and may avoid surgical open biopsy.
    - General treatment considerations
        - Multispecialty involvement important
        - Prognosis dependent on several factors; considerations should include:
            - Primary versus metastatic lesion
            - Tumor pathology
            - Location in cephalad-caudal direction (cervical vs. thoracic vs. lumbar vs. sacrum vs. pelvis)
            - Location within vertebral body (vertebral body vs. posterior element)
            - Presence of neurologic involvement and duration of deficit
            - Mechanical stability
        - Complete surgical excision (en bloc) can be difficult but may be an option in selected cases; however, surgical excision frequently consists of tumor debulking and stabilization.
        - Preoperative embolization should be considered, in particular for renal cell and thyroid carcinomas.
        - Adjuvant therapy (chemotherapy, external beam radiation therapy) should be considered and can be an important part of therapy for many spinal primary and metastatic tumors.
        - For more details on these tumors, refer to Chapter 9, Orthopaedic Pathology.
- **Metastasis—the most common tumors of the spine, spreading to the vertebral body first and later to the pedicles**

- ▫ Diagnosis
  - History of cancer
    - Breast, lung, thyroid, renal, gastrointestinal, and prostate metastases are the most common tumors to metastasize to bone.
    - Lymphoma, myeloma
  - Recent unexplained weight loss
  - Night pain
  - Age older than 50 years
- ▫ Examination—careful physical and neurologic examinations vital
- ▫ Imaging
  - Should include plain radiographs of entire spine
  - **MRI with gadolinium of suspected levels; may require imaging of entire neuraxis**
  - **CT scan of chest, abdomen, and pelvis can help identify possible primary lesion.**
  - Bone scan can assist in assessing for primary lesion and remote sites of involvement (but results can be negative in up to 25% of cases).
  - Percutaneous biopsy of spinal lesion may avoid surgical open biopsy and can confirm diagnosis.
- ▫ Treatment
  - Regardless of surgical or nonsurgical intervention, treatment should include multispecialty involvement.
  - Nonsurgical treatment
    - Nonoperative treatment should be considered for tumors that are radiosensitive, chemosensitive, or hormonally responsive.
    - Radiosensitivity varies among primary tumor types, but newer techniques have made traditionally radioresistant tumors radioresponsive.
    - Surgical intervention along with adjuvant radiation and/or chemotherapy should be considered for patients with mechanical instability or evolving/progressive neurologic deficit.
    - In the case of epidural spinal cord compression, radiation therapy should be combined with direct surgical decompression for the best clinical outcomes.
  - Surgical treatment
    - Indications

        - Progressive neurologic dysfunction that is unresponsive to radiation therapy
        - Persistent pain despite radiation therapy
        - Need for an open diagnostic biopsy
        - Pathologic mechanical instability
        - Radioresistant tumor
    - Life expectancy should play an important role with regard to whether surgical treatment is performed.
    - Techniques
        - Vertebroplasty is gaining favor in cases of metastatic disease of the spine (myeloma, breast) without instability or neurologic compromise and represents a minimally invasive alternative to open surgery.
        - In cases of neurologic deficit and/or spinal instability, anterior decompression and stabilization (preserving intact posterior structures) may result in recovery of neurologic function.
        - Posterior stabilization or a circumferential approach is indicated in cases of multiple levels of destruction, involvement of both the anterior and posterior columns, or translational instability.

▪ **Primary tumors**

□ Osteoid osteoma (<2 cm in size) and osteoblastoma (≥ 2 cm in size)

- Diagnosis
    - Common in the spine
    - May manifest as painful scoliosis in a child
    - Pain typically relieved by aspirin and/or NSAIDs
    - Osteoblastomas typically occur in the posterior elements in older patients, with neurologic involvement in more than half.
- Imaging
    - Bone scan can help localize the level.
    - Thin-cut CT can direct surgical excision.
    - MRI is sensitive but not specific; surrounding

hyperemic soft tissue may be misidentified as an aggressive lesion.

- Treatment
  - Scoliosis (lesion is typically at apex of convexity) resolves with early resection (within 18 months) in a child younger than 11 years.
  - If there is no scoliosis, aspirin and/or NSAIDs are the mainstay of treatment.
  - Surgery is performed if nonoperative treatment fails.
    - En bloc resection versus marginal or intralesional excision
    - CT-guided radiofrequency ablation (controversial)
    - Posterior spinal fusion may be required, depending on extent of resection

□ Aneurysmal bone cyst

- Diagnosis
  - May represent degeneration of more aggressive tumor
  - Manifests during second decade of life
  - Arises in the posterior elements, but possibly also involves the anterior elements
- Treatment
  - Marginal or wide excision if possible
  - Alternatively, curettage and bone grafting
  - Radiation therapy if lesion inaccessible

□ Hemangioma

- Diagnosis
  - Common; typically seen in asymptomatic patients
  - Symptomatic patients older than 40 years may seek treatment after small spinal fractures.
  - The classic patient with hemangioma has "jailhouse striations" on plain films with spikes of bone on CT.
  - Vertebrae are typically of normal size and not expanded (as in Paget disease).
- Treatment
  - Observation or radiation therapy in cases of persistent pain after pathologic fracture
  - Anterior resection and fusion are reserved for refractory cases or pathologic collapse and neural

compression, but massive bleeding may be encountered.

- □ Eosinophilic granuloma
  - Diagnosis
    - Usually seen in children younger than 10 years
    - More common in thoracic spine
    - May manifest as progressive back pain
    - **Classically, vertebral flattening (vertebra plana [Calvé disease]) seen on lateral radiographs**
    - Biopsy may be required for diagnosis unless the radiographic picture is classic.
  - Treatment
    - Symptoms are usually self-limiting.
    - Chemotherapy is useful for the systemic form.
    - Bracing may be indicated in children to prevent progressive kyphosis.
    - Low-dose radiation therapy may be indicated in the patient with neurologic deficits.
    - At least 50% reconstitution of vertebral height may be expected.
- □ Giant cell tumor
  - Diagnosis
    - Usually seen in the fourth and fifth decades of life
    - Destruction of the vertebral body in an expansile fashion
  - Treatment
    - Surgical excision and bone grafting
    - High recurrence rate is reported.
    - Radiation therapy should be avoided because of the possibility of malignant degeneration of the tumor.
- □ Plasmacytoma/multiple myeloma
  - Diagnosis
    - Shown as osteopenic lytic lesions on radiographs
    - Workup includes skeletal survey.
    - **Lesions are "cold" on bone scans in up to 25% of cases.**
    - Pain secondary to pathologic fractures
    - Increased calcium level and decreased hematocrit levels as well as abnormal protein measurements are common.
  - Treatment
    - Radiation therapy with or without chemotherapy

        - Surgery is reserved for patients with spinal instability and those with refractory neurologic symptoms.
- □ Chordoma
    - Diagnosis
        - Slow-growing lytic lesion in the midline of the anterior sacrum or the base of the skull
        - May occur in other vertebrae (cervical spine next most common)
        - Patient with this tumor may present with intraabdominal complaints and a presacral mass.
        - **Physaliferous cells in biopsy specimens**
    - Treatment
        - Surgical excision—treatment of choice (tumor is radioresistant)
        - Typically requires resection of sacral nerve roots to achieve margin
        - If half of the sacral roots (i.e., all roots on one side) are preserved, patient may still maintain bowel and bladder function.
        - High recurrence rate
        - Although a complete cure is rare, patients typically survive 10–15 years after diagnosis.
        - Lumbopelvic reconstruction is required after surgical resection of sacral lesions.
- □ Osteochondroma
    - Arises in the posterior elements and is frequently seen in the cervical spine
    - Treatment is by excision, which may be necessary to rule out sarcomatous changes.
- □ Neurofibroma
    - Benign tumor of neural origin
    - Can manifest as enlarged intervertebral foramina seen on oblique radiographs
    - Malignant degeneration to fibrosarcoma can occur, which may manifest as new-onset neurologic deficit.
- □ Malignant primary skeletal lesions
    - Diagnosis
        - Osteosarcoma, Ewing sarcoma, and chondrosarcoma are uncommon in the spine.
        - When they occur they are associated with a poor prognosis.
    - Treatment

- Chemotherapy and irradiation are the mainstays of treatment, but aggressive surgical excision may have a role.
- The lesions may actually be metastases, which are treated palliatively.

□ Lymphoma

- Can manifest as “ivory” vertebrae
- Usually associated with a systemic disease
- Lymphoma typically treated with radiation and/or chemotherapy
- Surgery typically only necessary if pathologic fracture is present

□ Fibrous dysplasia

- At least 60% of patients with polyostotic fibrous dysplasia have spinal involvement, mostly in the posterior elements.
- There is a strong correlation between the presence of a lesion and scoliosis, making scoliosis screening very important in the population with polyostotic disease.

Spinal Infections and Inflammatory Arthritides

- **Osteodiscitis—disc space infection**
  - Introduction
    - Bloodborne infection can primarily invade the disc space in children.
    - *Staphylococcus aureus* is the most common offender, but gram-negative organisms are common in older patients.
  - Diagnosis
    - Although all age groups are affected, children (mean age, 7 years) are affected more often.
    - Presentation
      - History—may or may not include recent spinal procedure such as spinal injection
      - Inability to walk, stand, or sit
      - Back pain/tenderness
      - Restricted range of motion
    - Laboratory findings—elevated ESR, CRP, and WBC count (often high normal or mildly elevated)
    - Imaging
      - Radiographic findings
        - Loss of normal lumbar lordosis—earliest finding
        - Disc space narrowing
        - End plate erosion
        - Findings do not occur until 10 days to 3 weeks after onset, and their absence is unreliable.
      - MRI with gadolinium is the diagnostic modality of choice.
      - Bone scan may be useful in the diagnosis as well.
  - Treatment
    - **Typically medical**
      - **Percutaneous biopsy should be obtained if possible.**
      - **IV antibiotics should be held until biopsy performed (if possible) to reduce incidence of negative culture results.**
      - **Antibiotic therapy should be targeted once culture and sensitivity results are known.**
    - Surgical indications

- Patient medically systemically ill (uncommon for osteomyelitis)
- Evidence of epidural abscess
- Failure of medical treatment
- Inability to obtain percutaneous biopsy
- No known diagnosis
- Mechanical instability (uncommon)
- Neurologic deficits (uncommon)

▪ **Pyogenic vertebral osteomyelitis**

□ Introduction

- Seen with increasing frequency

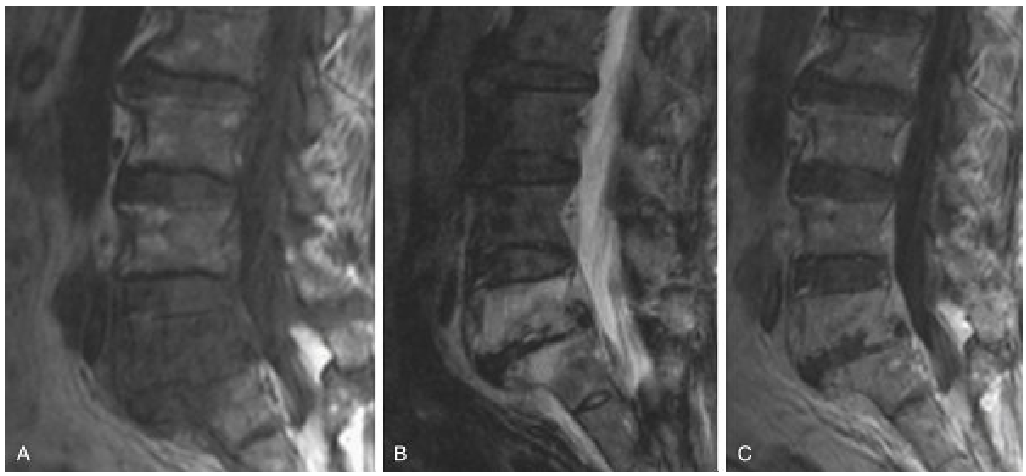

FIG. 8.22 Pyogenic spondylodiscitis at L5–S1 in an intravenous drug abuser. Sagittal T1-weighted MR image (A), T2-weighted spin tau inversion recovery image (B), and gadolinium-enhanced T1-weighted MR image (C) showing characteristic appearance of pyogenic osteodiscitis with end plate and disc space involvement.
From Kim PE et al: Spine: tumors and infections. In Law M et al, editors: *Problem solving in neuroradiology,* Philadelphia, 2011, Elsevier, p 589.

- Commonly still associated with a significant (6- to 12-week) delay in diagnosis
- Organism usually hematogenous (*S. aureus* in 50%–75% of cases)

□ Diagnosis

- History and physical examination
  - Older, debilitated patients
  - IV drug users are at increased risk.
  - History of unremitting spinal pain at any level is characteristic, and tenderness, spasm, and loss of motion are seen.
  - More common in patients with a history of pneumonia, urinary tract infection, skin infection, or immunologic compromise (transplantation, RA, diabetes mellitus, human immunodeficiency

virus [HIV positivity with $CD4^+$ counts <200 cells/μL])
        - Fungal spondylitis can be seen in patients with immunologic compromise.
        - Neurologic deficits—seen in older patients, patients with infections at more cephalic levels of the spine, patients with debilitating systemic illnesses such as diabetes or RA, and those with delayed diagnoses
    - Laboratory findings—elevated ESR, CRP, and WBC count (often high normal or mildly elevated)
    - Imaging
        - Plain radiographic findings
            - Osteopenia
            - Paraspinous soft tissue swelling (loss of a psoas shadow)
            - Erosion of the vertebral end plates
            - Disc destruction (disc space preserved in metastatic disease)
        - Bone scanning is sensitive for a destructive process.
        - MRI
            - Sensitive for detecting infection and specific in differentiating infection from tumor
            - Gadolinium enhances MRI sensitivity (Fig. 8.22).
        - Tissue diagnosis via blood cultures or aspiration of the infection is mandatory.
- □ Treatment
    - Nonoperative
        - After tissue diagnosis, 6–12 weeks of IV antibiotics is the treatment of choice.
        - Bracing may be used adjunctively.
    - Operative
        - Open biopsy is indicated when a tissue diagnosis has not been made.
        - Anterior débridement and strut grafting are reserved for refractory cases that are associated with abscess formation or cases involving neurologic deterioration, extensive bony destruction, or marked deformity.
        - Posterior surgery is usually ineffective for

débridement; posterior stabilization may occasionally be required after anterior débridement and strut grafting.

- **Epidural abscess**
  - Introduction
    - Bacterial infection that results in accumulation of purulent material within the epidural space
    - Most abscesses located posteriorly in the thoracic and lumbar spine
    - Can frequently extend across multiple segments
  - Diagnosis
    - History
      - Back pain is the most common presenting symptom, followed by neurologic deficit and fever.
      - Diagnosis is delayed in half of patients.
      - Patients are frequently more systemically ill than patients with osteodiscitis and osteomyelitis.
      - Risk factors include IV drug abuse, diabetes, and multiple medical problems.
    - Laboratory findings—elevated ESR and CRP values (often more elevated than in osteodiscitis)

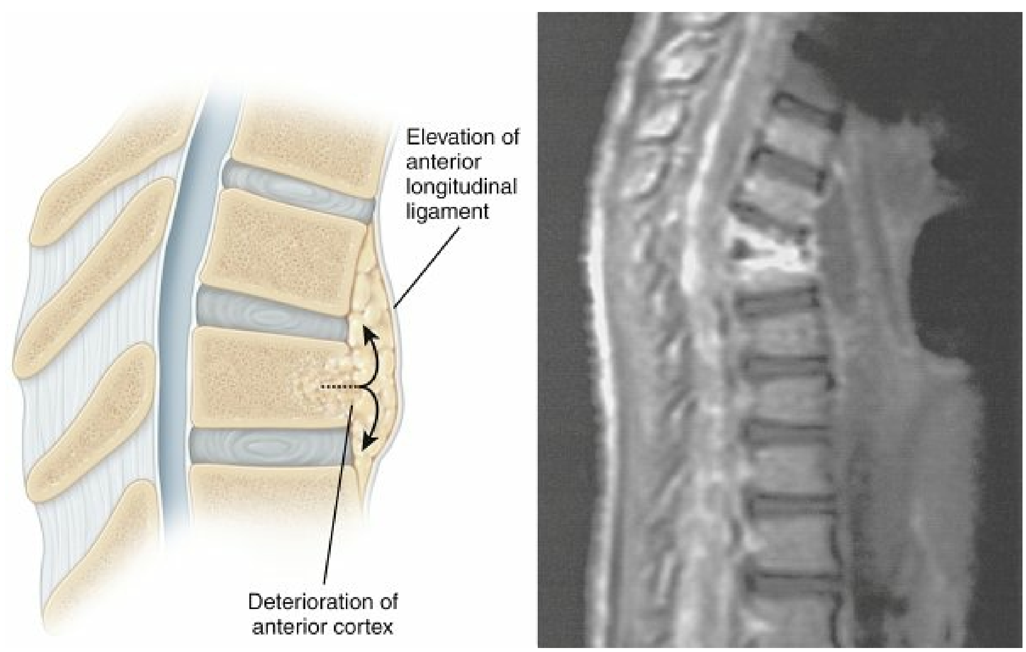

FIG. 8.23 Pathogenesis of spinal tuberculosis.
From Herring JA: *Tachdjian's pediatric orthopaedics*, ed 3, Philadelphia, 2002, Saunders, p 1832.

    - Imaging
      - **MRI—modality of choice; supplementation with gadolinium allows differentiation between**

epidural abscess and CSF.

- Abscess and CSF have high signal intensity on T2-weighted images.
- Gadolinium enhances the pus on T1-weighted images, whereas CSF remains low signal.

□ Management

- **Typically surgical—urgent evaluation and treatment**
  - Laminectomy is performed if the epidural abscess is predominantly posterior.
  - If there is concomitant vertebral osteomyelitis, anterior and posterior decompression is performed.

▪ **Spinal tuberculosis**

□ Introduction

- Most common extrapulmonary location of tuberculosis
- May be seen in HIV-positive population with a $CD4^+$ counts of 50–200/μL
- Originates in the metaphysis of the vertebral body and spreads under the anterior longitudinal ligament (Figs. 8.23 and 8.24)
  - This process leads to destruction of several contiguous levels or results in skip lesions (15%) or abscess formation (50%).

□ Diagnosis

- On early plain radiographs, anterior vertebral body destruction with preservation of the disc distinguishes tuberculosis from pyogenic infection.
- About two-thirds of patients have abnormal chest radiographs, and 20% have a negative test result for purified protein derivative of tuberculin or are anergic.
- Severe kyphosis, sinus formation, and (Pott) paraplegia are late sequelae.
- Spinal cord injury may occur secondary to direct pressure from the abscess, bony sequestra, or (rarely) meningomyelitis (poor prognosis).

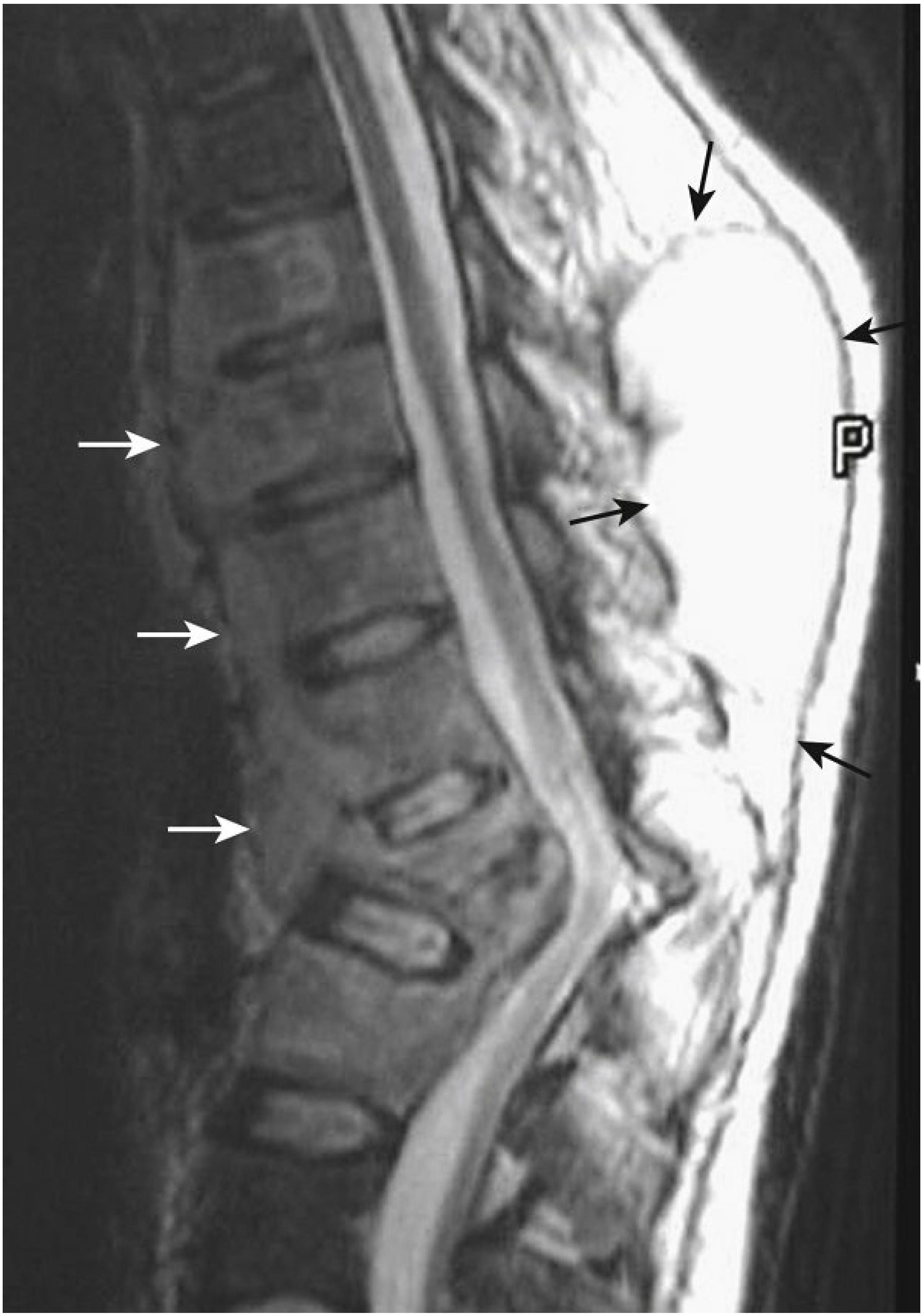
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FIG. 8.24 Typical features of tuberculous spondylitis. Sagittal T1-weighted MR image demonstrating many hallmarks of this disease: relative sparing of discs, subligamentous spread to multiple contiguous levels *(white arrows)*, extensive vertebral body destruction and deformity, including gibbus deformity, and large paraspinous "cold abscesses" *(black arrows)*.
From Kim PE et al: Spine: tumors and infections. In Law M et al, editors: *Problem solving in neuroradiology,* Philadelphia, 2011, Elsevier, p 589.

□ Treatment

- Nonoperative—antitubercular therapy is the mainstay of treatment. Frequently, triple and even quadruple therapy is required.
- Surgical indications
    - Neurologic deficit
    - Spinal instability
    - Progressive kyphosis
    - Failure of medical management

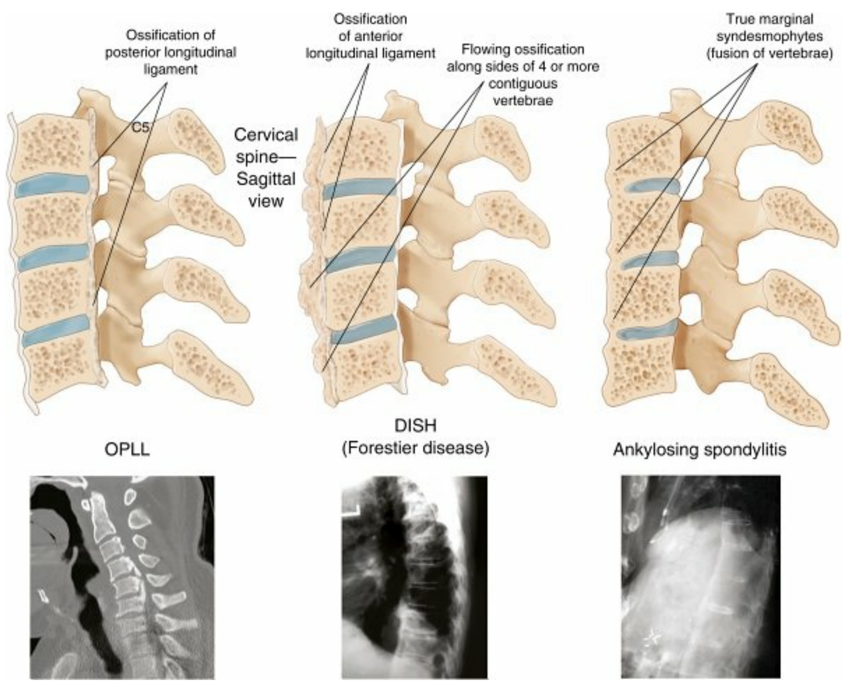


FIG. 8.25 Schematic drawings and corresponding radiographic appearance of ossification of the posterior longitudinal ligament, diffuse idiopathic skeletal hyperostosis, and ankylosing spondylitis.

    - Advanced disease with caseation, fibrosis, and avascularity that limits antibiotic penetration
- Procedure
    - Radical anterior débridement of the infection followed by uninstrumented autogenous strut grafting (Hong Kong procedure) is the accepted surgical treatment.
    - However, later evidence supports the use of instrumentation if necessary in the presence of

spinal tuberculosis.

  - Advantages include less progressive kyphosis, earlier healing, and a decrease in sinus formation.

- Adjuvant antitubercular therapy beginning 10 days before surgery has been recommended (controversial) but is not always possible.
- Use of antitubercular medications after surgery is mandatory.

▪ **Destructive spondyloarthropathy**

- Seen in patients with chronic renal failure who are undergoing hemodialysis
- Typically involves three adjacent vertebrae and two intervening discs
- Changes include subluxation, degeneration, and decrease of disc height.
- Although the process may resemble infection, it probably represents crystal or amyloid deposition.

▪ **Diffuse idiopathic skeletal hyperostosis—also known as** *Forestier disease* (Fig. 8.25)

- **DISH is defined by the presence of nonmarginal syndesmophytes (differentiates it from AS, which has marginal syndesmophytes) at three successive levels.**
- *Syndesmophytes* are vertical outgrowths that extend across the disc space and represent calcification of the anulus fibrosus and anterior and posterior longitudinal ligaments.
- DISH can occur anywhere in the spine but usually appears in the thoracic region and is more often seen on the right side.
- DISH is associated with chronic low back pain and is more common in patients with diabetes and gout.
- The prevalence of DISH has been found to be as high as 28% in autopsy specimens.
- DISH is associated with extraspinal ossification at several joints, including an increased risk of heterotopic ossification after total hip surgery.

▪ **Ankylosing spondylitis (see** Fig. 8.25)

□ Introduction

- 95% of patients with AS are positive for HLA-B27
- The usual patient with AS is a young man presenting with insidious onset of back and hip pain during the third or fourth decade of life.

□ Imaging

- Sacroiliac joint obliteration (iliac side affected first) and

marginal syndesmophytes allow radiographic differentiation from DISH.
- *Bamboo spine* is the descriptive term applied to the radiographic appearance of multiple vertebral levels ankylosed by marginal syndesmophytes.
- May result in fixed kyphotic deformities, leading to sagittal imbalance

□ Assessment
- Assessment of the patient for hip flexion contractures or cervicothoracic kyphosis is mandatory.
- Assessment of global and focal alignment, including chin-brow angle

□ Management
- Extension osteotomy and fusion of the lumbar spine with compression instrumentation can successfully balance the head over the sacrum.
- The cervical spine may be corrected with a C7–T1 osteotomy and fusion under local anesthesia.

□ Complications
- Nonunion
- Loss of correction
- Neurologic injury, especially C8 nerve root
- Aortic injury

□ Associated medical conditions
- Anterior uveitis
- Restrictive lung disease and pulmonary fibrosis
- Aortic regurgitation and stenosis
- Ileitis or colitis

Spinal Trauma

▪ **General considerations**

□ Spinal trauma can be the result of high-energy trauma with associated injuries.

□ Adherence to Advanced Trauma Life Support (ATLS) protocols remains imperative.
- **Primary survey (ABCs of resuscitation, with D and E)**
  - A—*a*irway maintenance with cervical spine protection
  - B—*b*reathing and ventilation
  - C—*c*irculation with hemorrhage control
  - D—*d*isability and neurologic assessment

    - E—*e*xposure of patient
- Initial radiologic workup performed during primary survey or shortly after
    - A rapid radiologic workup that includes at a minimum AP chest, AP pelvis, and lateral cervical spine views is standard.
    - Lateral cervical radiograph must include C7–T1 junction to be considered adequate. Radiographic lines should be assessed for continuity.
        - **Anterior soft tissue shadows**
            - **At C2: 6 mm**
            - **At C6: 20 mm**
        - Anterior spinal line
        - Posterior spinal line
        - Spinolaminar line
        - Spinous process line
    - CT scan
        - Because of its availability and greater processing speed, CT of cervical spine is replacing lateral cervical spine radiography for trauma evaluation.
        - Sagittal views detect 85% of cervical spine fractures.
        - CT is useful for evaluating C1 fractures and assessing bone in the canal but may miss an axial plane fracture (type II odontoid).
    - MRI
        - **Has advantages for demonstrating soft tissue abnormalities**
            - **Integrity of PLC**
            - Disc herniation
            - Canal compromise
            - Spinal cord injury and edema
            - Presence or absence of epidural hematoma
        - Increasingly used in cervical spine "clearance" (controversial)
- Secondary survey performed once primary survey and initial imaging complete.
    - Head-to-toe evaluation—each region fully

examined

- Facial injuries, hypotension, and localized tenderness or spasm should be investigated.
- Careful neurologic examination to document the lowest remaining functional level and to assess patient for the possibility of sacral sparing (sparing of posterior column function, indicating an incomplete spinal cord injury) is essential (see Fig. 8.1).
- The neurologic level, as defined by the standards of the **American Spine Injury Association (ASIA),** is the most cephalad level with normal bilateral motor and sensory function (Fig. 8.26).

- Additional x-rays as indicated by secondary survey
    - Complete cervical spine series (C1–T1)
    - Multiple-level injuries occur in 10%–20% of cases.
- If patient status deteriorates at any point during secondary survey, primary survey is reinitiated.

□ Shock and resuscitation

- **Hemorrhagic or hypovolemic shock**
    - Definition: the physiologic state of loss of intravascular volume leading to hypotension and tachycardia
    - Most common cause of hypotension of trauma patients (even those with spinal fracture)
    - Treatment—aggressive fluid resuscitation and management/control of the source of hemorrhage
    - Swan-Ganz catheter monitoring is helpful in the setting of spine trauma because neurogenic shock and hypovolemic shock often occur concurrently.
- **Neurogenic shock**
    - **Hypotension with bradycardia**
        - **Due to disruption of the sympathetic pathway within the spinal cord**
        - Most common in patients who sustain

      - a cervical or upper thoracic spinal cord injury
      - Hypotension due to decreased systemic vascular resistance
      - Bradycardia due to disruption of sympathetic pathway with unopposed vagal activity
      - Can be differentiated from hypovolemic shock by presence of relative bradycardia in neurogenic shock
    - Treatment
      - Initial management remains volume replacement, particularly if there is concomitant hemorrhagic shock.

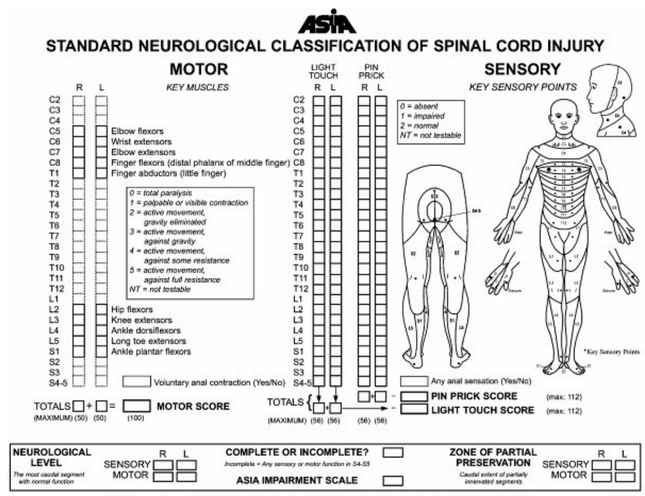


FIG. 8.26 American Spinal Injury Association neurologic classification of spinal cord injury.
From Kim DH et al: *Atlas of spine trauma: adult and pediatric,* Philadelphia, 2008, Elsevier, p 24.

      - However, once initial resuscitation is complete, vasopressors are frequently required (fairly quickly) to help restore systemic vascular resistance.

- **Spinal cord injury (SCI) (** Fig. 8.27)
  - General concepts
    - The first goal of treatment is stabilization.
      - Cervical inline traction and cervical collar
      - Patient is logrolled for examination and transport.
      - Backboard
        - Used for transportation only

- Patients are removed from backboards as soon as clinically safe.
- Decubitus ulcers can occur after only 30–60 minutes on a backboard.

- Skeletal traction
    - Halo vest immobilization
        - Indications
            - May be effective in controlling spinal motion in the upper cervical spine (O–C2); control of subaxial spine may be less effective.
            - Does not control axial distraction well
        - Not well tolerated, particularly by elderly patients, so use is declining.
        - Safe zone for anterior pin placement: above the eyebrow in the middle to lateral third to avoid the supraorbital nerve (Fig. 8.28)
        - Adults: 4 pins at 6 to 8 inch-lb pressure; children: 8 to 10 pins at 2 inch-lb pressure
        - Complications—pin loosening, pin infection, pressure sores, nerve injury, dural penetration
    - Gardner-Wells (GW) tongs
        - Can be used more acutely to realign the spine in the patient with a displaced fracture with or without neurologic injury
        - Pins parallel to the external auditory meatus approximately 1-cm above pinna
- High-dose methylprednisolone
    - **Role of steroids is unclear and controversial.**
        - Efficacy has been questioned, and many centers have discontinued its use.
        - Currently considered a treatment option at best and certainly not

"standard of care"

- Considered for cord injuries (not root injuries) with accompanying neurologic deficit (National Acute Spinal Cord Injury Studies [NASCIS] II and III)
    - A bolus of 30 mg/kg methylprednisolone over 15 minutes, with a maintenance infusion of 5.4 mg/kg/h
        - If started within 3 hours, administered for 24 hours.

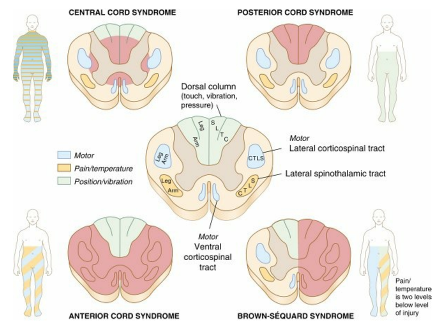


FIG. 8.27 Incomplete spinal cord injury syndromes.

        - If started within 3–8 hours, administered for 48 hours.
    - Administration of gastrointestinal prophylaxis should be considered to reduce risk of ulcer bleeds.
- **Contraindications to use of high-dose steroids:**
    - **Penetrating spinal wounds, particularly gunshot wounds**
    - **Injury more than 48 hours old**
    - **Peripheral nerve injuries such as brachoplexopathy, stingers, root level injuries, cauda equina**
    - **Pregnancy**
    - **Age younger than 13 years**
    - Concomitant infection
    - Uncontrolled diabetes

- ASIA classification
    - A: 0/5 motor score, complete sensory deficit

        - B: 0/5 motor score, incomplete sensory deficit
        - C: <3/5 motor score, incomplete sensory deficit
        - D: ≥3/5 motor score, incomplete sensory deficit
        - E: 5/5 motor score, no sensory deficit
    - Complete spinal cord injuries
        - No function below a given level
        - With complete injuries, an improvement of one nerve root level can be expected in 80% of the patients, and approximately 20% recover two functioning root levels.
        - Cannot be determined until the end of spinal shock, which is signified by return of the bulbocavernosus reflex, or 48 hours after the time of injury
    - Incomplete spinal cord injuries
        - Defined as partial sparing of distal motor or sensory function
        - Three important generalizations regarding prognosis:
            - The greater the sparing, the greater the recovery.
            - The more rapid the recovery, the greater the recovery.
            - When recovery plateaus, no further recovery will happen.
    - Spinal shock
        - **Spinal shock usually involves a 24- to 72-hour period of paralysis, hypotonia, and areflexia (flaccid paralysis).**
        - **Return of the bulbocavernosus reflex (anal sphincter contraction in response to squeezing of the glans penis or tugging on the Foley catheter) signifies the end of spinal shock.**
        - Injuries at or below the thoracolumbar level (conus or cauda equina) may permanently interrupt the bulbocavernosus reflex.
        - In complete injuries, further neurologic improvement is minimal.
        - Phases of spinal shock (variable)
            - Phase 1—areflexic/hyporeflexic phase
                - Typically first 24–48 hours
                - Loss of reflexes below

level of SCI

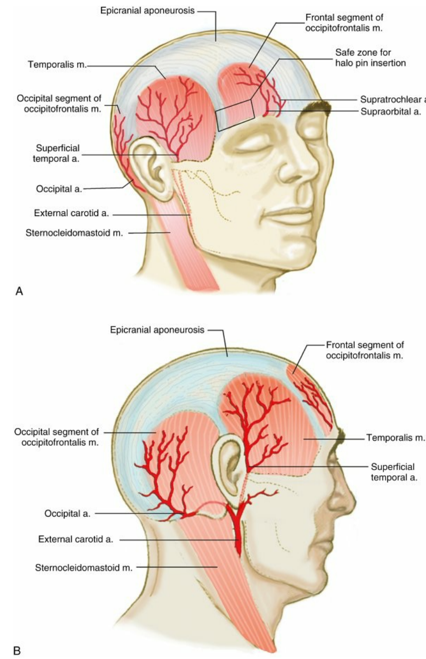


FIG. 8.28 Safe zones for placement of skull pins. (A) Anterior view and (B) posterolateral view, with relevant anatomy.
From Kim DH et al: *Atlas of spine trauma: adult and pediatric,* Philadelphia, 2008, Elsevier, p 99.

    - Due to loss of basal level of excitatory stimulation from brain to neurons involved in the reflex arc
    - As a result, there is less responsiveness to stimuli and therefore hyporeflexia or areflexia.
- Phase 2—initial reflex return
    - Next 1 or 2 days
    - Return of some but not all reflexes below level of SCI
    - First reflexes to return are polysynaptic; bulbocavernosus is polysynaptic and

typically the first reflex to return.

  - Monosynaptic reflexes such as deep tendon reflexes (DTRs) typically do not return until phase 3.
- Phase 3—initial hyperreflexia
  - Next 1–4 weeks
  - Abnormal strong reflexes

Table 8.9

Spinal Cord Injury Syndromes

Syndrome	Pathology	C
Central	Age >50 yr, extension injuries	A
Anterior	Various mechanisms; may include flexion-compression injury, possible vascular insult	Ir
Brown-Séquard	Penetrating trauma	L
Root	Foramina compression/herniated nucleus pulposus	B
Complete	Burst fracture/canal compression	N

  - Increased expression of neurotransmitter receptors results in increased reflex response with minimal

stimulation.
- Phase 4—final hyperreflexia/spasticity
  - Next 1–12 months
  - In addition to hyperreflexia, this phase results in altered skeletal muscle performance and hypertonia.
  - Loss of inhibitory input to motor neuron below level of SCI

□ Clinical syndromes (Table 8.9)

- Central cord syndrome
  - Most common incomplete spinal cord syndrome
  - Typical mechanism is hyperextension with preexisting canal stenosis.
  - Cord is compressed anteriorly by osteophytes and posteriorly by the infolded ligamentum flavum.
  - Cord is injured in the central gray matter, resulting in proportionately greater loss of motor function to upper extremities than to lower extremities.
  - **The upper extremity is affected more than the lower extremity.**
  - Variable sensory sparing
  - The prognosis is good for the recovery of ambulation, but the patient is less likely to recover upper extremity function.
- Anterior cord syndrome (spinothalamic tract injury)
  - The second most common incomplete cord injury
  - No typical mechanism for injury
    - Direct compression to anterior spinal cord
    - Less commonly, vascular injury to anterior spinal artery, or spinal cord ischemia (e.g., anterior spinal artery, artery of Adamkiewicz)
  - Damage is primarily in the anterior two-thirds of the cord.
    - Loss of motor response, pain reception, and temperature reception below the level of injury

            - Patients demonstrate greater motor loss in the legs than the arms.
            - Preservation of posterior/dorsal column; vibration sensation, proprioception, and deep pressure sensation intact
        - The prognosis for motor recovery is poor.
    - **Brown-Séquard syndrome (spinal cord hemisection)**
        - **Typical cause is penetrating trauma.**
            - Ipsilateral loss of motor and loss of position/proprioception function on the side of injury
            - Contralateral loss of pain and temperature to the side of injury (usually one to two levels below the insult)
        - **Best prognosis for recovery of ability to walk (90%)**
    - **Posterior cord syndrome**
        - **Very rare; least common incomplete spinal cord pattern**
        - Injury to posterior/dorsal column—loss of proprioception, vibrator sensation, and deep pressure sensation
        - Preservation of anterior column; motor response, pain reception, and temperature reception intact
    - **Autonomic dysreflexia**
        - Most commonly follows spinal cord injuries above T6 and encompasses a constellation of symptoms
            - Pounding headache (from severe hypertension)
            - Anxiety
            - Profuse head and neck sweating
            - Nasal obstruction
            - Blurred vision
        - **Due to sympathetic overdrive**
            - Most commonly triggered by bladder distension or fecal impaction
            - Undiagnosed orthopaedic injuries such as femur or ankle fracture
- □ Rehabilitation after spinal cord injury
    - Functional level determined by both sensory and motor level as dictated by

- Most distal intact functional sensory level *and*
- Most distal motor level where motor grade is 4 or greater

- Respiratory function by level of cord injury
  - C1–2 injury
    - Vital capacity only 5%–10% of normal
    - Ventilator dependence
    - Cough absent
  - C3–5 injury
    - Vital capacity 20% of normal
    - Cough weak and ineffective
  - Lower cervical and upper thoracic injury
    - Vital capacity 30%–50% of normal
    - Cough weak but may be effective
  - T11 injury and below
    - Respiratory dysfunction minimal
    - Vital capacity near normal
    - Cough strong
- Mobility and function determined by highest motor level
  - C3 or above—respiratory dependent
  - C4—transfer dependent
  - C5—transfer assist
  - C6—independent transfers
- Activities of daily living
  - C6—independent grooming and dressing; can operate flexor hinge wrist-hand orthosis
  - C7—able to use knife to cut food

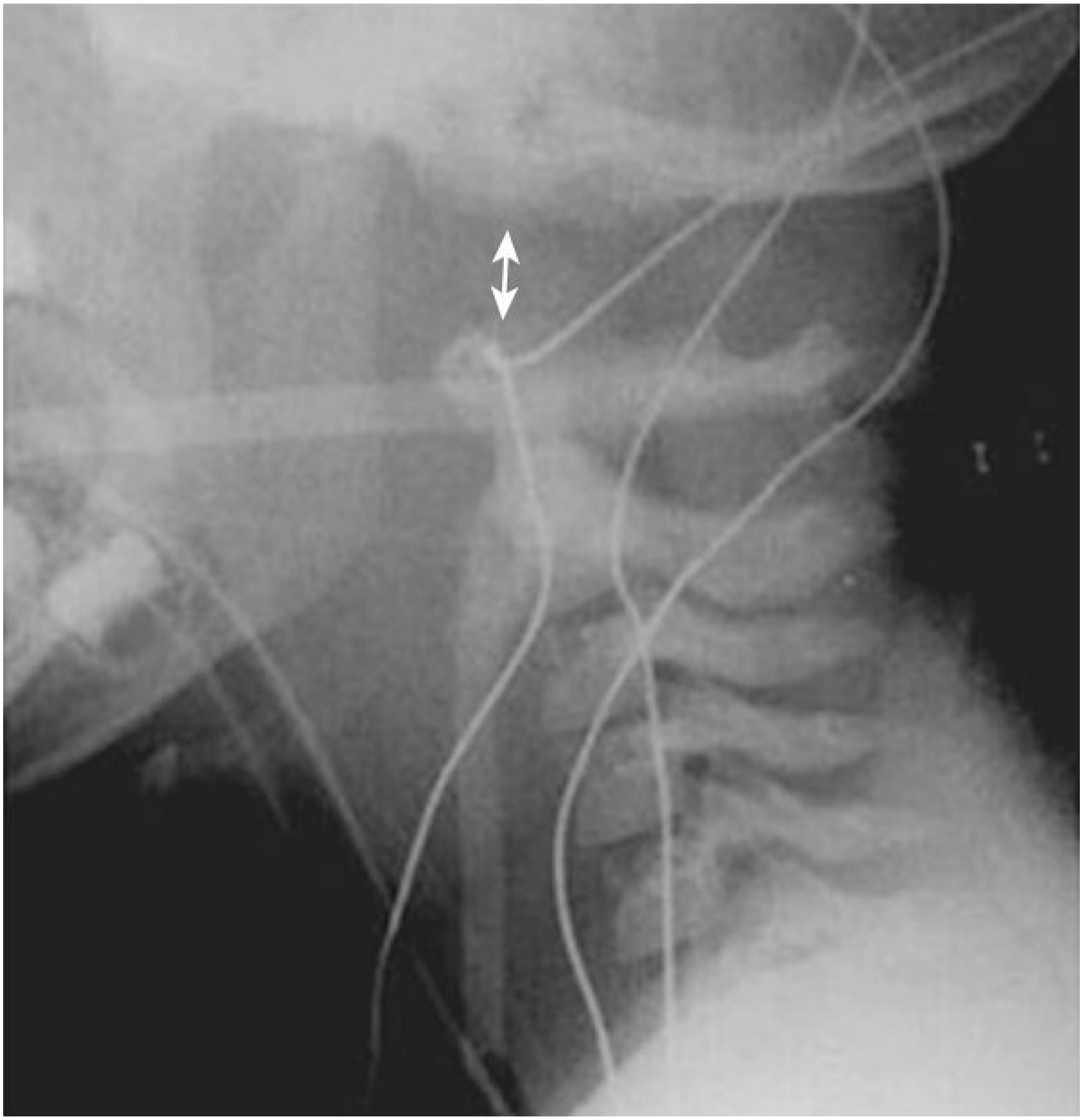


FIG. 8.29 Lateral radiograph of a skeletally immature cervical spine demonstrating complete occipitocervical dissociation *(double-headed arrow)*.
From Cianfoni A, Colosimo C: Imaging of spine trauma. In Law M et al, editors: *Problem solving in neuroradiology,* Philadelphia, 2011, Elsevier, p 477.

- **Syringomyelia (syrinx)**
  - Introduction
    - Confluent collection of abnormal CSF within the spinal cord
      - In regard to orthopaedic spine, most common etiology is posttraumatic syrinx and secondary to herniated disc.
      - Other primary causes of spinal syringomyelia include postinflammatory, arachnoid abnormalities (arachnoid cyst), tumor, and idiopathic.
      - Syringomyelia can also be related to abnormalities of the foramen magnum: tonsillar descent (Chiari malformation), arachnoid veil

with fourth ventricle outlet obstruction.

- Differentiating syringomyelia from hydromyelia
  - **Hydromyelia**—confluent CSF cavity within spinal cord that is a remnant of central canal of spinal cord
    - Typically considered a normal variant
    - Spinal cord typically not expanded by hydromyelia and therefore not associated with symptoms and not considered a pathologic entity
- **Differentiating syringomyelia from spinal cord edema**
  - **Spinal cord edema is increased fluid that is interstitial, and not a confluence of fluid.**
  - Edema can be secondary to spinal cord contusion or tumor-associated cyst.

□ Presentation

- Variable but typically due to the etiology of the syrinx and its associated pathophysiology
- Symptoms associated with partial CSF obstruction (e.g., tussive headaches, strain-related activities)
- Symptoms related to brainstem compression (e.g., swallowing difficulty, voice changes, nystagmus, ataxia, sleep apnea)

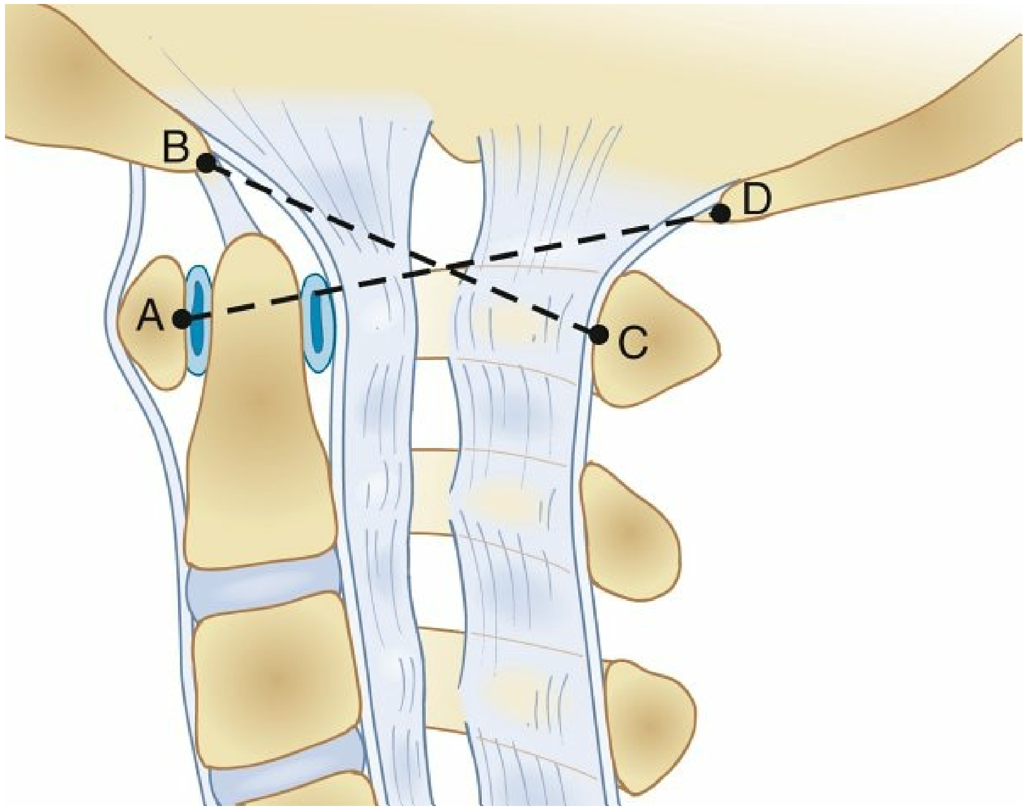


FIG. 8.30 Powers ratio. The distance from the basion (*B*) to the posterior arch of the atlas (*C*) divided by the distance of the anterior arch of the atlas (*A*) to the opisthion (*D*) should equal 1 or less. If it is greater than 1, the patient may have an anterior occipitocervical subluxation or dislocation.

- Symptoms related to syringomyelia (e.g., sensory loss [upper greater than lower typically], upper extremity weakness, hand and upper extremity atrophy, gait impairment, lower extremity spasticity, bowel and bladder dysfunction, dysesthetic pain)
- Imaging
    - MRI is method of choice
        - Does not disrupt CSF dynamics
        - T1-weighted image demonstrates intramedullary fluid-filled cavity.
        - MRI with gadolinium necessary to rule out possibility of associated spinal tumor.
        - T2-weighted images may help identify anatomic detail such as septa in the subarachnoid space.
    - CT myelogram
        - May have a role in determining obstructive arachnoid disease
            - In these cases, performing

myelography puncture at C1–2 rather than using lumbar route may allow for pooling of the contrast at the level of the web.
- This pooling may not be seen if contrast is introduced from the lumbar route, because the obstructive subarachnoid web acts as a one-way valve.

- **Upper cervical spine injuries**
  - Occipitocervical dissociation (OCD) (Fig. 8.29)
    - Head is disconnected from C1.
    - Frequently fatal
    - Diagnosis challenging on plain films (CT/MRI ≈85% sensitive)
    - Radiologic measurements
      - Powers ratio (Fig. 8.30)
        - Measure distance from basion to posterior arch of atlas; divide by distance of anterior arch of atlas to opisthion.
        - Ratio greater than 1.0 indicates instability of the atlantoaxial junction (from possible dislocation)
        - Only good for anterior occipitocervical dislocations; can miss posterior and traction OCD.
      - Harris method
        - Basion-axial interval—distance from basion to line drawn tangential to posterior border of C2 (normal, 4–12 mm)
        - Basion dental interval—distance from basion to odontoid
          - The distance between

the odontoid and basion is 4–5 mm in adults and up to 10 mm in children.

- Interval greater than 12 mm is abnormal.

- Classification—Harborview
  - Stage I—MRI evidence of injury to ligamentous stabilizers, alignment within 2 mm of normal, and distraction of 2 mm or less and no displacement on manual-traction radiograph
  - Stage II—same as stage I, except distraction of less than 2 mm on a manual-traction radiograph
  - Stage III—distraction of more than 2 mm on static radiographs
- Treatment
  - Nonoperative treatments typically not options
  - Surgical indications—stage II or III injuries or any injury with associated neurologic deficit
  - Procedure—posterior occipitocervical fusion (O–C2)

□ Occipital fracture

- Classification—Anderson-Montesano classification
  - Type I—comminuted impaction fracture of occiput; generally stable
  - Type II—shear or compression fracture extending into base of the skull; variably stable
  - Type III—avulsion injuries that have a transverse fracture component; generally unstable—may be associated with occipitocervical dissociation
- Treatment
  - Operative indications
    - Evidence of mechanical instability
    - Presence of neurologic deficit
  - Stable injuries—cervical collar
    - Posterior occipitocervical fusion stabilization for unstable injuries

□ C1 ring fractures

- Classification—Levine-Edwards
  - Posterior arch fractures—hyperextension
  - Lateral mass fractures—axial load with lateral bend
  - Isolated anterior arch fractures—hyperextension

- Burst fractures (Jefferson)—axial load
- Treatment based predominantly on stability of transverse ligament
  - Indications
    - Combined lateral mass displacement greater than 6.9 mm (8.1 mm with standard radiographic magnification) suggestive of transverse ligament rupture (Fig. 8.31).
    - ADI
      - ADI greater than 3.5 mm indicates that transverse ligament is damaged.
      - ADI greater than 5 mm indicates both the transverse and alar ligaments are damaged.
    - Residual combined lateral mass displacement greater than 6.9 mm or ADI greater than 3.5 mm after halo stabilization
  - Operative procedures
    - Halo vest stabilization for 6–12 weeks for fractures with an intact transverse ligament
    - Posterior spinal fusion (C1–2 or occiput–C2) if the transverse ligament is incompetent

□ Atlantoaxial instability

- Classification—Fielding and Hawkins
  - Type I—rotationally unstable but transverse alar ligament intact; odontoid is the pivot point.

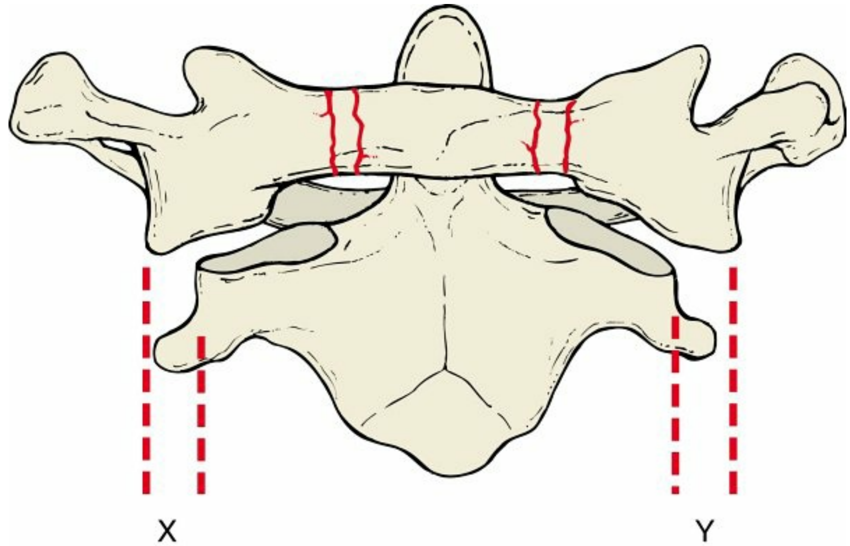


FIG. 8.31 Lateral mass overhang. A sum of $X + Y$ greater than 6.9 mm is suggestive of rupture of the transverse ligament.

- Type II—rotationally unstable, with transverse alar ligament incompetence; one facet acts as the pivot.
- Type III—both facets subluxed anteriorly, ADI greater than 5 mm
- Type IV—both facets subluxed posteriorly
- Type V—frank dislocation

- Treatment
  - Nonoperative options
    - Limited in patients with true traumatic atlantoaxial instability versus patients with instability due to chronic conditions
    - External immobilization considered if transverse ligament intact (type I) and possibly type II. Careful follow-up and conversion to surgical decompression if progression of deformity.
  - Operative indications
    - Presence of neurologic deficits or failure of closed treatment
  - Procedure
    - Posterior C1–2 fusion; occiput included if instability is associated with occipitocervical dislocation

□ Odontoid fracture

- Classification—Anderson-D'Alonzo (Fig. 8.32)

        - Type I—avulsion of alar ligaments from the tip
        - Type II—fracture at the base of odontoid
        - Type IIA—comminuted fracture of the base of odontoid
        - Type III—fractures that extend into the body of C2
- Treatment
    - Operative indications—based on risk of development of nonunion. Risk factors for nonunion in type II
        - **Displacement greater than 5 mm**
        - Posterior displacement
        - Age greater than 40 years
        - Delayed treatment
        - Angulation greater than 10 degrees
    - Type I—immobilization in rigid cervical orthosis
    - Type II and IIA
        - **Nondisplaced—immobilization in rigid cervical orthosis (controversial)**
        - **Displaced types II and IIA fractures are generally considered to require operative treatment because of the high rate of nonunion with nonoperative treatment.**

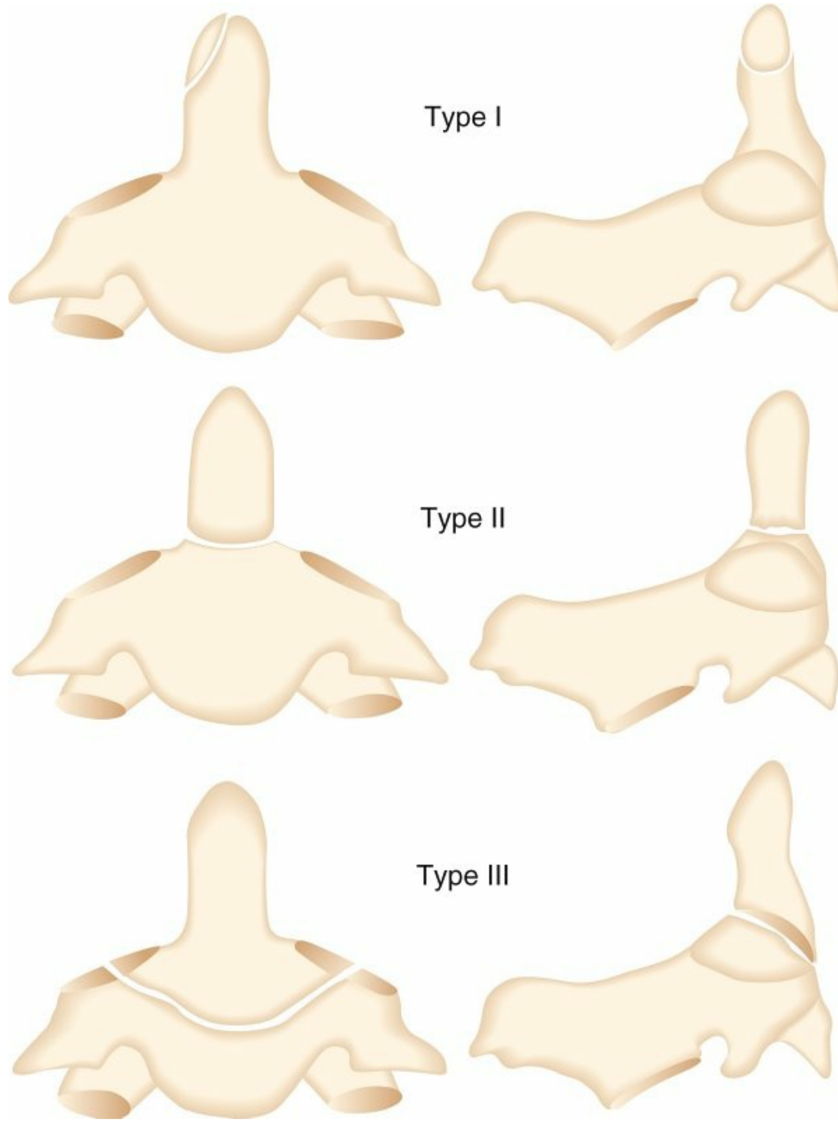


FIG. 8.32 Anderson-D'Alonzo classification of odontoid fractures. Type I is an oblique avulsion fracture from the upper portion of the dens. Type II is a fracture of the odontoid process at its base. Type III is an odontoid fracture through the body of C2.

- Type III—typically high incidence of union; most heal in rigid external cervical orthosis. Operative treatment considered if initial displacement greater than 5 mm.
- Procedures
    - Posterior C1–2 fusion
    - Direct osteosynthesis—anterior odontoid screw (Fig. 8.33)
        - Fracture must be reducible. Nonreduced fracture is a contraindication to anterior odontoid screw.
        - Fracture geometry must be favorable: anterior

superior to posterior inferior (posterior oblique pattern) (Fig. 8.34)
- This procedure is associated with a higher failure rate than posterior fusion but theoretically preserves atlantoaxial motion.

- Complications
  - Overall nonunion rate for type II: approximately 32%
  - Patients older than 80 years do poorly whether treatment is operative or nonoperative.
  - Airway problems postoperatively or with halo vest immobilization

▪ **C2 fracture (traumatic spondylolisthesis of the axis, or hangman's fracture)**

□ Classification—Levine-Edwards (Fig. 8.35)

- Type I—minimally displaced fracture of the pars secondary to hyperextension and axial loading (<3 mm displacement, no angulation)
- Type IA—same as type I except fracture lines are asymmetric

FIG. 8.33 Direct osteosynthesis of type II dens fracture. Postoperative lateral cervical radiograph demonstrating placement of an anterior odontoid screw for direct osteosynthesis of type II dens fracture. *Arrows* identify combined anterior and posterior C1 ring fractures. From Kim DH et al: *Atlas of spine trauma: adult and pediatric,* Philadelphia, 2008, Elsevier, p 178.

- Type II—displaced fractures (>3 mm) of the pars, with subsequent flexion after hyperextension and axial loading
- Type IIA—flexion without displacement; *care must be taken* not to mistake this for a type I fracture, which represents total disc avulsion, because traction may worsen a type IIA fracture.
- Type III—bilateral pars fracture with bilateral facet dislocations (rare)—mechanism is flexion-distraction followed by hyperextension
  - □ Treatment
    - Type I—rigid cervical orthosis
    - Type II—operative; typically C1–2 fixation or direct osteosynthesis
    - Type IIA—halo vest or surgery **(no traction)**
    - Type III—generally operative, usually C2–3

fusion (may require C1–3 fixation, depending on comminution of pars and quality of fixation into C2)

- Complications—vascular injury; vertebral artery injury is rare but increasingly diagnosed by MR angiogram.
- C1–2 posterior cervical fixation techniques (Table 8.10)
    - C1–2 modified Gallie fusion
        - Autograft iliac crest placed over C2 spinous process and against posterior arch of C1
        - Held in place by sublaminar wire under arch of C1 and under spinous process of C2 (total of one sublaminar wire)
    - C1–2 Brooks fusion
        - Two separate iliac crest autografts placed between C1 and C2
        - One sublaminar wire is placed on either side (total of two sublaminar wires).

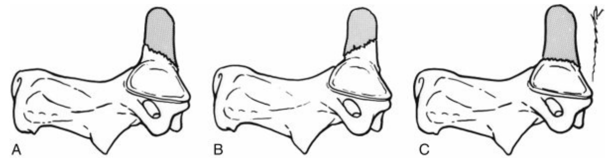


FIG. 8.34 Subclassification of type II odontoid fractures based on fracture line orientation. (A) Anterior oblique. (B) Posterior oblique. (C) Horizontal. Fracture lines that are anterior oblique (A) are the most difficult to treat with an anterior odontoid screw and are most likely to result in screw cutout. Conversely, the posterior oblique fracture line (B) is more amenable to direct osteosynthesis, because the screw can be placed perpendicular to the fracture orientation.

From Kim DH et al: *Atlas of spine trauma: adult and pediatric,* Philadelphia, 2008, Elsevier, p 205.

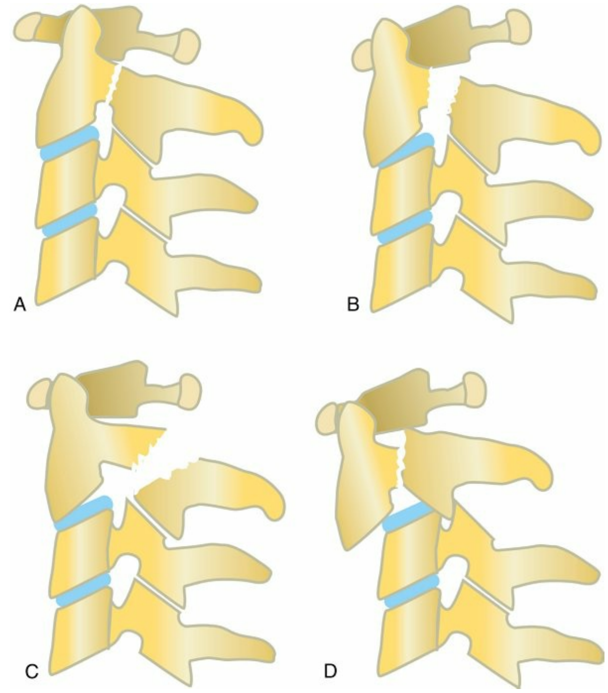


FIG. 8.35 Levine-Edwards classification for C2 traumatic spondylolisthesis fractures. (A) Type I: axial compression resulting in minimal displacement. (B) Type II: hyperextension and axial load resulting in angulation with displacement. (C) Type IIa: flexion distraction resulting in angulation without displacement. (D) Type III: flexion distraction resulting in associated C2–3 facet dislocation. From Kim DH et al: *Atlas of spine trauma: adult and pediatric,* Philadelphia, 2008, Elsevier, p 214.

- C1–2 transarticular (Magerl) screws
  - Preoperative CT scan to assess for location of vertebral artery at C1–2 junction is imperative.
  - Adequate intraoperative radiographs are required, or the technique should not be used.
  - Cannulated screw is placed under fluoroscopic guidance over a guidewire.

- Screw is placed through the C1–2 facet joint (transarticular), thereby coupling C1–2.
- C1 lateral mass–C2 pedicle (Harms) screws
  - C1 screws are placed through the lateral masses. Starting point of the screw is the center of the lateral mass.
  - C2 screws are placed traditionally as pedicle screws. In the case of aberrant vertebral artery a shorter, more straight-ahead pars screw can be used in C2 instead.

Table 8.10

Biomechanics of C1–2 Posterior Cervical Fixation Techniques

	Flexion	Extension	Rotation
Modified Gallie	Good	Poor	Poor
Brooks fusion	Good	Good	Poor
C1–2 transarticular screws	Better	Better	Better
C1–lateral mass/C2–pedicle screw	Best	Best	Best

- Complications
  - **Vertebral artery may be injured as it runs in the transverse foramen of C2 or as it lies on the superior aspect of C1 in the**

groove/sulcus of the vertebral artery.

- C2 (greater occipital) nerve lies just dorsal to the C1–2 joint. Injury can result in numbness in the posterior aspect of the skull.
- Neurologic injury
- Dural leaks
- Nonunion/malunion

- **Subaxial cervical spine (C3–7) injuries**
  - **Classification**
    - **Allen-Ferguson (based on mechanism)—descriptive classification**
      - Based on position of the head and neck at the time of injury (flexion/extension) and the mode of failure (distraction/compression) (Table 8.11)
        - Compressive flexion
        - Distractive flexion
        - Compressive extension
        - Vertical compression
        - Distractive extension
        - Lateral flexion
      - Decision for surgery using mechanistic classification can be difficult, but general considerations include:
        - Patient with associated neurologic instability
        - Disruption of PLC
        - Fracture dislocations and distractive flexion injuries (jumped facets)
      - Burst fracture without neurologic injury and with intact PLC and acceptable alignment can be considered for treatment with external immobilization (controversial).
    - **Subaxial Cervical Spine Injury Classification System (SLIC) (Table 8.12)**
      - Based on three separate injury axes
        - Fracture morphology
        - Discoligamentous complex (DLC) integrity

        - Neurologic status
    - Scoring
        - Each axis considered an independent determinant for prognosis and management
        - Each axis receives numerical score, with increasing severity receiving a higher numerical value
        - No set value defined as requiring surgical treatment; however, higher numerical values suggest increased need for operative intervention
- □ Treatment goals
    - Address neurologic deficits.
        - Typically, approach is selected according to location of compression.
            - Anterior cervical discectomy and/or corpectomy for anterior compression
            - Posterior laminectomy for posterior compression
        - Restoring spinal alignment can help through indirect decompression.
    - Achieve immediate stability and long-term fusion. Approach varies depending on injury pattern and presence of associated neurologic instability.
    - Restore spinal alignment.
- □ **Special considerations: MRI in facet fracture-dislocations (jumped facets) remains controversial.**
    - The role of MRI to evaluate the disc before or after closed reduction is controversial, particularly as it relates to neurologic status.
    - The purpose is to identify potential anterior causes of impingement to the spinal cord during the reduction maneuver.
        - **Closed reduction before MRI**
            - Patient must be awake, alert, and cooperative.
            - Patient must be able to comply with a thorough neurologic exam during reduction.
        - **MRI before closed reduction**
            - Patient unable to cooperative with a thorough neurologic examination

during reduction
- Presence of alcohol or drugs in system, obtunded patient, etc.
- Neurologically intact

- **Closed reduction is achieved with Gardner-Wells tongs or halo and slow progressive application of traction.**
  - Neurologic exam performed after each successive addition of weight.
  - Lateral cervical radiographs obtained after each successive addition of weight
  - MRI is generally required before open reduction.
    - If patient is obtunded, neurologic symptoms develop, or closed reduction fails, MRI should be obtained to evaluate disc.

▪ **Thoracic and lumbar spine injuries (see Table 8.11)**

□ General considerations

- Anatomic considerations
  - Upper thoracic spine (T1–10) is stabilized by ribs, facet joint orientation, and sternum and may provide additional stability and is less susceptible to trauma.
  - Thoracolumbar junction is a transition zone from relatively rigid thoracic spine to relatively mobile lumbar spine.
  - Middle thoracic spine is a vascular “watershed” area, and vascular insult can lead to cord ischemia.
  - Spinal cord ends and the cauda equina begins at level of L1–2, so lesions below L1 (in general) have a better prognosis because the nerve roots (not the cord) are affected.
- **Column theory**
  - Spinal cord originally described by Denis as three columns
    - Anterior column—equivalent to the anterior longitudinal ligament, anterior one-third of the vertebral body, and corresponding portion of the intervertebral disc and anulus

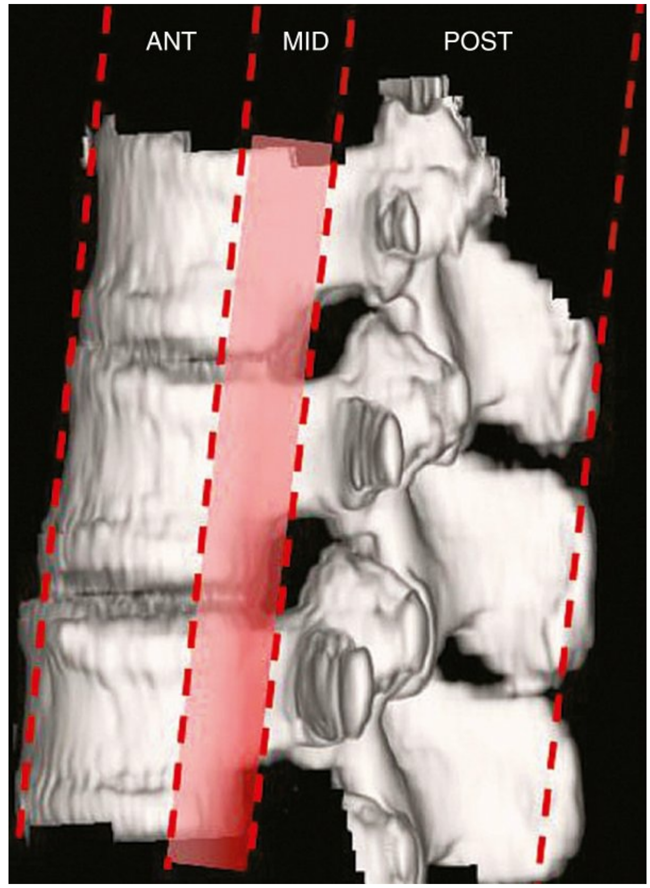


FIG. 8.36 Three-column theory for spinal trauma as demonstrated on lateral 3D CT reconstruction. The original classification highlighted the significance of the middle column *(MID; red shading)* in regard to neurologic involvement and potential mechanical instability. Newer classifications focus on the involvement of the posterior ligamentous complex as well. *ANT,* Anterior column; *POST,* posterior column.

From Cianfoni A, Colosimo C: Imaging of spine trauma. In Law M et al, editors: *Problem solving in neuroradiology,* Philadelphia, 2011, Elsevier, p 476.

Table 8.11

Subaxial Cervical Spine Injury Classification (Allen-Fergus

Level	Injury Type	Classification	Co
Occipitocervical dislocation	I	Traynelis et al.	Ar
	II		Di

	III		Po
Occipital condyle fracture	I	Anderson-Montesano	Im
	II		Oc
	III		Av
C1 ring fracture	Posterior arch fracture		La
	Two- and three-part fractures		La
	Four-part fracture		Jef
C2 fracture	Traumatic spondylolisthesis	Levine	Ha
	I or IA		IA
	II or IIA		
	III		Bil
	Odontoid fracture		
	I	Anderson-D’Alonzo	Av

	II		Fra
	III		Fra
C2 body fracture			
Transverse ligament disruption			C1
C1–2 rotatory subluxation	I	Fielding-Hawkins	Ro
	II		Ro
	III		Ro
	IV		Ro
Subaxial cervical spine		Allen-Ferguson	
	Compressive flexion		

	Distractive flexion		
	Axial compression		
	Compressive extension		
	Distractive extension		
	Lateral flexion		
	Compression		Co
Subaxial cervical spine (cont'd)	Burst		Bu
			Fle
			Fa
	Posterior element fracture		Sp

Thoracolumbar spine	Compression	Denis	
	Burst		
	Stable		
	Unstable		
	Seatbelt injury		Ch
	Fracture-dislocation		

- Middle column—equivalent to the posterior longitudinal ligament, posterior two-thirds of the body, and corresponding portion of the intervertebral disc and anulus
- Posterior column—equivalent to the spinous process, lamina, pedicles, transverse process, and ligamentum

flavum; interspinous ligament; supraspinous ligament; and facets

- More recently, the "fourth column" has been described in the thoracic spine.
    - Intact sternum and rib complex may impart additional stability to the thoracic spine.
    - Clinical significance still not completely known in trauma

- Associated injuries
    - Adynamic ileus is common.
    - Calcaneus fractures are associated in approximately 10% of cases.

□ Classifications

- Denis—based on three-column theory described earlier (Fig. 8.36). Four main types of spinal injuries:
    - Compression fractures involve only the anterior column; by definition, middle column not involved.
    - Burst fractures involve the middle and anterior column; posterior column may or may not be involved.

Table 8.12

Subaxial Cervical Spine Injury Classification System

Category	POINTS
Morphology	
No abnormality	0
Compression	1
Burst	+1 = 2
Distraction (e.g., facet perch, hyperextension)	3
Rotation/translation (e.g., facet dislocation, unstable teardrop or advanced-stage flexion-compression injury)	4
Discoligamentous Complex (DLC)	
Intact	0
Indeterminate (e.g., isolated interspinous widening, MRI signal change only)	1
Disrupted (e.g., widening of disc space, facet perch, or dislocation)	2
Neurologic Status	
Intact	0
Root injury	1
Complete cord injury	2
Incomplete cord injury	3
Continuous cord compression in setting of neurologic deficit (neurologic modifier)	+1

From Vaccaro AR et al: The subaxial cervical spine injury classification system: a novel approach to recognize the importance of morphology, neurology, and integrity of the disco-ligamentous complex, *Spine (Phila Pa 1976)* 32:2365–2374, 2007.

- Flexion-distraction (Chance) injuries involve failure of the posterior and middle columns in tension. Axis of rotation is at anterior longitudinal ligament.
- Fracture-dislocations involve failure of all three columns; high rate of associated neurologic injuries.

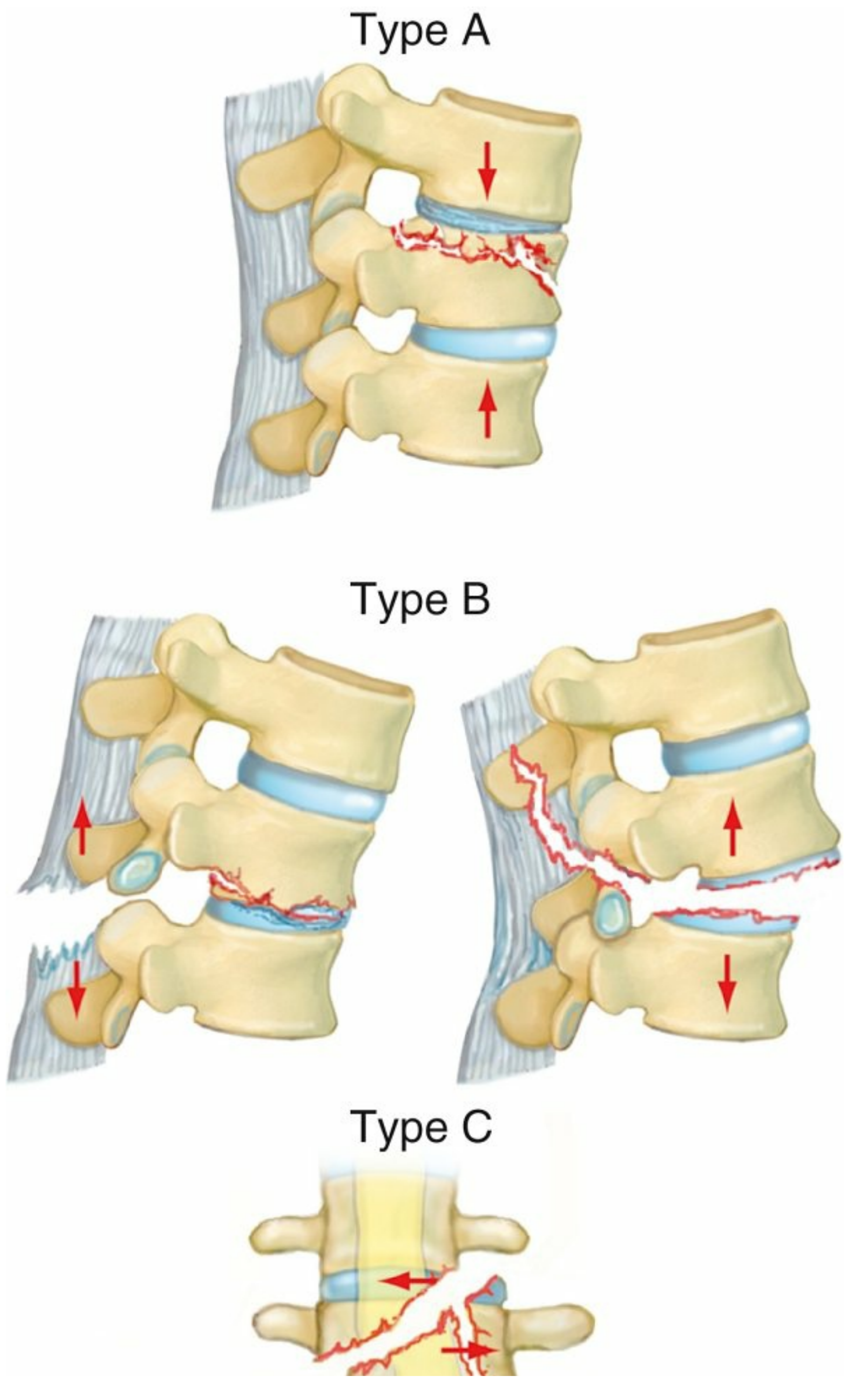
- **AO classification (Fig. 8.37)**

- Type A—compression fractures caused by axial loading
- Type B—distraction injuries with ligamentous (B1) or osseoligamentous (B2) injury posteriorly
- Type C—multidirectional injuries, often fracture-dislocations; very unstable with very high likelihood of neurologic injury

- **Thoracolumbar Injury Severity Score (TLISS) (Table 8.13)**
  - Based on three separate injury axes:
    - Injury mechanism
    - Integrity of PLC
    - Neurologic status
  - Scoring:
    - Score is total of three components
    - Score of 3 or less suggests nonoperative treatment.
    - Score of 4 suggests operative or nonoperative treatment
    - Score of 5 or greater suggests operative treatment.

□ **Treatment**

- General
  - No clear agreement on indications for surgery
  - Typically, presence of neurologic deficits and disruption of PLC increase likelihood of surgery
- Compression fracture
  - Stable fracture


Type A
Type B
Type C

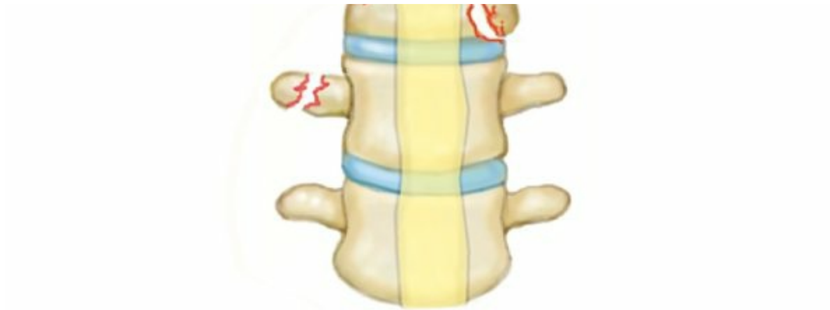


FIG. 8.37 Thoracolumbar spine injuries based on AO classification.
From Kim DH et al: *Atlas of spine trauma: adult and pediatric,* Philadelphia, 2008, Elsevier, p 271.

    - Most compression managed in an orthosis or symptomatically
- Burst fractures
    - May be treated in a hyperextension orthosis if there is no neurologic deficit and PLC remains intact
    - **Disruption of PLC**
        - **Typically, posterior approach and posterior spinal fusion with instrumentation to reconstruct PLC**
        - Traditionally, three levels above and two levels below injury; however, newer instrumentation may allow for short segment fixation.
- Presence of neurologic deficit
    - Anterior approach considered for decompression of retropulsed middle column.
    - Posterior approach considered in presence of lamina fracture.
        - Lamina fractures with neurologic deficits are associated with possible nerve root entrapment with corresponding dural tear. Typically require stabilization.
    - Laminectomy alone typically contraindicated owing to the high risk of progressive kyphosis.
- Flexion-distraction (Chance)
    - Bony flexion-distraction injury—hyperextension external orthosis
    - Ligamentous flexion-distraction injury
        - High rate of posttraumatic kyphosis due to incompetent PLC
        - Surgical treatment: posterior spinal

fusion

Table 8.13

Thoracolumbar Injury Severity Score

Mechanism	Points
Compression	1
Lateral angulation >15 degrees	+1
Burst	+1
Translational/rotational	3
Distraction	4
Neurologic injury	
Nerve root	2
Spinal cord or conus injury	
Complete	2
Incomplete	3
Cauda equina	3
Posterior ligamentous complex	
Intact	0
Indeterminate	2
Injured	3

Adapted from Vaccaro AR et al: The thoracolumbar injury severity score: a proposed treatment algorithm, *J Spinal Disord Tech* 18:209-215, 2005.

Table 8.14

Frankel Classification for Grading of Functional Motor Recovery After Spinal Cord Injury

Frankel Grade	Function
A	Complete paralysis
B	Sensory function only below injury level
C	Incomplete motor function (grades 1–2 of 5) below injury level
D	Fair to good (useful) motor function (grades 3–4 of 5) below injury level
E	Normal function (grade 5 of 5)

- Fracture-dislocations
    - Frequently associated with neurologic injury
    - Most are highly unstable and require operative stabilization with multiple points of fixation above and below the injury level.
    - May require anterior approach for decompression and/or achieve anterior column support for additional stability.

□ Complications

- Potentially negative outcomes are numerous and include neurologic injury, nonunion, and malunion.
- Delayed instability
    - Associated with greater than 3.5 mm of subluxation
    - Associated with greater than 11 degrees of difference in angulation between adjacent motion segments

□ Prognosis—Frankel classification useful for assessing functional recovery from spinal cord injury (Table 8.14)

▪ **Gunshot wounds to the spine**

- Typically mechanically stable injures that do not require surgery for mechanical instability
- Progressive neurologic decline and retained projectile in canal—surgical removal should be considered.
- Neurologically intact or stable and projectile retained in spinal canal
    - L1 and below—removal of projectile should be considered.
    - T12 and above—removal of projectile controversial; may result in worsening neurologic

deficit

- **Penetrating spine injuries accompanied by injury to abdominal content**
  - **Associated hollow viscera injury (gastrointestinal perforation)—tetanus prophylaxis and IV antibiotics for 7–14 days**
  - **Associated solid viscera injury (kidney, liver, etc.)—treated with oral antibiotics**

▪ **Considerations in pediatric spine trauma**

□ Many pediatric spinal injuries are analogous to those occurring in the adult population.

□ Notable differences

- Bony skeleton more ductile in child than in adult
- **Head is relatively larger than body.**
  - Therefore pediatric torso must be elevated 2–3 cm to maintain inline cervical alignment.
  - Special pediatric spine board can be used, or if not available, blankets or towels can be placed under torso to create necessary elevation.
- Skull is thinner in child.
  - Pediatric skull tongs and halo require more pins at lower torque.
  - **Total 6 to 8 pins at 2 to 4 inch-lb**
- Spinal cord and vertebral body relationship varies with increasing age.
  - Spinal cord begins at approximate level of L3 at birth.
  - Spinal cord stops growing around infancy.
  - Final spinal cord length ends with conus medullaris, typically ending around T12–L1/L1–2.
  - Therefore in adult, lumbar spine houses cauda equina, spinal nerve roots.

□ **Spinal cord injury without radiographic abnormality (SCIWORA)**

- Clinical entity occurring primarily in children
- Thought to be secondary to tenuous spinal cord blood supply and greater elasticity in vertebral column than in spinal cord
- Original description by Pang and Wilberger in 1982 defined SCIWORA as objective findings of spinal cord injury/myelopathy without evidence of ligamentous injury or fractures on plain x-rays or tomographic studies.
  - Original description did not include MRI as a diagnostic modality.
  - Original description excluded penetrating trauma,

    - electric shock, obstetric complications, and congenital spinal spine abnormalities.
    - Newer imaging studies, including MRI, have identified ligamentous and disc injury, complete spinal cord transections, and spinal core hemorrhage; however, normal MRI findings have also been described.

□ **C2 pediatric dens fracture**
  - **Most common pediatric cervical spine fracture**
  - Typically occurs in patients younger than 6 years
  - Frequently fractures through basilar synchondrosis (residual disc) of dens
  - Treatment
    - Traction must be avoided; can result in distraction of dens.
    - Reduction in hyperextension followed by Minerva or compression halo vest.

□ **Pediatric atlantoaxial (C1–2) rotatory subluxation**
  - Similar to that in adults, except that typically due in pediatric population to loss of ligamentous stability between C1 and C2. Results in rotation with lateral tilt.
    - Can occur spontaneously
    - Secondary to trauma
  - Etiology in pediatric population includes
    - Atlantoaxial instability secondary to pharyngeal infections (Grisel syndrome)
    - Down syndrome
    - Morquio syndrome
    - Achondroplasia
    - Klippel-Feil syndrome
    - Spondyloepiphyseal dysplasia
    - Larsen syndrome
  - Differentiating from torticollis
    - Torticollis is secondary to fibrosis of sternal head of sternocleidomastoid (SCM) muscle.
    - Typically palpable mass within SCM in congenital torticollis

□ **Pseudosubluxation of cervical spine in the pediatric population**
  - Cervical spine mobility, particularly in flexion and extension, is physiologically greater in pediatric population.
    - **Most commonly occurs at C2–3 followed by C3–4 in pediatric population**
    - Excess motion in children younger than 8 years is

considered normal.

- Radiographic evaluation
  - Anterior ADI can be up to 5 mm in children.
  - Up to 4 mm or 40% anterior displacement of C2 on C3 can be seen.
  - Subluxation can be accentuated if child's head in slight flexion.
  - Normal prevertebral soft tissue shadow on lateral radiograph
  - Absence of anterior soft tissue swelling
  - Swischuk line—line drawn through posterior arch of C2 should be within 2 mm of the spinolaminar line drawn at C1–3.

□ Pediatric flexion-distraction injuries (Chance fracture)

- Mechanism analogous to adult flexion-distraction injuries
  - Axis of rotation is anterior to vertebral body at anterior longitudinal ligament.
  - **High association with intraabdominal injuries**
- Adult flexion-distraction injuries typically occur between T11 and L1, but pediatric flexion distraction injuries can occur lower, at L1–2 and L2–3, owing to different center of gravity.
- Treatment
  - Bony flexion-distraction injuries in neurologically intact patient can be treated closed with extension bracing.
  - Purely ligamentous flexion-distraction injuries frequently require surgery, owing to late ligamentous instability.

□ Apophyseal ring spine avulsion fractures

- Introduction
  - Avulsion of apophyseal ring in association with disc herniation
  - Pathophysiology unclear; associated with relative weakness of apophyseal ring during childhood
  - May have association with Scheuermann disease (debated)
  - Patients typically adolescents or young adults
  - Acute spinal trauma is not always identified.
  - Must be differentiated from posterior longitudinal ligament, anulus, or calcified herniated disc, and posterior discoosteophytic ridge.
- Imaging

- Although some writers report that this injury can be identified on plain radiographs in up to 70% of patients, it can still be missed in about one-third of cases.
- CT able to identify injury in nearly all cases.
- MRI does not identify bone as well as CT, so apophyseal avulsion can be missed on MRI.

Testable Concepts

Section 1 Introduction

- Careful history is vital to accurate diagnosis and management of spinal pathology.
- Physical examination should include motor, sensory, reflexes, and when appropriate rectal examination.
- In absence of trauma and red flag signs, plain radiographs are not required unless symptoms have persisted longer than 4 to 6 weeks.
- False positive–MRIs are common, and imaging should be correlated carefully with history and physical examination.

Section 2 Cervical Spine

- Cervical spondylosis most commonly occurs at C5–6 followed by C6–7.
    - Cervical nerve roots exit above their corresponding vertebrae (e.g., C5 exits at C4–5 neural foramen). Consequently, disc herniations at C5–6 involve the C6 nerve root.
    - Natural history of cervical spondylotic myelopathy is most commonly characterized by stepwise deterioration followed by a period of stability.
    - False positive–MRIs are common, with 25% of asymptomatic patients older than 40 years demonstrating a herniated nucleus pulposus or foraminal stenosis.
    - Operative indications include myelopathy with motor and/or gait impairment and radiculopathy with persistent disabling pain that has failed nonoperative measures.
    - Complications of anterior cervical discectomy and fusion include recurrent laryngeal nerve injury, dysphagia, airway obstruction, nonunion, and adjacent segment disease. Nonunion should be treated with posterior spinal fusion.
    - Canal-expanding laminoplasty are used for multilevel spondylosis, congenital cervical stenosis, and ossification of the posterior longitudinal ligament. It is contraindicated in the setting of fixed kyphosis.
    - In selected cases, cervical TDR may be considered. However, presence of spinal deformity, segmental spinal instability, facet arthropathy, and inability to adequately radiographically visualize the implant intraoperatively are contraindications to cervical TDR placement, and ACDF should be considered instead.
    - Surgical options for discogenic neck pain are limited and should be avoided.

- Cervical stenosis
    - Pavlov (Torg) ratio of less than 0.80 or a sagittal diameter of less than 14 mm are considered risk factors for late neurologic involvement.
    - Absolute stenosis is defined as anterior-posterior canal diameter of less than 10 mm.
- Rheumatoid spondylitis
    - In the cervical spine can commonly be asymptomatic but can present as occipital headaches due to compression of the greater occipital nerve (C2).
    - Progressive cervical instability secondary to pannus formation and erosion of the joint sand capsular structures occurs in up to 90% of patients. This can manifest as atlantoaxial subluxation (AAS), atlantoaxial invagination (AAI), or subaxial subluxation (SAS).
    - AAS is most common. A posterior atlantodens interval (ADI) less than 14 mm is associated with an increased risk of neurologic injury and usually requires surgical treatment. C1–2 fixation is most commonly performed with C1 lateral mass screws and C2 pedicle/pars screws and is biomechanically the strongest construct of C1–2 fixation techniques.
    - Surgery is less successful in Ranawat grade IIIB patients but should still be considered.
    - Consideration for flexion/extension lateral cervical spine radiographs should be considered before elective surgery in patients with rheumatoid arthritis.
- Ankylosing spondylitis (AS) patients who present with neck pain should be carefully evaluated for an occult cervical spine fracture.
- Cervical spine injury can be associated with spinal shock and/or neurogenic shock.
    - Spinal shock is over with return of the bulbocavernosus reflex.
    - Neurogenic shock is hypotension secondary to loss of sympathetic tone with bradycardia.
- Incomplete spinal cord syndromes are anatomically classified and all involve some sparing of distal function.
    - Central cord is most common, typically affecting elderly patients with a spondylotic cervical spine. It presents as motor and sensory loss greater in the upper than lower extremity. Independent ambulation is regained in approximately half of elderly patients and almost all young patients.
    - Anterior cord syndrome is the second most common and has the worst prognosis of ambulation. It presents as greater motor loss in the legs than in the arms.
    - Brown-Sequard syndrome presents as ipsilateral motor weakness on the side of injury, with contralateral loss of pain and temperature. It has the best overall prognosis.
    - Posterior cord syndrome is most uncommon and results in loss of

proprioception, vibratory sensation, and deep pressure due to injury to the dossal column.

- Autonomic dysreflexia is a syndrome of uncontrolled sympathetic nervous output occurring in patients with a spinal cord injury above T6. It presents as hypertension, pupillary dilatation, headache, pallor, and reflex tachycardia. Treat with urinary catheterization, fecal disimpaction, antihypertensives, and atropine in severe cases.

Section 3 Thoracic Spine

- Most thoracic herniated discs are treated symptomatically and nonoperatively.
- Indications for surgery include progressive thoracic myelopathy and persistent unremitting radicular pain.
- Anterior transthoracic approaches allow direct access to the herniation but require entering into the chest cavity. Discetomy and hemicorpectomy are performed as needed.
    - Posterior laminectomy alone is contraindicated because of an inability to retract the spinal cord and high associated rate of neurologic injury.
    - Posterior transpedicular, costotransversectomy, or posterolateral extracavitary approaches may allow for access to the disc herniation while avoiding the need to enter into the chest cavity; however, they require stabilization and fusion to reduce the risk of late spinal instability.

Section 4 Lumbar Spine

I. Lumbar Degenerative Disc Disease

- Most herniations are posterolateral, where the posterior longitudinal ligament is the weakest, and typically affect the traversing (caudal) nerve root. Therefore, L4–5 posterolateral disc herniation results in L5 nerve root compression.
- Far lateral herniation or foraminal stenosis involves the exiting (cephalad) nerve root. Therefore L4–5 far-lateral disc herniation results in L4 nerve root compression.
- Greater than 90% of patients seeking treatment for back and leg pain recover within 1–3 months of onset of symptoms with conservative measures.
- Failure to improve after 6 weeks warrants further investigation. Radiographs are generally the first imaging studies performed, even before MRI.
- Surgery is indicated in the presence of persistent symptoms despite 12 weeks of conservative measures, progressive weakness, or evidence of bowel or bladder dysfunction. Partial discectomy with or without laminectomy is the most common procedure performed.

- Outcomes from the SPORT trial (2-year follow-up)
    - No significant differences in primary outcome measures for operative compared with nonoperative groups
    - However, trends favoring surgical intervention in primary outcome measures
    - Statistically significant improvement in secondary outcome measures for surgical intervention, sciatica bothersomeness, and self-rated improvement.
- Workers' compensation patients are more likely to continue to receive disability compensation and have worse symptoms, functional status, and satisfactions outcomes.
- Complications include vascular injury, nerve root injury, infection (1% but increased in diabetics), discitis, cauda equine syndrome, and dural tears.
    - Treatment of dural tear includes bedrest and subarachonoid drain placement. If adequately repaired, clinical outcomes are generally unaffected.

II. Lumbar Spinal Stenosis

- Spinal stenosis can be classified anatomically into central, ateral recess, and foraminal stenosis. "**Tandem stenosis**" is the occurrence of both cervical and lumbar stenosis and can present as neurogenic claudication, radiculopathy, and myelopathy.
    - Central stenosis is narrowing of the central spinal canal bordered laterally by the medial border of the superior articular process.
    - Lateral stenosis is narrowing of the subarticular recess, bounded by the takeoff of the nerve root from the common dural sac to the medial border of the pedicle.
    - Foraminal stenosis is narrowing of the neural foramen, bounded by the disc anteriorly, pars intraarticularis posteriorly, and pedicles superiorly and inferiorly.
- Central stenosis that fails nonoperative management should be treated with laminectomy and partial medial facetectomy. Surgical instability (via removal of a facet), a pars defect, spondylolisthesis, scoliosis, and radiographic instability are indications for inclusion of fusion.
- Lateral recess stenosis that fails nonoperative management should be treated with decompression of the hypertrophied lamina and ligamentum flavum, and partial medial facetectomy.
- Residual foraminal stenosis is a common reason for persistent radicular pain after laminectomy.
- Outcomes from the SPORT trial (4-year follow-up) demonstrated significant improvement in pain and function for operative compared with nonoperative groups.

III. Spondylolysis and Spondylolisthesis

- Spondylolysis is a defect in the pars interarticularis without slippage, while spondylolisthesis is slippage of one vertebra in relationship to another.
- Wiltse classification divided spondylolisthesis into six types, with the isthmic type occurring most commonly at L5–S1, while degenerative types occur most commonly at L4–5.
- Isthmic spondylolisthesis can present in childhood or in adults.
    - Pediatric
    - Low-grade (<50%) slips typically respond to nonoperative treatment but should be followed serially to watch for possible progression.
    - High-grade (>50%) slips are typically more symptomatic and have a higher rate of progression. Surgical stabilization with posterolateral fusion, frequently from L4–S1, should be considered.
    - Adult
    - Associated with increased pelvic incidence
    - Operative treatment frequently requires associated decompression for neurologic compression, stabilization, and posterolateral fusion.
- Degenerative spondylolisthesis is more common in women.
    - Can present with symptoms of both central and lateral recess spinal stenosis
    - Operative treatment for degenerative spondylolisthesis involves decompression of nerve roots and stabilization with posterolateral fusion.
    - Outcomes from the SPORT trial (4-year follow-up) demonstrated significant improvement of pain and function for operative compared with nonoperative groups.

IV. Cauda Equina

- Typically secondary to large extruded disc, surgical trauma, and/or hematoma
- Presents with bowel and bladder dysfunction, saddle anesthesia, and varying degrees of lower extremity weakness
- Urgent/emergent MRI can help assess for compression of the cauda equina, with surgical decompression as soon as possible.

Section 5 Adult Deformity

I. Scoliosis—Coronal Plane Deformity

- Adult scoliosis is typically lumbar/thoracolumbar and more symptomatic than its childhood counterpart.
- Right thoracic curves greater than 50 degrees are at the highest risk for

progression (usually 1 degree/yr), followed by right lumbar curves.
- Sagittal plane imbalance is a strong predictor of disability, and preservation of normal sagittal alignment is critical.
- Whether to end a fusion at L5 or S1 distally is controversial. Fusion to L5 is associated with development of L5–S1 degenerative disc disease and progressive sagittal imbalance. Fusion to the sacrum is associated with increased incidence of pseudarthrosis and gait disturbance.

II. Kyphosis—Sagittal Plane Deformity

- Kyphosis is a sagittal plane deformity and can occur with or without an associated coronal plane deformity (scoliosis).
- Can occur secondary to a variety of sources; however, common causes include osteoporotic compression fractures, postlaminectomy kyphosis, and junctional kyphosis above and below a previous surgical site.

Section 6 Sacropelvis

- Sacroiliac joint dysfunction and coccygodynia are typically self-limiting and treated nonoperatively.
- In selected cases, sacroiliac fusions may be an option if conservative treatments fail and symptoms are severe and persistent.
- Sacral insufficiency fractures can occur in patients with osteopenia/osteoporosis and should therefore be part of the evaluation and management.

Section 7 Spinal Tumors

- Metastatic disease is the most common malignancy of the spine and most commonly involves the vertebral body.
- Red flags for metastatic disease include a history of cancer, unexplained weight loss, night pain, and age older than 50 years.
- Multispecialty involvement is important.
- MRI with gadolinium is the imaging technique of choice.
- CT scan of chest, abdomen, and pelvis can help identify possible primary lesions.
- Wide excision is typically performed for primary bone tumors without known metastases and solitary metastases with likelihood of prolonged survival.
- Decompressive surgery techniques
    - Upper cervical spine (occiptio-atlanto-axial junction) typically posterior approach combined with stabilization
    - Posterior element tumors addressed posteriorly with or without stabilization
    - Vertebral body tumors typically addressed anteriorly with or without

stabilization
    - Multilevel involvement

Section 8 Spinal Infections and Inflammatory Arthritides

I. Osteodiscitis

- Most commonly presents as pain and elevated erythrocyte sedimentation rate and C-reactive protein levels.
    - Radiographs are often normal, with loss of lumbar lordosis and disc space narrowing the earliest findings.
    - Treatment is with IV antibiotics, and C-reactive protein should be used to monitor the response.
    - Surgical irrigation and débridement and bone grafting are reserved for cases refractory to medical management.
    - Pyogenic vertebral osteomyelitis is usually from hematogenous spread and involves *Staphylococcus aureus* in 50%–75% of cases.

II. Epidural Abscess

- Typically presents with patients being more systemically ill than osteodiscitis and osteomyelitis patients.
- Management is typically surgical, with irrigation and débridement of infected tissue and drainage of abscess.

III. Tuberculosis Spondylitis

- Differs from pyogenic infections in several ways:
    - Disc spaces typically preserved with tuberculosis spondylitis
    - Associated spinal deformity more common (typically kyphosis)
    - More typically associated with large paravertebral abscess/phlegmon.
    - More likely to spread along anterior longitudinal ligament to involve adjacent vertebral bodies

IV. Ankylosing Spondylitis

- Associated with HLA-B27, but only 2% of patients with HLA-B27 have AS, and therefore not used in the diagnosis.
- Sacroiliac joint obliteration (iliac side affected first) and marginal syndesmophytes allow radiographic differentiation from diffuse idiopathic skeletal hyperostosis (DISH).
- Spine often becomes fused in kyphosis. Posterior extension osteotomies and fusion can be utilized to address the deformity.

V. Diffuse Idiopathic Skeletal Hyperostosis

- Typically seen in older patients and more common in the thoracic spine
- Radiographs typically demonstrate undulating "nonmarginal syndesmophytes"

Section 9 Skeletal Trauma

I. Upper Cervical Spine Injuries (C1–2)

- ASIA classification of spinal cord injury is based on motor strength and complete versus incomplete sensory deficit.
- C1 ring fractures may be stable or unstable depending on the integrity of the transverse ligament. Combined lateral mass displacement of greater than 6.9 mm indicates transverse ligament disruption. Posterior spinal fusion is recommended.
- Odontoid fracture treatment is based on their risk of developing nonunion.
    - Type I: Avulsion of tip of dens; treated in rigid orthosis
    - Type 2: Through waist of dens; highest risk of nonunion
    - Risk factors for nonunion include displacement greater than 5 mm, angulation greater than 100 degrees, posterior displacement, age older than 50 years, and delayed treatment.
    - Surgical treatment is typically posterior C1–2 fusion. In selected cases, anterior odontoid screw may be an option if the fracture is reducible and fracture obliquity is amenable to fixation.
    - Type 3: Through body of C2; treated in rigid orthosis
- Traumatic spondylolisthesis of C2 (hangman's fracture)
    - Fracture through pars of C2
    - Trial of external rigid orthosis is option for patients with less than 4 mm translation and 10 degrees of angulation.
    - Axial distraction with significant angulation/flexion (Type IIa) are at higher risk for neurologic injuries.

II. Lower Cervical Spine (C3–7)

- Bilateral facet joint dislocations demonstrate greater than 50% translation and are more often associated with spinal cord injury.
- Timing of MRI in reduction of facet dislocations is controversial.
    - Most authors recommend obtaining an MRI prior to closed reduction in the obtunded, noncommunicative, or unexaminable patient.
    - Closed reduction before MRI can be consider in the awake, alert, and cooperative patient who can participate in a full neurologic examination.

III. Thoracolumbar and Lumbar Spine Injuries

- Flexion-distraction injuries involve failure of the posterior and middle columns in tension.
    - These injuries are frequently treated with surgical stabilization via posterior approach.
    - Occasionally they require additional anterior decompression and stabilization.
- Axial load burst fractures may be treated in an orthosis if kyphosis is minimal, patient is neurologically intact, and posterior ligamentous complex is intact.

Chapter 8 Review Questions

1. Which of the following incomplete spinal cord injury syndromes has the *worst* prognosis for recovery?
   B. Anterior cord syndrome
   C. Posterior cord syndrome
   D. Central cord syndrome
   E . Brown-Séquard syndrome
   F . Nerve root injury syndrome
   ANSWER 1: **A.**

2. What is the most likely diagnosis in a patient with paresthesias in the thumb and index finger and weakness of elbow flexion and wrist extension?
   A. Carpal tunnel syndrome
   B. Radial tunnel syndrome
   C. C5 radiculopathy
   D. C6 radiculopathy
   E. C7 radiculopathy
   ANSWER 2: **D.**

3. A 43-year-old man presents 2 years after undergoing anterior cervical discectomy and fusion (ACDF) for cervical radiculopathy. He has had complete resolution of his arm pain but has a 2-month history of neck pain. Radiograph demonstrates a fibrous nonunion. What should you now recommend?
   A. Revision ACDF
   B. Total disc arthroplasty
   C. Physical therapy for cervical strengthening and over-the-counter analgesics
   D. CT myelography
   E. Posterior fusion with lateral mass plating
   ANSWER 3: **C.**

4. A patient reports progressive hand clumsiness and unsteadiness with walking. Examination reveals presence of the Hoffmann sign and atrophy of the hand intrinsics. MRI demonstrates multilevel cervical spondylosis and

stenosis. Lateral flexion and extension radiographs show mild cervical kyphosis in the neutral position, with restoration of lordosis on extension. Which of the following procedures is most likely to result in poor long-term results?

A. Anterior cervical discectomy with fusion at the involved levels

B. Anterior and posterior decompression with circumferential fusion

C. Anterior corpectomy and fusion with a fibula strut

D. Laminectomy and bilateral foraminotomies

E. Laminectomy and posterior fusion with lateral mass plating

ANSWER 4: **D.**

5. A 66-year-old woman with rheumatoid arthritis has atlantoaxial instability and basilar invagination. What MRI findings would suggest the need for cervical fusion?

A. Cervical medullary angle of 120 degrees

B. C1–2 motion of 6 mm on flexion radiograph

C. Cord diameter in flexion of 10 mm

D. Posterior atlantodens interval of 15 mm

E. Erosion of the tip of the odontoid

ANSWER 5: **A.**

6. If a 75-year-old man with no prior history of back or leg pain were to undergo MRI of the lumbar spine, what is the chance that the study would demonstrate disc degeneration and/or bulging?

A. 20%

B. 35%

C. 50%

D. 70%

E. 90%

ANSWER 6: **E.**

7. Which radiographic picture is most likely to be seen in a man with a left-sided Trendelenburg gait?

A. Central disc herniation at L3–4

B. Left paracentral disc herniation at L3–4

C. Left paracentral disc herniation at L4–5

D. Left paracentral disc herniation at L5–S1

E. Left far lateral disc herniation at L4–5

ANSWER 7: **C.**

8. Flexion-distraction injuries of the thoracolumbar spine are most frequently associated with injury to what organ system?

A. Cardiac system

B. Central nervous system

C. Vascular system

D. Gastrointestinal system

E. Pulmonary system

ANSWER 8: **D.**

9. Which of the following conditions is an indication for fusion when a laminectomy for spinal stenosis is performed?

A. Prior laminectomy at an adjacent level

B. Degenerative spondylolisthesis at the level of the laminectomy

C. Removal of 25% of each facet joint at surgery

D. Low back pain

E. Foraminal stenosis at the level of the laminectomy

ANSWER 9: **B.**

10. In patients undergoing fusion with instrumentation for adult scoliosis, which of the following is the most likely site for a pseudarthrosis to be discovered?

A. T5–6

B. T7–8

C. L1–2

D. L4–5

E. L5–S1

ANSWER 10: **E.**

11. A 42-year-old man presents with right lower extremity pain in an S1 radicular pattern for 6 weeks. He relates that he underwent a right-sided L5–S1 discectomy with successful relief of similar pain 5 years ago. Which of the following imaging studies would offer the greatest amount of information?

A. Lumbar MRI with gadolinium

B. CT

C. CT with contrast myelography

D. Lumbar lateral flexion-extension radiographs

E. SPECT

ANSWER 11: **A.**

12. Four weeks after an otherwise successful lumbar microdiscectomy, with complete relief of his preoperative sciatica, a 36-year-old man presents with the sudden onset of severe back and buttock pain. Examination and laboratory findings are unremarkable, with the exception of an erythrocyte sedimentation rate of 90 mm/hr. What is the most appropriate step in management at this time?

A. A short course of oral steroids

B. MRI with gadolinium

C. Anteroposterior and lateral flexion/extension radiographs

D. Open biopsy of the surgical disc space

E. Anterior débridement and interbody fusion

ANSWER 12: **B.**

13. What is the most common presenting symptom in an adult with vertebral osteomyelitis?

A. Fever

B. Night sweats

C. Unexplained weight loss

D. Dizziness

E. Back pain

ANSWER 13: **E.**

14. A 56-year-old man with type 2 diabetes presents with a 3-month history of constant thoracolumbar back pain. He is getting worse despite nonoperative treatment. If you suspect a pyogenic spine infection, what is the most accurate test for diagnosis?

A. Plain radiograph

B. CT with intravenous contrast

C. SPECT

D. MRI

E. Differential technetium Tc 99m and gallium (Ga) 67 scanning

ANSWER 14: **D.**

15. A 22-year-old woman has had posterior neck discomfort for the past 6 months. SPECT reveals increased activity at the C7 spinous process. CT demonstrates multifocal involvement of the spinous process lamina and facet of C7, and a CT-directed needle biopsy reveals osteoblastoma. What is the best course of action?

A. Observation

B. En bloc excision

C. Curettage

D. Radiation therapy

E. En bloc excision followed by radiation therapy

ANSWER 15: **B.**

16. A 62-year-old woman has pain in her back and right anterior thigh. MRI suggests a neoplastic lesion at L2. Results of all other metastatic workup, including bone scan and CT of the chest, abdomen, and pelvis, are negative except for the lesion at L2. History reveals that she was treated for breast cancer without known metastatic disease 12 years ago and is thought to be free of disease. What is the next most appropriate step in management?

A. CT-guided biopsy

B. Vertebroplasty

C. En bloc resection and anterior fusion

D. Radiation therapy

E. Repeat MRI in 3 months

ANSWER 16: **A.**

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CHAPTER 9

Orthopaedic Pathology

Ginger E. Holt

Presentation

- **History**
  - Age of the patient: Certain diseases are common in particular age groups (Table 9.1).
  - Inquiring about personal history of cancer, genetic diseases, radiation, and trauma (or lack thereof) is pertinent.
- **Physical examination**
  - Evaluation for chronic lymphedema (angiosarcoma), genetic conditions (café au lait spots, neurofibromas), and prior irradiation (radiation-induced fracture or sarcoma) is important in musculoskeletal diseases.
  - Breast, lungs, thyroid, kidney, and prostate (mnemonics: “BLT and a kosher pickle” and “PT Barnum Likes Kids”) are the five common osteophiles metastatic to bone.
- **Laboratory studies: Diagnostic tests for musculoskeletal neoplasms include**
  - Prostate-specific antigen (PSA) for prostate cancer
  - **Serum and urine electrophoresis (SPEP and UPEP) for myeloma**
  - Erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) for infection

Imaging

- **Radiographs in two planes should be obtained to establish answers to Enneking’s four questions:**
  - Location: Epiphyseal, metaphyseal, diaphyseal, etc.
  - Tumor-bone interaction
  - Bone-tumor interaction; refers to the interplay between the host bone and the tumor, described by Lodwick (Table 9.2; Figs. 9.1 to 9.3)
  - Matrix: What are the tumor cells producing (bone, cartilage, etc.) (Fig. 9.4; Table 9.3; see Figs. 9.1 and 9.2)?
- **Plain radiographs are used to look at both number and location of bone lesions.**
  - Number of bone lesions according to patient age
    - Age over 50 years: If there are multiple destructive lesions the most likely diagnosis is metastatic bone disease, multiple myeloma, or lymphoma.
    - Age under 30 years: Multiple lytic, oval lesions in the same extremity may be vascular tumors (hemangioendothelioma) or fibrous lesions (Jaffe-Campanacci).
    - Age under 5 years: Multiple destructive lesions may represent metastatic disease such as neuroblastoma, Wilms

tumor, or Langerhans cell histiocytosis (LCH).

Table 9.1

Bone Lesions by Patient Age

	<5 Years	<30 Years	>30 Years
Malignant lesions	LCH (Letter-Siwe) LCH (Hand-Schüller-Christian) Metastatic rhabdomyosarcoma Metastatic neuroblastoma	Ewing sarcoma Osteosarcoma	Chondrosarcom Metastases Lymphoma Myeloma Chordoma Adamantinoma
Benign lesions	Osteomyelitis Osteofibrous dysplasia	Osteoid osteoma Osteoblastoma Chondroblastoma Aneurysmal bone cyst LCH Osteofibrous dysplasia Non-ossifying fibroma	Giant cell tumo Paget disease

Table 9.2

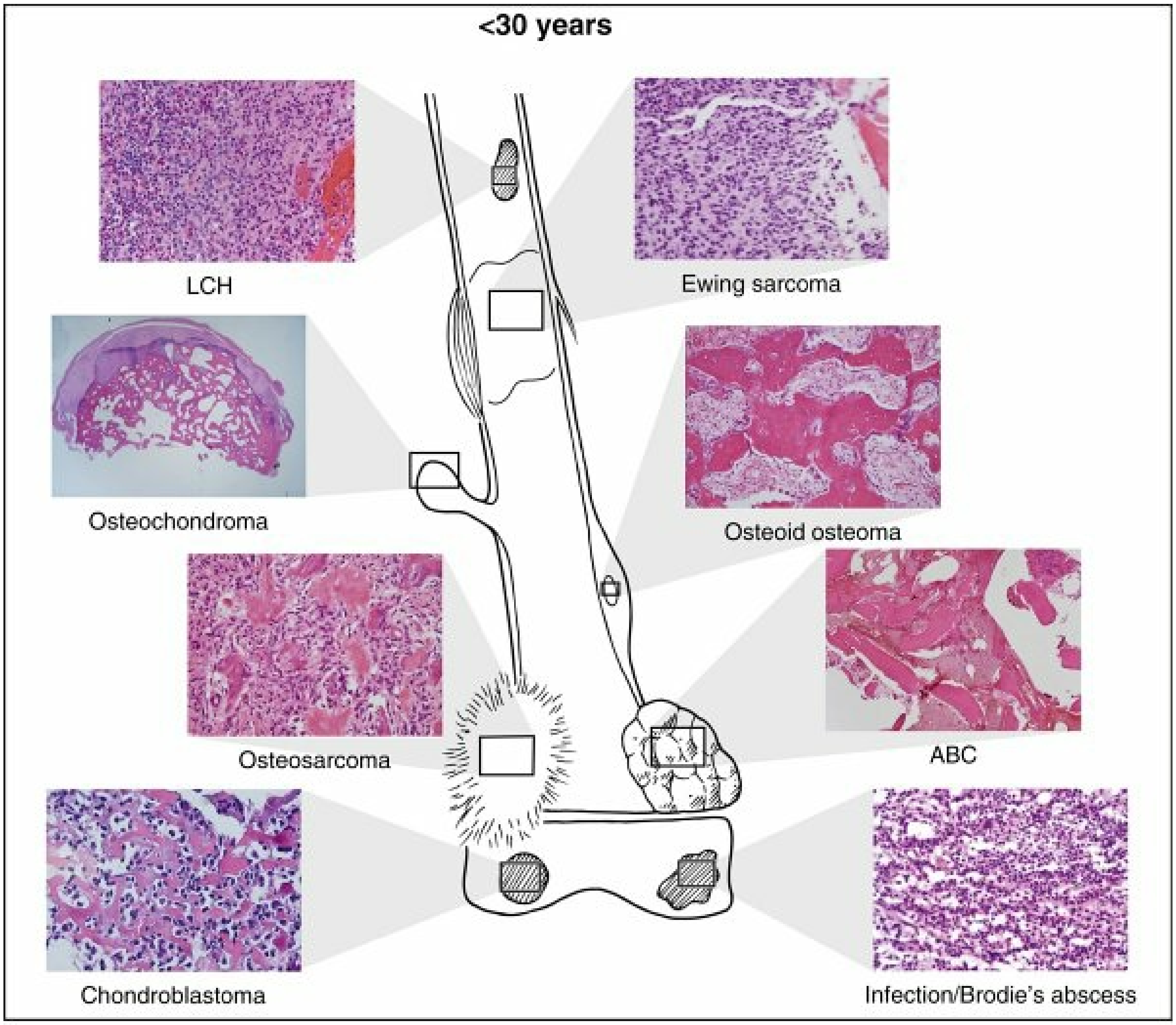
Tumor-Bone Interaction (From Lodwick)

Lesion	Type I	Type II
Radiographic appearance	Geographic A: Sclerotic B: Distinct C: Indistinct	Moth-eaten
Examples	A: Nonossifying fibroma B: Unicameral bone cyst C: Giant cell tumor	Osteomyelitis Metastases
Image		
Description	 FIG. 9.1 Example of tumor-bone interaction. Lodwick type I interaction. Distal tibia lesion with a geographic border and a sclerotic rim.	 FIG. 9.2 Lodwick type II interaction. Proximal femur with a motheaten appearance. Metastatic carcinoma.

- All age groups: Fibrous dysplasia and Paget disease may manifest with multiple lesions.

- Anatomic location within bone: Certain lesions have a predilection for occurring within a certain bone or a particular part of the bone (Table 9.4; see Fig. 9.4).

- **A chest radiograph is used to look for primary lung disease and metastases.**
- **Technetium Tc99m whole-body bone scan is used to look for occult bone involvement. A whole-body bone scan result can be "cold" in patients with myeloma, in whom a radiographic skeletal survey is more sensitive.**
- **MRI is used to evaluate the primary tumor site.**
- **CT may be used for three-dimensional imaging if MRI is contraindicated (e.g., by cardiac pacemaker) or to evaluate a suspected osteoid osteoma or mineralization in a mass.**


<30 years
LCH
Ewing sarcoma
Osteochondroma
Osteoid osteoma
Osteosarcoma
ABC
Chondroblastoma
Infection/Brodie's abscess

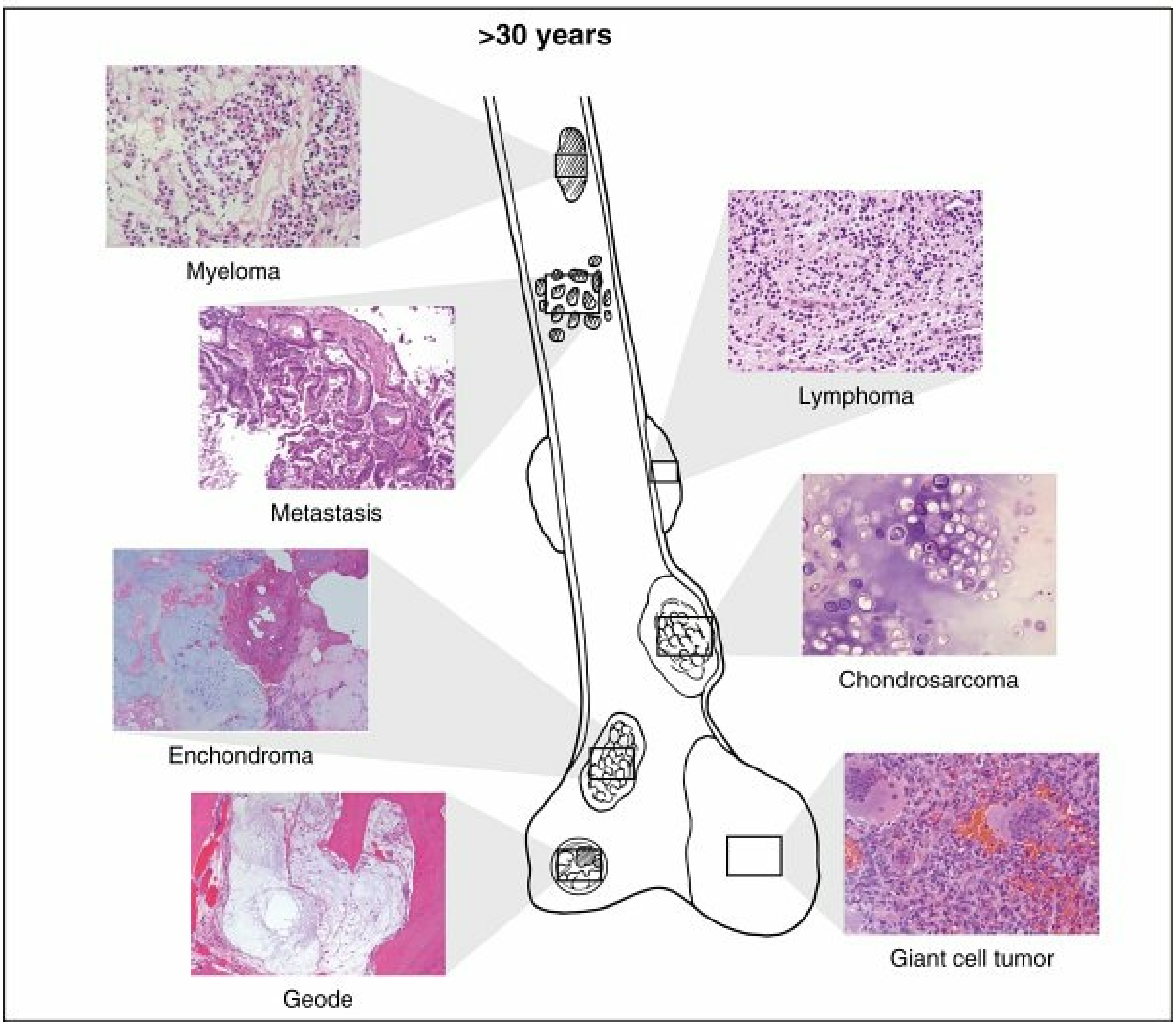

>30 years
Myeloma
Lymphoma
Metastasis
Chondrosarcoma
Enchondroma
Giant cell tumor
Geode

FIG. 9.4 Site of the lesion. (A) Distribution of various lesions in a long tubular bone in a growing skeleton (growth plate is open; patient <30 years old). (B) Distribution of various lesions in a long tubular bone after skeletal maturity (growth plate is closed; patient >30 years old).

Table 9.3

Classification of Primary Tumors of Bone and Bone Matrix [a]

Histologic Type	Benign	Malignant
Hematopoietic		Myeloma Lymphoma
Chondrogenic	Osteochondroma Chondroma Chondroblastoma Chondromyxoid fibroma	Primary chondrosarcoma Secondary chondrosarcoma Dedifferentiated chondrosarcoma Mesenchymal chondrosarcoma Clear cell chondrosarcoma
Osteogenic	Osteoid osteoma Osteoblastoma	Osteosarcoma Parosteal osteosarcoma Periosteal osteosarcoma
Unknown origin	Giant cell tumor (fibrous) histiocytoma	Ewing tumor Malignant giant cell tumor Adamantinoma
Fibrogenic	Fibroma Desmoplastic fibroma	Fibrosarcoma Malignant fibrous histiocytoma
Notochordal		Chordoma
Vascular	Hemangioma	Hemangioendothelioma Hemangiopericytoma
Lipogenic	Lipoma	Liposarcoma
Neurogenic	Neurilemoma	Malignant peripheral nerve sheath tumor

[a] Classification is based on that advocated by Lichtenstein L: Classification of primary tumors of bone, *Cancer* 4:335-341, 1951.

Table 9.4

Tumors by Location

Epiphyseal	Chondroblastoma
	Giant cell tumor

	Clear cell chondrosarcoma (femoral head)
Metaphyseal	Osteosarcoma
	Chondrosarcoma
	Metastatic disease
Diaphyseal	A = adamantinoma
	E = eosinophilic granuloma
	I = infection
	O = osteoid osteoma/osteoblastoma
	U = Ewing sarcoma
	Y = mYeloma, lYmphoma, fibrous dYsplasia
	Metastatic disease
Flat bones	Chondrosarcoma
	Fibrous dysplasia
	Hemangioma
	Paget disease
	Ewing sarcoma
Spine	
Anterior column	Giant cell tumor
	Metastatic disease
Posterior column	Osteoid osteoma/osteoblastoma
	Aneurysmal bone cyst
Sacrum	
Midline	Chordoma
Eccentric	Aneurysmal bone cyst / giant cell tumor/metastatic disease

Biopsy (Bone and Soft Tissue)

- **Biopsy determines tumor type and grade. Clinicians must follow several surgical principles (** Table 9.5).
  - **Longitudinal incision in line with future resection. Longitudinal incision is extensile and allows for excision of the biopsy tract at the definitive surgical resection**.
  - Biopsy performed through a single compartment.
  - Avoidance of critical structures such as major nerves and blood vessels.
  - Inclusion of the soft tissue component of a bone tumor in the biopsy specimen. This principle avoids creating a stress riser and fracture in an already compromised bone.

Table 9.5

Principles of Musculoskeletal Biopsy

Principle	Rationale
Longitudinal incision in line with future resection **Biopsy performed through a single compartment**	Longitudinal incision is extensile Biopsy tract can be excised with final resection remaining extensile
Avoidance of critical structures (e.g., neurovascular bundles)	Contamination of critical structures precludes limb salvage
Biopsy includes soft tissue component when present	Bone is weakened when its cortex is disrupted Bone requires decalcification for evaluation, and this process may affect pathology
Maintenance of strict hemostasis **Use of a drain in line with the incision when needed**	Avoid increased contamination outside of the biopsy tract by iatrogenic spread of tumor

  - Culture the biopsy specimen.
- **The three general types of biopsy are fine needle aspiration (FNA), core, and open.**
  - FNA is used to determine whether a mass is cancer or not. A needle is used to draw a few cells from a mass. FNA is the least invasive method but may not collect enough tissue.
  - Core biopsy uses a coring device to remove a larger tissue sample and can diagnose the type and grade of the tumor. Ultrasound, CT, or MRI may be used to guide the procedure.
  - Open biopsy may be used if the other two mechanisms are not able to render a diagnosis. The two types of open biopsy are excisional and incisional.
    - Excisional biopsy is used when a lesion is less than 3 cm; the

procedure removes the entire mass with clear margins.
  - Incisional biopsy is used when a lesion is more than 3 cm; the procedure removes a small amount of tissue for diagnosis using the principles listed previously.

- **Immunohistochemistry (IHC) and molecular testing can aid in the diagnosis of some bone and soft tissue tumors (** Table 9.6).

Molecular Biology (Bone and Soft Tissue)

- **Chromosomes—sarcoma-associated translocations. The most well known is Ewing sarcoma, which results from balanced translocation of chromosomes 11 and 22. The gene fusion product from this balanced translocation is the** *EWS-FLI1* gene.
- **Oncogenes—genes with sequences that cause cancer.** *EWS-FLI1* and *SSX1-SYT* are oncogenes.
- **Tumor suppressor genes—genes that inhibit cell proliferation. Mutations allow for unregulated tumor growth. Examples are** *Rb* (retinoblastoma), which is mutated in 35% of osteosarcomas, and *p53*, which is mutated in 50% of all tumors and 20%–65% of osteosarcomas (Table 9.7).
- **Hereditary cancer syndromes are associated with tumor suppressor genes or specific genetic defects. The syndromes most commonly associated with osteosarcoma are Li Fraumeni syndrome (** *p53* gene) and congenital bilateral retinoblastoma (*RB1* gene); with chondrosarcoma is multiple hereditary exostoses (MHE); and with malignant peripheral nerve sheath tumor (MPNST) is neurofibroma type 1 (NF-1) (*NF1* gene) (Table 9.8).

Grading (Bone and Soft Tissue)

- **Grading uses the histologic appearance of a tumor and is based on nuclear atypia (extent of loss of structural differentiation), pleomorphism (variations in size and shape), and nuclear hyperchromasia (increased nuclear staining). Grading of tumors covers a morphologic range.**
  - Most systems use three grades.
  - The grade of tumor that is most strongly correlated with the potential for metastasis:
    - In bone: **Most malignant bone lesions are high grade.**
    - In soft tissue: Soft tissue tumors manifest with a greater variety of grades (Table 9.9).

Staging (Bone and Soft Tissue)

- **Staging systems are used for communicating, planning treatment, and predicting prognosis. The staging systems of the Musculoskeletal Tumor Society (also called the** *Enneking system*) and the American Joint Commission on Cancer (AJCC) are the most common for musculoskeletal diseases. Staging systems exist for both bone and soft tissue sarcomas.
  - Enneking system: Benign and malignant bone and soft tissue tumors (Table 9.10)
    - Benign—stages 1, 2, and 3
    - Malignant—stages I, II, and III
  - AJCC system for tumors of bone, listed in order of importance (Table 9.11)
    - Stage (presence of metastases = stage IV)
    - Discontinuous tumor (stage III)
    - Grade
      - Well-differentiated, low-grade (G1)
      - Moderately differentiated (G2)
      - Poorly differentiated (G3)
    - Size (>8 cm)
  - AJCC system for soft tissue sarcoma, listed in order of importance (Table 9.12)
    - Stage (presence of metastases = stage IV)

Table 9.6

Immunohistochemistry and Molecular Testing for Bone and Soft Tissue Tumors

Marker	Pathology	Tumor
SMA	Smooth muscle	Leiomyosarcoma
Desmin	Skeletal muscle	Rhabdomyosarcoma
***MyoD1*/Myogenin (*myf-4*)**	Skeletal muscle	Rhabdomyosarcoma
S-100	Neural tissue	Schwannoma, MPNST
CD34/CD31	Endothelial cells/vascularity	Hemangioma, hemangioendothelioma, angiosarcoma
β-Catenin	Membrane marker Wnt signaling pathway	Fibromatosis
CD99		Ewing sarcoma, PNET (peripheral neuroectodermal tumor)
Keratin		Epithelioid sarcomas, synovial sarcoma, carcinoma, adamantinoma
EMA		Epithelioid sarcomas, synovial sarcoma
Vimentin		Soft tissue sarcoma
CD20, CD45		Lymphoma
CD138		Myeloma

Table 9.7

Common Chromosomal Translocations in Bone and Soft Tissue Tumors

Diagnosis	Chromosomal Abnormality	Genes
Ewing sarcoma/PNET	t(11;22)	*EWS-FLI1*
Myxoid liposarcoma	t(12;16)	*TLS-CHOP*
Alveolar rhabdomyosarcoma	t(2;13)	*PAX3-FKHR*
Clear cell sarcoma	t(12;22)	*EWS-ATF1*
Synovial sarcoma	t(X;18)	*SSX1-SYT*
Myxoid chondrosarcoma (extraskeletal)	t(9;22)	*EWS-CHN*
Osteosarcoma	None	None

- Grade (G1, G2, G3)
- Size as a continuous variable (>5 cm, >10 cm, >15 cm)

Treatment (Bone and Soft Tissue)

- **Surgical procedures**
  - The goal of the treatment of malignant bone tumors is to remove the lesion with minimal risk of local recurrence (Table 9.13).
  - Limb salvage surgery (LSS) is wide-margin surgical resection excising a cuff of normal tissue and is performed when two essential criteria are met:
    - Local control of the lesion must be at least equal to that achieved if amputation surgery were done.
    - The remaining limb must be functional.
  - Surgical margins are defined as follows (Fig. 9.5).
    - **Intralesional margin:** The plane of dissection goes directly through the tumor. Used for benign tumors only, such as giant cell tumor (GCT) of bone and aneurysmal bone cyst (ABC).

Table 9.8

Musculoskeletal Syndromes, Genes, and Neoplasms

Syndrome	Disease	Musculoskeletal Neoplasm	Genetic Association
Li-Fraumeni	SBLA (sarcoma, breast, leukemia and adrenal gland) syndrome	Osteosarcoma	*p53*
Retinoblastoma	Bilateral malignant tumor of the eye in children	Osteosarcoma	*RB1*
Rothmund-Thomson	Sun-sensitive rash with prominent poikiloderma and telangiectasias	Osteosarcoma	*RECQL4*
Multiple hereditary exostoses	Multiple osteochondromas	Chondrosarcoma	*EXT1, EXT2*
Ollier disease	Enchondromas	Chondrosarcoma	*PTHR1*
Maffucci	Enchondromas + angiomas and CNS, pancreatic, and ovarian malignancies	Chondrosarcoma and/or angiosarcomas	*PTHR1*
McCune-Albright	Polyostotic fibrous dysplasia, precocious puberty, and café au lait spots		*GNAS*
Mazabraud	Fibrous dysplasia + soft tissue myxomas		*GNAS*
Jaffe-Campanacci	Multiple nonossifying		

	fibromas with café au lait skin patches		
POEMS	Polyneuropathy (peripheral nerve damage) Organomegaly (abnormal enlargement of organs) Endocrinopathy (damage to hormone-producing glands) M protein (an abnormal immunoglobulin) Skin abnormalities (hyperpigmentation)	Myeloma	
Hand-Schüller-Christian disease (less than 5 years old)	Multifocal LCH and exophthalmos, diabetes insipidus, and lytic skull lesions	LCH	
Letterer-Siwe disease (infants)	Multifocal LCH, visceral and bone disease; is fatal	LCH	
Stuart-Treves	Chronic lymphedema	Angiosarcoma	
NF-1	Multiple neurofibromas	MPNST	*NF1*
Familial adenomatous polyposis	Multiple intestinal polyps, colon cancer, hepatoblastoma	Desmoid tumors	*APC*

Table 9.9

Histologic Grading of Soft Tissue Tumors [a]

Grade	Differentiation	PERCENT
I	Good	<10
II	Moderate	10–30
III	Poor	>50

[a] Based on FNCLCC (Fédération Nationale des Centres de Lutte Contre Le Cancer) grading system.

- **Marginal margin:** A marginal line of resection goes through the reactive zone of the tumor; the reactive zone contains inflammatory cells, edema, fibrous tissue, and satellites of tumor cells. It is used commonly for atypical lipomas and well-differentiated liposarcomas.

        - **Wide margin:** Also known as wide excision; the entire tumor is removed with a cuff of normal tissue. This is the most common margin for a soft tissue sarcoma.
        - **Radical margin:** A radical margin is achieved when the entire tumor and its compartment (all surrounding muscles, ligaments, and connective tissues) are removed. Examples are amputation and surgery or removal of the entire anterior thigh compartment, vastus intermedius, vastus lateralis, and vastus medialis.
- **Adjuvant therapy**
    - Chemotherapy (Table 9.14)
        - Multiagent chemotherapy has a significant effect on both the efficacy of limb salvage and disease-free survival for bone sarcomas.

Table 9.10

Staging System of the Musculoskeletal Tumor Society (Enneking System)

Stage	Grade, Tumor Size, and Metastasis Status	Description
IA	$G_1T_1M_0$	Low-grade Intracompartmental No metastases
IB	$G_1T_2M_0$	Low-grade Extracompartmental No metastases
IIA	$G_2T_1M_0$	High-grade Intracompartmental No metastases
IIB	$G_2T_2M_0$	High-grade Extracompartmental No metastases
IIIA	$G_{1/2}T_1M_1$	Either grade Intracompartmental With metastases
IIIB	$G_{1/2}T_2M_1$	Either grade Extracompartmental With metastases

High-grade (G_2) lesions are intermediate between low-grade, well-differentiated tumors (G_1) and high-grade, undifferentiated tumors (G_3). The size of the tumor is determined through specialized imaging, including radiography, tomography, nuclear studies, CT, and MRI. Compartments are specified to describe the tumor site. These compartments are usually defined on the basis of fascial borders in the extremities. Of note, the skin and subcutaneous tissues are classified as a compartment, and the potential periosseous space between cortical bone and muscle is often considered a compartment as well. T_0 lesions are confined within the capsule and within the compartment of origin. T_1 tumors have extracapsular extension into the reactive zone around it, but both the tumor and the reactive zone are confined within the compartment of origin. T_2 lesions extend beyond the anatomic compartment of origin by direct extension or some other means (e.g., trauma, surgical seeding). Tumors that involve major neurovascular bundles are almost always classified as T_2 lesions. Both regional and distal metastases have ominous prognoses; therefore, the distinction is simply between the absence of metastases (M_0) and the presence of metastases (M_1).

Table 9.11

American Joint Committee on Cancer Staging System for Primary Malignant Tumors of Bone for Those Tumors Diagnosed On or After January 1, 2010

Stage	Tumor Grade	Tumor Size (cm)
IA	Low	<8
IB	Low	>8
IIA	High	<8
IIB	High	>8
III	Any tumor grade, skip metastases (discontinuous tumors in the primary bone site)	
IV	Any tumor grade, any tumor size, distant metastases	

Adapted from Edge SB, et al, editors: *AJCC cancer staging manual*, ed 7, New York, 2010, Springer, pp 281–290.

Table 9.12

American Joint Committee on Cancer Staging System for Primary Malignant Tumors of Soft Tissue for Those Tumors Diagnosed On or After January 1, 2010

Stage IA	T1a	N0	M0	G1, GX
	T1b	N0	M0	G1, GX
Stage IB	T2a	N0	M0	G1, GX
	T2b	N0	M0	G1, GX
Stage IIA	T1a	N0	M0	G2, G3
	T1b	N0	M0	G2, G3
Stage IIB	T2a	N0	M0	G2
	T2b	N0	M0	G2
Stage III	T2a, T2b	N0	M0	G3
	Any T	N1	M0	GX
Stage IV	Any T	Any N	M1	GX

TX: Primary tumor cannot be assessed.

T0: No evidence of primary tumor.

T1: Tumor ≤5 cm in greatest dimension. (Size should be regarded as a continuous variable, and the measurement should be provided.)

T1a: Superficial tumor.b

T1b: Deep tumor.b

T2: Tumor >5 cm in greatest dimension.

T2a: Superficial tumor.

T2b: Deep tumor.

NX: Regional lymph nodes cannot be assessed.

G1: Low grade

G2: Intermediate grade

G3: High grade

GX: Any grade

N0: No regional lymph node metastasis.

N1b: Regional lymph node metastasis.

M0: No distant metastasis.

M1: Distant metastasis.

Adapted from Edge SB, et al, editors: *AJCC cancer staging manual*, ed 7, New York, 2010, Springer, pp 291–298.

Table 9.13

Treatment Regimens for Malignant Bone Tumors

Treatment	Disease
Chemotherapy + surgery	Ewing sarcoma, osteosarcoma
Radiation + surgery	Soft tissue sarcoma
Limb salvage surgery/wide excision	Chondrosarcoma, adamantinoma, chordoma, parosteal osteosarcoma
Open reduction and internal fixation (ORIF) (+ radiation/chemotherapy)	Metastases, lymphoma, myeloma
Intralesional resection	GCT, ABC, nonossifying fibroma, LCH, osteoblastoma, chondroblastoma
Radiofrequency ablation	Osteoid osteoma

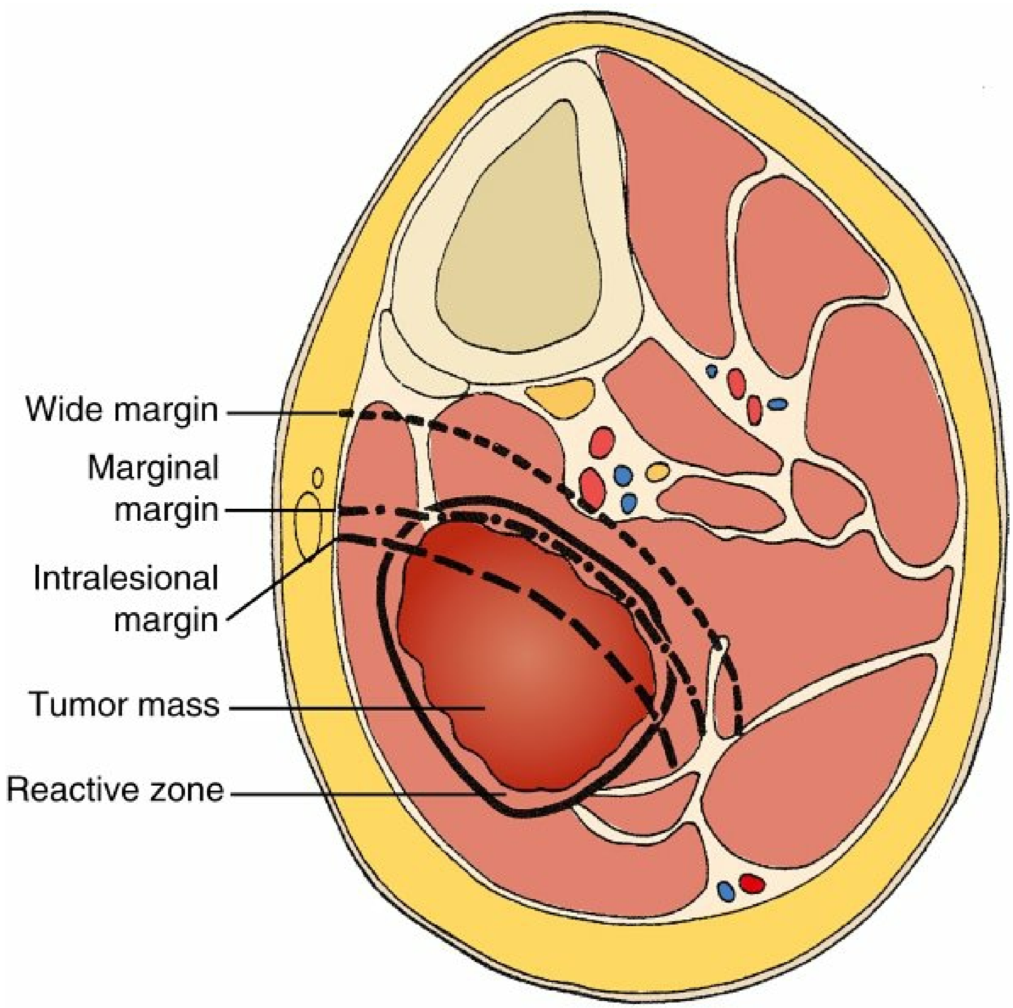


FIG. 9.5 Types of surgical margins. An intralesional line of resection enters the substance of the tumor. A marginal line of resection travels through the reactive zone of the tumor. Wide-margin surgical resection removes the tumor along with a cuff of normal tissue.
From Sim FH, et al: Soft tissue tumors: diagnosis, evaluation and management, *Am Acad Orthop Surg* 2:209, 1994. ©1994 American Academy of Orthopaedic Surgeons. Reprinted with permission.

Table 9.14

Chemotherapy Treatment for Bone Sarcomas

Chemotherpy Agent	Toxicity	Disease
Doxorubicin (Adriamycin)	Cardiotoxic	OGS EWS
Cisplatin	Audiotoxic Nephrotoxic Neurotoxic (peripheral)	OGS
Methotrexate	Oral cavity toxicity	OGS
Ifosfamide	Nephrotoxic Neurotoxic (central encephalopathy)	EWS
Vincristine	Neurotoxic (peripheral)	EWS
Cyclophosphamide (Cytoxan)	Secondary leukemia/ lymphoma Cystitis Bladder cancer	EWS
Etoposide	Secondary leukemia	EWS

EWS, Ewing sarcoma; *OGS,* osteogenic sarcoma.

- The common mechanism of action of chemotherapy drugs is the induction of programmed cell death (apoptosis).
- Most protocols entail preoperative regimens (neoadjuvant chemotherapy) followed by surgical resection and then postoperative chemotherapy.
- Patients with localized osteosarcoma or Ewing sarcoma have up to a 60%–70% chance for long-term disease-free survival with the combination of multiagent chemotherapy and surgery.
- The role of chemotherapy in soft tissue sarcoma remains more controversial. Chemotherapy is used for rhabdomyosarcoma and synovial sarcoma.

□ Radiation therapy (Table 9.15)

Table 9.15

Radiation Therapy for Soft Tissue Sarcomas

	Preoperative Radiotherapy	Postoperative Radiotherapy
Dose	50 Gy	66 Gy
Field size	Smaller (includes only tumor volume)	Larger (includes tumor volume and entire postoperative surgical field)
Complications	Short-term: Wound healing	Long-term: Soft tissue fibrosis Bone necrosis and fracture

- External beam irradiation produces free radicals and direct genetic damage and is used in the following scenarios:
    - For local control of selected Ewing sarcoma, lymphoma, myeloma, and metastatic bone disease
    - As an adjunct in treatment of soft tissue sarcomas, in which it is used in combination with surgery.
- Radiation may be delivered preoperatively (5000 cGy/50 Gy), followed by resection of the lesion with increased risk of wound healing.
- Postoperative external beam irradiation (6600 cGy/66 Gy) yields equal local control rates, with a lower postoperative wound complication rate but a higher incidence of postoperative fibrosis.
- There are several complications of radiation therapy.
    - Postradiation sarcoma: A sarcoma sometimes manifests within the field of irradiation for a previous malignancy (e.g., Ewing sarcoma, breast cancer, lymphoma). The histologic appearance is the same as that of a high-grade sarcoma. Postradiation sarcomas are more common in patients who undergo chemotherapy with alkylating agents combined with irradiation.
    - Radiation necrosis of bone: Late stress fractures occur in bones in which high-dose irradiation has been applied. It is more common in older women who have undergone periosteal bone stripping.
    - Radiation neuritis, arteritis, and lymphedema: Painful scarring of the nerves and/or diminished blood flow to the extremity can occur in areas where the blood vessels and nerves have been irradiated.

▪ **For the remaining sections of this chapter, it can be beneficial to recognize the more common tumors (** Table 9.16).

Section 2 Soft Tissue Tumors

Introduction

- **Soft tissue tumors are common. They may appear as painless small lumps or large masses.**
- **Soft tissue tumors can be broadly classified as benign or malignant (sarcoma) or characterized by reactive tumorlike conditions.**
- **Lesions are further classified according to composition; for example, whether they tend to produce collagen (fibrous lesion), fat, or vascular tissue.**

Malignant Soft Tissue Tumors (Soft Tissue Sarcomas)

- **Presentation**
  - Masses are deceptively painless and commonly are inappropriately assumed to be lipomas.
  - A mass that is more than 5 cm, growing, and deep to the superficial fascia should be presumed to be a soft tissue sarcoma (STS) until proven otherwise, and it should be assessed with three-dimensional imaging first (ideally MRI).
  - Patients often experience enlarging painless or painful soft tissue masses.
  - In some instances, the masses are small and may be present for a long time before they are recognized as tumors

Table 9.16

Most Common Musculoskeletal Tumors

Tumor Type	Name
Soft tissue tumor	
Children	Hemangioma
Adults	Lipoma
Malignant soft tissue tumor	
Children	Rhabdomyosarcoma
Adults	Malignant fibrous histiocytoma
Primary benign bone tumor	Osteochondroma
Primary malignant bone tumor	Osteosarcoma
Secondary benign lesion	Aneurysmal bone cyst
Secondary malignancies	Undifferentiated pleomorphic sarcoma Osteosarcoma Fibrosarcoma
Phalangeal tumor	Enchondroma
Soft tissue sarcoma of the hand and wrist	Epithelioid sarcoma
Soft tissue sarcoma of the foot and ankle	Synovial sarcoma

Courtesy Luke S. Choi, MD, Resident, Department of Orthopaedic Surgery, University of Virginia.

- **Imaging**
  - **MRI is the best imaging modality for defining the anatomy of and helping characterize the lesion.**
  - MRI provides information on tumor size, grade, depth, and anatomic location and aids in surgical planning.
    - On T1-weighted images, STSs have a high signal intensity (isointense with muscle), and on T2-weighted images, they have a low signal intensity.
    - With the administration of intravenous gadolinium contrast agent, an STS typically demonstrates a peripheral enhancing

zone and a nonenhancing, necrotic center.

- **CT of the chest is performed to evaluate for metastasis.**

- **Treatment**
  - Radiation therapy is an important adjunct to surgery in the treatment of soft tissue sarcomas.
  - External beam irradiation can be delivered preoperatively or postoperatively with the same oncologic outcome.
  - Intensity-modulated radiation therapy (IMRT) is a common type of external beam radiation therapy used for soft tissue sarcomas.
- **Other features**
  - In the United States, approximately 12,000 new cases of soft tissue sarcoma are diagnosed each year.

Table 9.17

Soft Tissue Sarcomas With Lymph Node Metastases—ESARC

Tumor	Characteristic
Epithelioid sarcoma	Occurs in young adults Most common STS of the hand
Synovial sarcoma	Translocation [t(X;18)] leading to *SYT-SSX* fusion products
Angiosarcoma	Associated with Stewart-Treves syndrome Cutaneous spread
Rhabdomyosarcoma	Most common pediatric STS
Clear cell sarcoma	Occurs in young adults Common tumor of lower extremity/foot

  - Poor prognostic factors include the presence of metastases, high histologic grade, and size greater than 5 cm. **Unplanned removal of a soft tissue sarcoma is the most common error in treatment of STSs.**
  - **Residual tumor may exist at the site of the operative wound, and in all patients with an unplanned removal, repeat excision should be performed**.
  - Delay in diagnosis may also occur if the clinician does not recognize that the lesion is malignant.
  - Metastasis: Most soft tissue sarcomas metastasize to the lung.
    - **Lymph node metastasis occurs with 5% of soft tissue sarcomas.**
    - **Epithelioid sarcoma, synovial sarcoma, angiosarcoma, rhabdomyosarcoma, and clear cell sarcoma (mnemonic: ESARC) are the tumors that most commonly metastasize to the lymph nodes (Table 9.17).**

Soft Tissue Sarcoma Subtypes

- **There are 50 different subtypes of soft tissue sarcoma.**
- **Soft tissue sarcomas all have the same presentation, imaging, treatment, and differential diagnosis; their histologic findings and, in some cases, molecular signature are what distinguishes one from another.**
- **Undifferentiated pleomorphic sarcoma (UPS; previously** *malignant fibrous histiocytoma*).
    - Histology: The spindle and histiocytic cells are arranged in a storiform (cartwheel) pattern. Short fascicles of cells and fibrous tissue appear to radiate about a common center around slitlike vessels. Chronic inflammatory cells may also be present.
- **Fibrosarcoma**
    - Histology: There is a fasciculated growth pattern, with fusiform or spindle-shaped cells, scanty cytoplasm, and indistinct borders, and the cells are separated by interwoven collagen fibers. There is a herringbone pattern, which consists of intersecting fascicles in which the nuclei in one fascicle are aligned transversely but in an adjacent fascicle are aligned longitudinally.
- **MPNST**
    - Histology: Spindle cells arranged in sweeping fascicles, with areas of nodular and whorled appearance. Immunohistochemistry shows S-100 positivity.
    - Other features: Tumor may arise de novo or in the setting of neurofibromatosis.
- **Leiomyosarcoma**
    - Histology: Fascicular growth pattern with spindle cells that intersect at right angles; IHC: positivity for SMA and desmin.
- **Angiosarcoma**
    - Histology: Cells resemble endothelium of blood vessels.
    - Other features
        - Highly malignant
        - Lymph node and cutaneous metastases are common (ESARC).
        - Infiltrative with poor margins; amputation may be necessary to achieve local control.
- **Liposarcoma**
    - Presentation: Liposarcomas rarely occur in the subcutaneous tissues.
    - Histology: Heterogeneous group of tumors, having in common the presence of lipoblasts (signet ring–shaped cells)
    - Other features
        - They are classified into the following types:
            - Well-differentiated liposarcoma (low grade) (Fig.

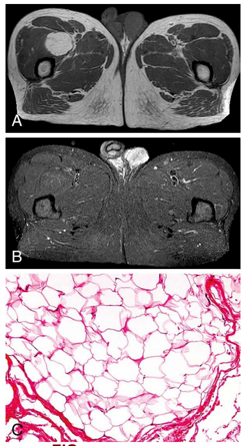
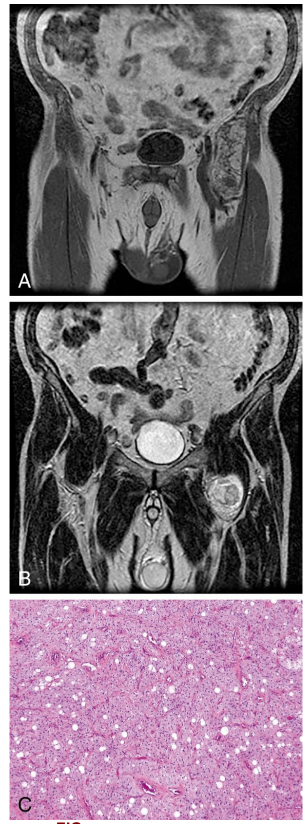
9.6 in Table 9.18)
                - Lipomalike
                - Sclerosing
                - Inflammatory
            - Myxoid liposarcoma (intermediate grade)
            - Dedifferentiated (high grade) (Fig. 9.7 in Table 9.18)
            - Round cell liposarcoma (high grade)
            - Pleomorphic liposarcoma (high grade)
        - **Liposarcomas metastasize according to the grade of the lesion.**
            - Well-differentiated liposarcomas have a very low rate of metastasis (<10%).
            - The metastasis rate of intermediate-grade liposarcomas is 10%–30%.
            - The metastasis rate of high-grade liposarcomas is more than 50%.
- **Rhabdomyosarcoma**
    - Presentation
        - Rapidly growing soft tissue mass in a patient less than 30 years old
        - The most common sarcoma in young patients
    - Histology
        - Racquet-shaped cells and cross-striations within the tumor cells (rhabdomyoblasts); IHC: positivity for myogenin and *MyoD1*
    - Treatment: Rhabdomyosarcomas are sensitive to multiagent chemotherapy and wide-margin surgical resection after chemotherapy. External beam irradiation may also also used.
- **Synovial sarcoma**
    - Presentation
        - May be present for years or may manifest as a rapidly enlarging mass in patients less than 30 years of age
        - **Synovial sarcoma is the most common sarcoma in the foot.**
    - **Imaging**
        - **Radiographs or CT may show mineralization within the lesion in up to 25% of cases (spotty mineralization may even resemble the peripheral mineralization seen in heterotopic ossification).**
    - Histology
        - The tumor is often biphasic, with both epithelial and spindle cell components. It may be monophasic with spindle cells only.

- The epithelial component may show epithelial cells that form glands or nests, or they may line cystlike spaces.
- IHC: **Positivity for keratin and epithelial membrane antigen (EMA)**

Table 9.18

Fatty Tumors

	Lipoma	Liposarcoma	De-Differen
History	Slowly enlarging mass May be incidentally found	Slowly enlarging mass May be incidentally found	Mass tha to gr Enlargin Pain
Imaging	Consistent with fat on all imaging	Consistent with fat on all imaging May have areas of heterogeneity	Some areas other are tissue sa
Pathology	Fat	Fat Immature lipoblasts *MDM2*-positive	Fat juxtapos
Treatment	Marginal excision	Marginal excision ± irradiation	Wide excisi
Image			
Description			

	 FIG. 9.6 Lipoma. (A) T1-weighted MR image of a lipoma in the vastus intermedius. (B) On T2-weighted fat suppression images the lesion is completely suppressed, appearing identical to fat on both images. (C) Histologic specimen shows acellular, mature fat consistent with a benign lipoma.	 FIG. 9.7 Liposarcoma. (A) T1-weighted MR image shows a left rectus lesion that is consistent with fat in some areas, with signal suppression. (B) On fat suppression image, the low-grade fat areas are suppressed but the liposarcoma regions are not. (C) Histologic specimen shows immature lipoblasts intermixed with spindle cells.	

□ Genetics

- **Translocation between chromosome 18 and the X chromosome—t(X;18)—is always present in tumor cells, and staining of the tumor cells yields positive results for keratin and EMA.**
- **The balanced translocation results in gene fusion products. The two most common are *SYT-SSX1* and *SYT-SSX2.***

□ Treatment

- Wide surgical resection with adjuvant radiotherapy (XRT) is the most common method of treatment.

            - **Synovial sarcoma is an unusual soft tissue sarcoma in which chemotherapy has shown a clinical benefit.**
        - Other features
            - **Lymph nodes may be involved (ESARC).**
            - **The name is derived from the histologic appearance, not from origination from the synovium. This is not an intraarticular tumor.**
    - **Epithelioid sarcoma**
        - Presentation
            - Rare nodular tumor that commonly occurs in the upper extremities of young adults
            - **The most common sarcoma of the hand**
        - Histology: Cells range in shape from ovoid to polygonal, with deeply eosinophilic cytoplasm (cellular pleomorphism is minimal).
        - Treatment: Wide-margin surgical resection
        - Differential diagnosis: Granuloma, rheumatoid nodule, or inclusion cyst. Often misdiagnosed as benign process.
    - **Clear cell sarcoma**
        - Presentation
            - Slow-growing mass in association with tendons or aponeuroses
            - Usually occurs about the foot and ankle but may also involve the knee, thigh, or hand
        - Histology: Characterized by compact nests or fascicles of rounded or fusiform cells with clear cytoplasm; multinucleated giant cells are common.
        - Treatment: Wide-margin surgical resection with adjuvant radiation
        - Other features: Metastases to lymph nodes (ESARC)
    - **Dermatofibrosarcoma protuberans**
        - Presentation
            - Rare, nodular, cutaneous tumor that occurs in early to middle adulthood
            - A low-grade tumor with a tendency to recur locally that rarely metastasizes
        - Histology: The central portion of the nodules shows uniform fibroblasts arranged in a storiform pattern around an inconspicuous vasculature.
        - Treatment: Wide-margin surgical resection, which may require skin grafting

Benign Soft Tissue Tumors

- **Benign soft tissue tumors may occur in all age groups.**
- **Their biologic behavior varies from asymptomatic and self-limiting to growing and symptomatic.**
- **On occasion, benign lesions grow rapidly and invade adjacent tissues.**

Tumors of Fibrous Tissue

- **Fibromatosis**
  - Palmar (Dupuytren) and plantar (Ledderhose) fibromatoses: These disorders consist of firm nodules of fibroblasts and collagen that develop in the palmar and plantar fascia. The nodules and fascia become hypertrophic, producing contractures.
  - Extraabdominal desmoid tumor; most locally invasive of all benign soft tissue tumors.
    - Presentation
      - Commonly occurs in adolescents and young adults
      - Patients with Gardner syndrome (familial adenomatous polyposis) have colonic polyps and a 10,000-fold increased risk for development of desmoid tumors.
      - On palpation, the tumor has a distinctive "rock-hard" character.
      - Multiple lesions may be present in the same extremity (10%–25%).
    - Histology:
      - Well-differentiated fibroblasts and abundant collagen. The lesion infiltrates adjacent tissues.
      - IHC: Positivity for estrogen receptor β and β-catenin
    - Treatment
      - Medical management including NSAIDS, tamoxifen, and cytotoxic chemotherapy
      - Behavior of the tumor is unpredictable: Recurrent nodules may remain dormant for years or may grow rapidly for some time and then stop growing, especially in pregnancy because of the high level of circulating estrogen.
  - Nodular fasciitis
    - Presentation: A common reactive lesion that manifests as a painful, *rapidly enlarging* mass in the upper extremity of a young person less than 30 years old

- Histology: Short, irregular bundles and fascicles; a dense reticulum network; and only small amounts of mature collagen characterize the lesion histologically. Mitotic figures are common, but atypical mitoses are not a feature.
- Treatment: Wide marginal excision

Tumors of Fatty Tissue

- **Lipomas: Common benign tumors of mature fat**
  - Presentation
    - Painless lesion that occurs in a subcutaneous, intramuscular, or intermuscular location
    - History of a mass is long, but sometimes the mass is only recently discovered.
  - Imaging
    - Radiographs may show a radiolucent lesion in the soft tissues if the lipoma is deep within the muscle or between the muscle and bone.
    - **CT or MRI shows a well-demarcated lesion with the same signal characteristics as those of mature fat on all sequences. On fat suppression sequences, the lipoma has a uniformly low signal (see Fig. 9.5).**
  - Treatment: If the mass is growing or causing symptoms, excision with a marginal resection is performed.
  - Differential diagnosis: Liposarcoma (see Table 9.18; Fig. 9.8)

Tumors of Neural Tissue

- **Schwannoma (a.k.a. neurilemoma): Benign nerve sheath tumor**
  - Presentation: Mass that may be painful and associated with the presence of Tinel sign.
  - **Imaging: MRI may demonstrate an eccentric mass arising from a peripheral nerve or may show only an indeterminate soft tissue mass (low signal on T1-weighted images and high signal on T2-weighted images).**
  - Histology
    - The lesion is composed of Antoni A and B areas.
      - Antoni A area
        - Compact spindle cells usually having twisted nuclei, indistinct cytoplasm, and, occasionally, clear intranuclear vacuoles

- There may be nuclear palisading, whorling of cells, and Verocay bodies.
- Antoni B area
  - Less orderly and cellular
  - Arranged haphazardly in the loosely textured matrix (with microcystic changes, inflammatory cells, and delicate collagen fibers)
- □ Treatment: Intraneural excision for painful or symptomatic masses

- **Neurofibroma: Solitary or multiple (neurofibromatosis)**
  - □ Presentation: Superficial/skin lesions, slow-growing and painless
  - □ Histology: Interlacing spindle cells with wavy, dark-staining nuclei with no pleomorphism
  - □ Treatment: Excision with a marginal margin
- **Neurofibromatosis (von Recklinghausen disease)**
  - □ Autosomal dominant trait (both peripheral and central forms)
  - □ Café au lait spots (smooth) and Lisch nodules (melanocytic hamartomas in the iris)
  - □ Variable skeletal abnormalities (metaphyseal fibrous defect [nonossifying fibroma], scoliosis, and bowing of long bones)
  - □ Pain and an enlarging soft tissue mass may herald conversion to a sarcoma (5%–30% of affected patients).

Vascular Tumors

- **Vascular malformation, also known as hemangioma or arteriovenous malformation (AVM)**
  - □ Presentation
    - Cutaneous, subcutaneous, or intramuscular lesion
    - Large tumors have signs of vascular engorgement (aching, heaviness, swelling).
    - It is helpful to examine the patient in both the supine and standing positions (the lesion often fills with blood after several minutes of gravity dependence).
  - □ Imaging
    - Radiographs may reveal small phleboliths.
    - MRI demonstrates a heterogeneous lesion with numerous small blood vessels and fatty infiltration.
  - □ Treatment
    - NSAIDs, vascular compression stockings, and activity modification if local measures adequately control discomfort
    - Sclerotherapy using an intralesional sclerosing agent such as

alcohol
- Surgical resection may be performed for lesions refractory to other therapy; local recurrence rate is high.

Synovial Proliferative Disorders

- **Pigmented villonodular synovitis (PVNS)**
  - Reactive condition (not a true neoplasm) characterized by an exuberant proliferation of synovial villi and nodules
  - May occur locally (within a joint) or diffusely
  - Presentation
    - The knee is affected most often, followed in frequency by the hip and shoulder.
    - Manifests as pain and swelling in the affected joint
    - Recurrent, atraumatic hemarthrosis is the hallmark (arthrocentesis demonstrates a bloody effusion).
  - Imaging: Cystic erosions may occur on both sides of the joint.
  - Histology: Highly vascular villi are lined with plump, hyperplastic synovial cells; hemosiderin-stained, multinucleated giant cells; and chronic inflammatory cells.
  - **Treatment**
    - **Aimed at complete synovectomy by arthroscopy for resection of all the intraarticular disease, followed by open posterior synovectomy to remove the posterior extraarticular extension**
    - **The local form of PVNS may be treated with partial synovectomy**.
  - Other features
    - Local recurrence is common (30%–50% of cases) despite complete synovectomy.
    - Colony-stimulating factor-1 (CSF-1) pathway has been targeted for therapy.
- **Synovial chondromatosis**
  - Synovial proliferative disorder that occurs within joints or bursae, ranging in appearance from metaplasia of the synovial tissue to firm nodules of cartilage
  - Presentation
    - Patients less than 30 years old present with pain, stiffness, and swelling.
    - The knee is the most common location.
  - Imaging: Demonstrates intraarticular fine, stippled calcification known as *rice bodies*

- Treatment: Arthroscopic resection of the rice bodies and synovectomy

Posttraumatic Conditions

- **Hematoma**
  - Presentation
    - Hematoma may occur after trauma to an extremity.
    - Organizes and resolves with time
  - Imaging
    - MRI is often not able to distinguish a simple hematoma from a sarcoma with spontaneous hemorrhage.
    - With use of gadolinium contrast agent, a hematoma has a thin rim of peripheral enhancement, whereas an STS has a nodular pattern of rim enhancement.
  - Treatment: Observation to ensure resolution
  - Differential diagnosis
    - Hemorrhage into the body of a sarcoma may occur spontaneously or after minor trauma, so that the tumor masquerades as a benign process.
    - A lack of fascial plane tracking and subcutaneous ecchymosis suggests that the bleeding is contained by a pseudocapsule; this is an important physical examination finding.
- **Myositis ossificans (heterotopic ossification)**
  - Presentation
    - Develops after single or repetitive episode(s) of trauma (occasionally, the patient cannot recall the traumatic episode)
    - Most common locations are over the diaphyseal segments of long bones (in the middle aspect of the muscle bellies).
  - Imaging
    - Radiographs show peripheral mineralization with a central lucent area as maturation progresses.
    - Lesion is not attached to the underlying bone, but in some cases, it may become fixed to the periosteal surface.
  - Histology: Shows a zonal pattern, with mature, trabecular bone at the periphery and immature tissue in the center
  - Treatment: Observation

Clinical Pearls for Soft Tissue Sarcoma (Table 9.19)

Section 3 Bone Tumors

Presentation

- **The patient with a bone tumor may present with pain, a mass, or a fracture, or the mass lesion be incidentally found.**
- **Pain may occur from a mechanical disruption of bone, a pathologic fracture, or compression by an expanding tumor.**
- **Pain may occur with weight bearing and may progress to constant pain at rest that is not relieved by pain medications.**
- **High-grade tumors typically manifest with a short interval of pain (1–3 months).**
- **With low-grade tumors there may be a longer interval of mild to moderate pain (> 3 months).**
- **Osteoid osteoma has a characteristic night pain or diurnal pain pattern relieved with aspirin or NSAIDS**.
- **Bone sarcomas**
  - Malignant neoplasms of connective tissue (mesenchymal) origin
  - Exhibit rapid growth in a centripetal manner and invade adjacent normal tissues
  - Each year in the United States, about 2800 new bone sarcomas are diagnosed.
  - High-grade, malignant bone tumors tend to destroy the overlying cortex and spread into the soft tissues.
  - Low-grade tumors are generally contained within the cortex or the surrounding periosteal rim.
  - **Bone sarcomas metastasize primarily via the hematogenous route; the lungs are the most common site**.
  - **Osteosarcoma and Ewing sarcoma may also metastasize to other bone sites either at initial manifestation or later in disease**.
- **Benign bone tumors**

Table 9.19

Clinical Pearls for Soft Tissue Sarcoma

Prognostic factors	Size: ≥5 cm Grade: high Depth: deep to superficial fascia
Imaging (MRI)	Decreased signal on T1-weighted images Increased signal on T2-weighted images
Genetics	Synovial sarcoma: t(X;18); *SYT-SSX* fusion products Myxoid liposarcoma: t(12:16)(q13:p11) Rhabdomyosarcoma (alveolar): t(2:13)
Unique metastatic patterns—to *lymph nodes* + lungs (ESARC)	Epithelioid Synovial sarcoma Angiosarcoma Rhabdomyosarcoma Clear cell sarcoma
Treatment	Lesions >5 cm: LSS + XRT Lesions < 5cm and in subcutaneous location: LSS alone Rhabdomyosarcoma: chemotherapy ± LSS
Syndromes	NF-1: MPNST Stuart-Treves: angiosarcoma
Characteristic locations	Hand: epithelioid sarcoma Foot: clear cell sarcoma, synovial sarcoma

- These may be small with a limited growth potential or large and destructive.

- **Tumor simulators and reactive conditions**
  - These processes occur in bone but are not true neoplasms (e.g., osteomyelitis, aneurysmal bone cyst, bone island).

Bone-Producing Lesions

- **Osteoid osteoma**

- □ Self-limiting benign bone lesion
- □ Presentation
  - Young patient (<30 years of age)
  - **Pain at night, or diurnal pattern that increases with time**
  - **Pain is classically relieved by salicylates and other NSAIDs.**
  - **Pain may be referred to an adjacent joint, and when the lesion is intracapsular, it may simulate arthritis.**
  - Common locations include the diaphyseal bone, proximal femur, tibia, and spine.
  - May produce painful nonstructural scoliosis, growth disturbances, and flexion contractures
    - Scoliosis caused by an osteoid osteoma results in a curve with the lesion on the concave side. This is thought to result from marked paravertebral muscle spasm.
- □ Imaging
  - Radiographs usually show intensely reactive bone and a radiolucent nidus (Fig. 9.9 in Table 9.20). Because of the intense reactive sclerosis, it may be possible to detect the nidus only with CT or MRI.
  - **The nidus is less than 1 cm in diameter, although the area of reactive bone sclerosis may be greater**.
  - **CT is superior to MRI in detecting and characterizing osteoid osteomas because CT provides better contrast between the lucent nidus and the reactive bone**.
- □ Histology
  - There is a distinct demarcation between the nidus and the reactive bone—**nidus shows mineralized woven bone with nonmalignant rimming osteoblasts and appears similar to osteoblastoma.**
  - Trabecular organization is haphazard.
  - The greatest degree of mineralization is in the center of the lesion.
- □ Treatment
  - Patients can be treated with three different methods: NSAIDs, CT-guided radiofrequency ablation, and surgical removal.
  - In about 50% of patients treated with NSAIDs, the lesions burn out over time (several years), with no further medical or surgical treatment necessary.
  - **CT-guided radiofrequency ablation (RFA) is the standard of care**.
    - A radiofrequency probe is placed into the lesion,

and the nidus is heated to 80°C.
- A lesion close to a critical structure (i.e., neurovascular bundle or the spinal cord) is a contraindication to RFA; in this situation, surgery is preferred.

- Differential diagnosis: Osteoblastoma, stress fracture

- **Osteoblastoma**
  - Bone-producing tumor that is greater than 2 cm; its growth is not self-limiting.
  - Presentation
    - Pain
    - Common locations include the spine, proximal humerus, proximal femur, and acetabulum.
  - Imaging
    - Bone destruction with or without the characteristic reactive bone formation in osteoid osteoma.
    - Area of bone destruction occasionally has a motheaten or permeative appearance simulating a malignancy.
    - Size is greater than 2 cm (Fig. 9.10A in Table 9.20).
  - Histology: Mineralized woven bone with nonmalignant rimming osteoblasts that appears similar to osteoblastoma (Fig. 9.10B).
  - Treatment: Intralesional resection with curettage
  - Differential diagnosis: Osteoid osteoma and osteoblastoma are easily confused; a comparison is shown in Table 9.20.
- **Osteosarcoma**
  - General
    - Spindle cell neoplasm that produces osteoid
    - There are many types of osteosarcoma.
      - **Lesions include high-grade intramedullary osteosarcoma (ordinary or classic osteosarcoma), parosteal osteosarcoma, periosteal osteosarcoma, telangiectatic osteosarcoma, osteosarcoma occurring with Paget disease, and osteosarcoma after irradiation**.
    - Presentation: pain or a pathologic fracture
    - Imaging: Variable according to type
    - Treatment
      - Multiagent chemotherapy has dramatically improved long-term survival and the potential for limb salvage.
      - Agents typically used are:
        - Doxorubicin (cardiac toxicity)
        - Cisplatin (neurotoxicity)

        - Methotrexate (for cases of myelosuppression, leucovorin also administered)
    - Chemotherapy both kills the micrometastases that are present in 80%–90% of the patients at presentation and sterilizes the reactive zone around the tumor.
    - Preoperative chemotherapy is delivered for 8–12 weeks, followed by resection of the tumor.
- Other features
    - Rate of long-term survival is approximately 60%–70%.
    - Osteosarcoma metastasizes most commonly to the lung and next most commonly to bone.
    - Prognostic factors that adversely affect survival include (1) expression of P-glycoprotein, high serum levels of alkaline phosphatase and LDH, vascular invasion, and no alteration of DNA ploidy after chemotherapy, (2) the absence of anti–heat-shock protein 90 antibodies after chemotherapy, and (3) a poor response to chemotherapy as shown by the presence of histologic tumor necrosis (<90%).
    - Osteosarcoma is associated with an abnormality in the tumor suppressor genes *Rb* (retinoblastoma) and *p53* (Li-Fraumeni syndrome).

□ **High-grade intramedullary osteosarcoma**

- Also called “classic” osteosarcoma, this neoplasm is the most common type of osteosarcoma and usually occurs about the knee in children and young adults, but its incidence has a second peak in late adulthood.
- Presentation: Pain, in the proximal humerus, proximal femur, and pelvis
- Imaging
    - Radiographs demonstrate a lesion in which there is bone destruction and bone formation (Fig. 9.11 in Table 9.21). On occasion, the lesion is purely sclerotic or lytic.
    - MRI and CT are useful for defining the anatomy of the lesion with regard to intramedullary extension, involvement of neurovascular structures, and muscle invasion.

- Histology: Diagnosis depends on two histologic criteria: (1) the tumor cells produce osteoid and (2) the stromal cells are malignant.
- Treatment: Neoadjuvant chemotherapy (i.e., before surgery), followed by wide-margin surgical resection and adjuvant chemotherapy (i.e., after surgery)
- Other features: More than 90% of intramedullary osteosarcomas are high-grade and penetrate the cortex early to form soft tissue masses (stage IIB lesions).

□ Parosteal osteosarcoma (low-grade surface)

- Presentation
  - Painless mass that occurs on the surface of the metaphysis of long bones
  - Most common sites are the posterior aspects of the distal femur, proximal tibia, and proximal humerus.
- Imaging: Characteristic radiographic appearance: a heavily ossified, lobulated mass "stuck on bone," with *no* intramedullary extension (see Fig. 9.11)
- Histology: Regularly arranged osseous trabeculae; between the nearly normal trabeculae are slightly atypical spindle cells.

Table 9.20

Osteoid Osteoma Versus Osteoblastoma

	Osteoid Osteoma	Osteoblastoma
Presentation	Diurnal pain pattern/night pain Pain relieved by aspirin/NSAIDs	Random pain pattern Pain not relieved by aspirin/NS
Imaging	Central radiolucent nidus <1 cm Large secondary bone reaction Characteristic "target" appearance	Central radiolucent nidus >2 c Minimal secondary bone react gives lesion a more aggress appearance
Location	Diaphyseal (typical)	Diaphyseal or metaphyseal Posterior spine elements
Growth pattern	Self-limited	Unlimited
Pathology	Same as osteoblastoma *No* associated aneurysmal bone cyst	Same as osteoid osteoma 40% can have associated aneur bone cyst
Treatment	RFA Surgery if tumor is close to nerves or blood vessels (e.g., spine)	Intralesional excision

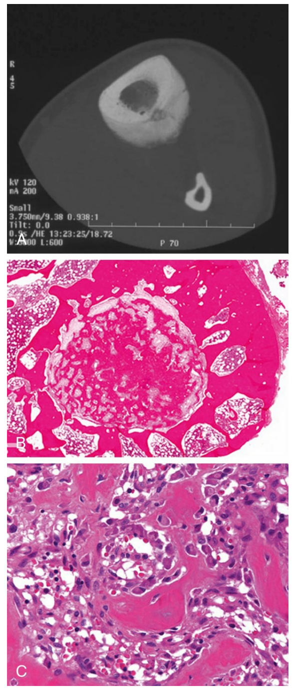
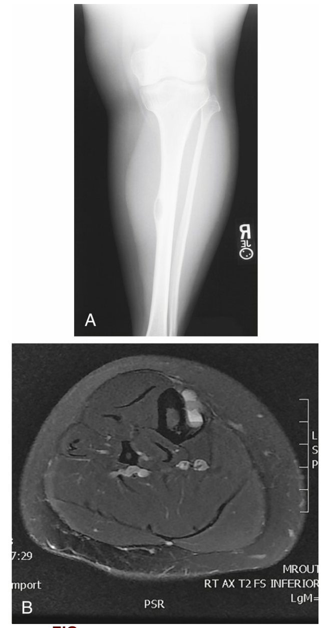
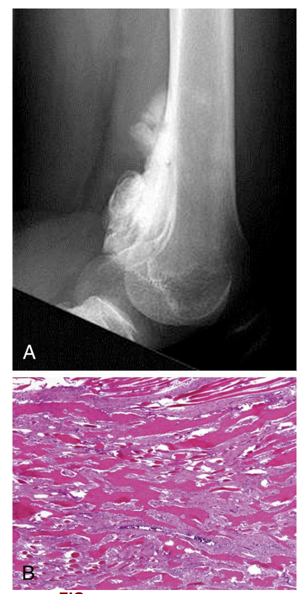
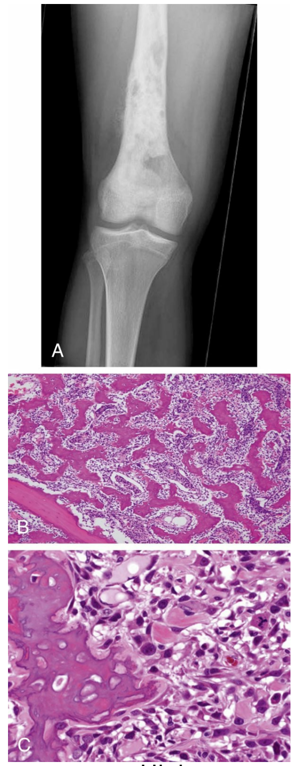
Image		
Description	 FIG. 9.9 Osteoid osteoma of the tibia. (A) Radiograph shows a well-circumscribed lytic lesion with immature surrounding bone and a central nidus. (B) Low-power photomicrograph shows a well-demarcated small round tumor surrounded by reactive bone. (C) Higher-power photomicrograph shows haphazardly interconnecting trabeculae of woven bone lined by plump osteoblasts.	 FIG. 9.10 Osteoblastoma. (A) Plain radiograph showing a diaphyseal, cortically based lesion with a nidus >2 cm. (B) This is confirmed on T2-weighted MR image, on which lesion is greater than 2 cm. Histologic appearance is the same as that of osteoid osteoma.

Table 9.21

Comparison of Osteosarcomas

	Conventional (Intramedullary)	Periosteal
Patient age (yr)	<30 and >60	<30
Presentation	Pain	Pain

Imaging	Mixed lytic/destructive aggressive intramedullary bone producing lesion Common location metaphyseal	Sunburst saucerized surface lesion Diaphyseal Characteristic location femur c tibia
Histology	Poorly arranged osseous trabeculae with malignant rimming osteoblasts Atypical spindle cells	Osseous trabeculae Chondroblastic elements
Five-year survival	65%	80%
Treatment	Chemotherapy LSS	Chemotherapy LSS
Image		
Description		 FIG. 9.12 Periosteal osteosarcoma of the distal femur. (A) Lateral radiograph shows a surface lesion arising from the anterior cortex creating a sunburst appearance. (B) Photomicrograph (×200) showing cartilage *(lower left)* and bone formation *(upper right)*.

		 FIG. 9.11 High-grade intramedullary osteosarcoma of the distal femur. (A) Radiograph shows a poorly defined osteoblastic lesion in the metadiaphyseal distal femur. (B) Low-power photomicrograph shows lacelike mineralizing osteoid surrounding atypical osteoblasts. (C) Higher-power photomicrograph shows woven bone (to the *left* of the image) surrounded by highly malignant rimming osteoblasts.	

- **Treatment**
    - **Resection with a wide margin is curative**.
    - Low-grade lesion: Chemotherapy *not* required

□ Periosteal osteosarcoma (intermediate-grade surface)

- Rare surface form of osteosarcoma that occurs most often in the diaphysis of long bones (typically the femur or tibia)
- Presentation: Pain
- Imaging: Radiographic appearance is fairly constant: a sunburst-type lesion rests on a saucerized cortical

depression (Fig. 9.12 in Table 9.21).
- Histology: The lesion is predominantly chondroblastic, and the grade of the lesion is intermediate.
- Other features
  - **The prognosis for periosteal osteosarcoma is intermediate between those of very low-grade parosteal osteosarcoma (Fig. 9.13 in Table 9.21) and high-grade intramedullary osteosarcoma**.
  - **Preoperative chemotherapy, resection, and maintenance chemotherapy constitute the preferred treatment**.
  - **The risk of pulmonary metastasis is 10%–15%**.

□ High-grade surface osteosarcoma
- Presentation: Pain
- Imaging: A mixed lytic sclerotic aggressive surface lesion in the metaphysis or diaphysis
- Histology: Areas of malignant spindle cells with a high degree of cellular atypia and a variable amount of osteoid formation
- Treatment: Same as for conventional osteosarcoma
- Other features: Prognosis is the same as for conventional osteosarcoma

□ Telangiectatic osteosarcoma
- Presentation: Pain
- Imaging: The radiographic features of telangiectatic osteosarcoma are those of a destructive, lytic, expansile lesion. Telangiectatic osteosarcomas occur in the same locations as aneurysmal bone cysts, and the radiographic appearances of the two can be confused.
- Histology: Prominent blood-filled cysts separated by malignant hypercellular and anaplastic stroma
- Treatment: Same as for conventional osteosarcoma
- Differential diagnosis: Aneurysmal bone cyst

Nonosteogenic Osteosarcoma/Malignant Fibrous Hystiocytoma

▪ **Presentation**

□ Pain and swelling.

□ Most common locations include the distal femur, proximal tibia, proximal femur, ilium, and proximal humerus.

▪ **Imaging: This lesion is destructive, with either purely lytic bone destruction or a**

mixed pattern of bone destruction and formation (Fig. 9.14).

- **Histology: Malignant fibrous hystiocytoma (MFH) is a primary bone osteosarcoma with a mesenchymal origin and cellular pattern, but no osteoid is produced or seen on histologic examination. The histologic findings determine the diagnosis (i.e., undifferentiated pleomorphic sarcoma [UPS], fibrosarcoma).**
- **Treatment: Same as for osteogenic sarcoma: chemotherapy and surgery.**
- **Other: UPS, MFH, fibrosarcoma, leiomyosarcoma**
  - Presentation and localization are similar to those of osteosarcoma.
  - Lytic bone destruction is often in a permeative pattern (Fig. 9.15).
- Table 9.21 compares the common osteosarcoma varieties.

Chondrogenic Lesions

- **Comparison of chondrogenic lesions is shown in** Table 9.22 and Figs. 9.16 to 9.18.
- **Enchondroma**

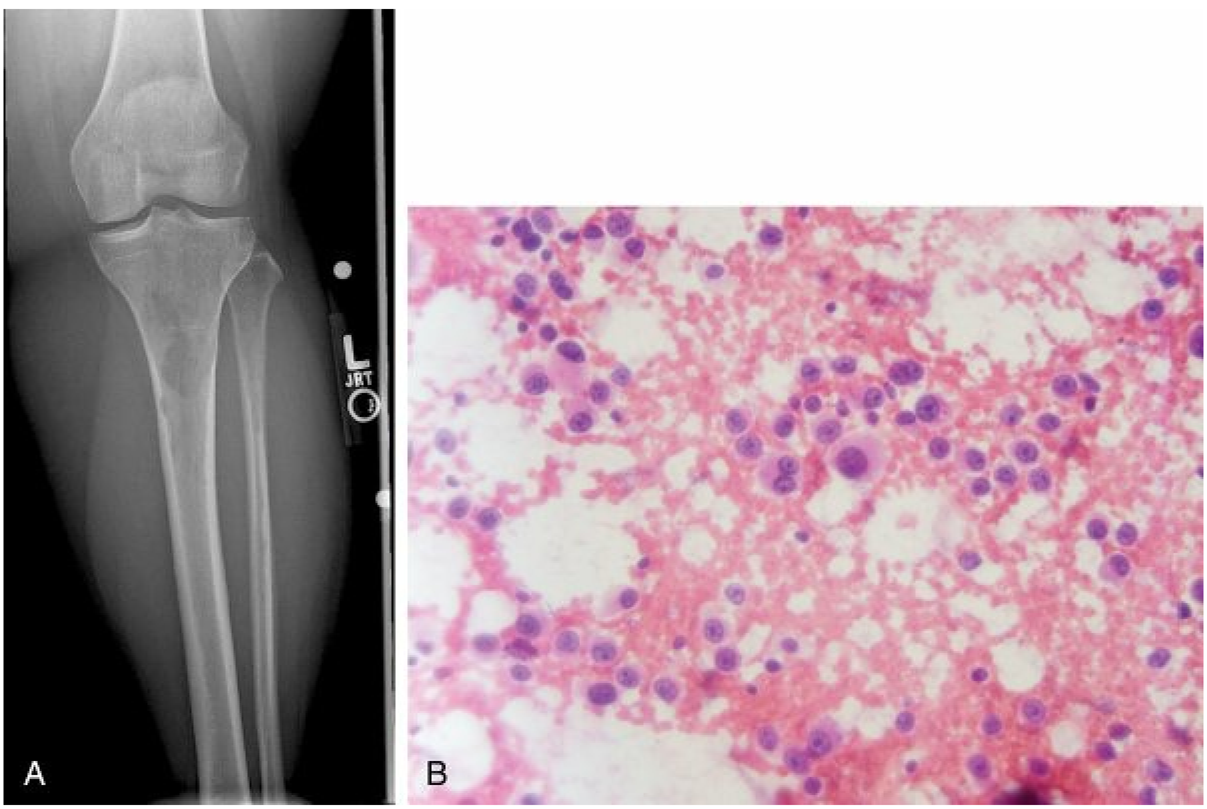


FIG. 9.14 Multiple myeloma in the tibia. (A) Radiograph shows poorly circumscribed lytic lesions in the proximal tibia and fibula. (B) Higher-power photomicrograph (×400) shows sheets of atypical plasma cells with eccentric clock face nuclei.

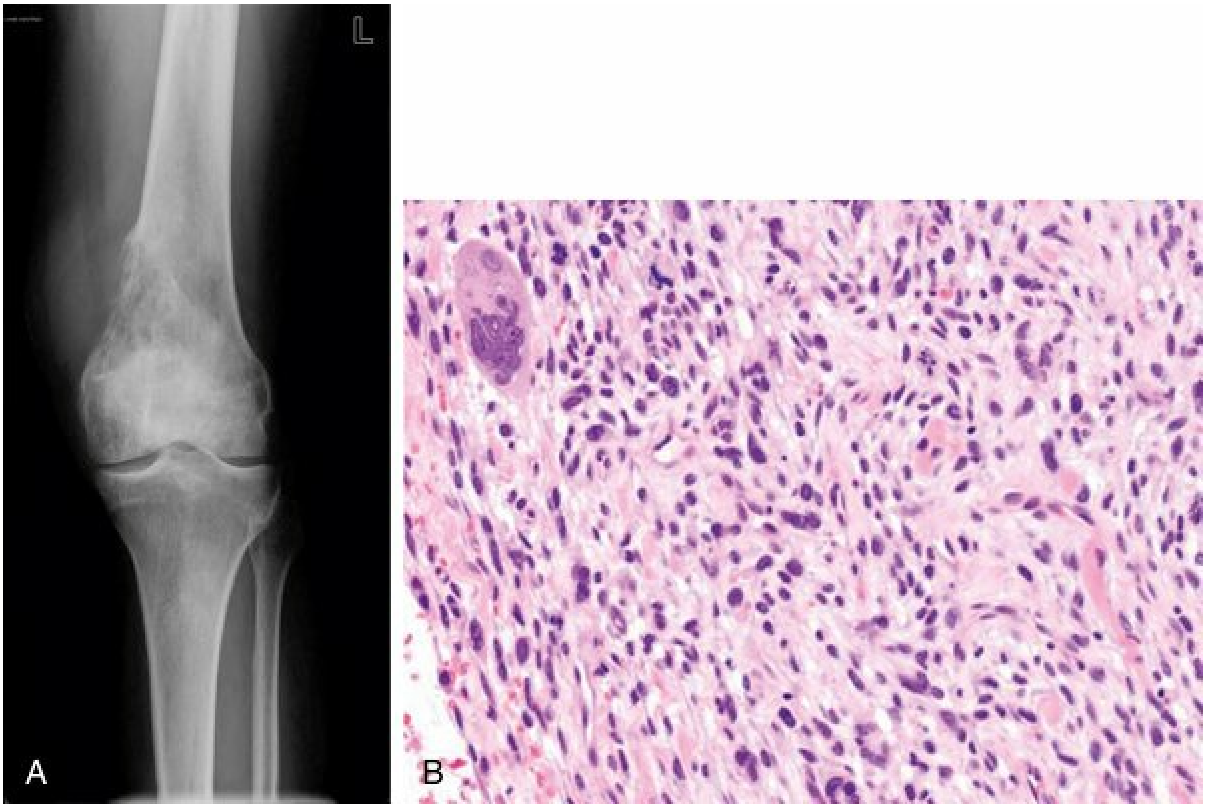


FIG. 9.15 Nonosteogenic osteosarcoma of the femur. (A) Radiograph shows a permeative lesion in the metaphysis of the distal femur. (B) Histologic specimen shows a combination of undifferentiated spindle and pleomorphic cells (×20).

- □ Benign cartilage in the medullary cavity in the metaphysis of long bones, especially the proximal femur, humerus, and distal femur.
- □ Presentation: Asymptomatic and found incidentally
- □ Imaging: Radiographically there may be a prominent stippled or mottled calcified appearance (see Fig. 9.17).
- □ Histology: Composed of binuclear cells that lie in lacunar spaces; the lesion is hypocellular, and the cells have a bland appearance (no pleomorphism, anaplasia, or hyperchromasia).
- □ Treatment
  - When lesions are not causing pain, serial radiographs are obtained to ensure that the lesions are inactive (not growing). Radiographs are obtained every 3–6 months for 1–2 years and then annually as necessary.
  - For most enchondromas, no treatment other than observation is required. When surgical treatment is necessary, enchondromas are treated with intralesional resection by curettage.
- □ **Differential diagnosis**
  - **Enchondroma can be distinguished from low-grade chondrosarcoma on serial plain radiographs**.
  - **On radiographs of low-grade chondrosarcomas, cortical bone changes (large erosions [>50%] of the cortex, cortical thickening, and destruction) or lysis of the previously**

mineralized cartilage is visible.**

- **Other features**
  - **Enchondromas are also common in the hand, where they usually occur in the diaphysis and metaphysis**.
  - **Lesions in the hand may be hypercellular and display worrisome histologic features, and pathologic fractures in the hand are common**.

- **Ollier disease/Maffucci syndrome**
  - When there are many lesions, the involved bones are dysplastic, and the lesions tend toward unilaterality, the diagnosis is multiple enchondromatosis, or Ollier disease.
  - Inheritance pattern is sporadic.
  - If soft tissue angiomas are also present, the diagnosis is Maffucci syndrome.
  - **Patients with multiple enchondromatosis are at increased risk of malignancy (in Ollier disease, 30%; in Maffucci syndrome, 100%).**
  - **Patients with Maffucci syndrome also have a markedly increased risk of visceral malignancies, such as astrocytomas and gastrointestinal malignancies.**

- **Osteochondroma**
  - Benign surface lesions probably arise secondary to aberrant cartilage (from the perichondrial ring) on the surface of bone.
  - Presentation
    - Painless mass discovered incidentally.
    - Occurs about the knee, proximal femur, and proximal humerus.
  - Imaging
    - Characteristic appearance: A surface lesion in which the cortex of the lesion and the underlying cortex are confluent with the medullary canal (see Fig. 9.18).
    - Osteochondroma may have a narrow stalk (pedunculated) or a broad base (sessile).
    - The lesion typically occurs at the site of a tendon insertion, and the affected bone is abnormally wide.
    - **Underlying cortex is covered by a thin cap of cartilage (usually only 2–3 mm thick; in a growing child, the cap thickness may exceed 1–2 cm)**.
  - Histology: Chondrocytes are arranged in linear clusters, in appearance resembling the normal physis.
  - Treatment
    - When asymptomatic, these lesions are treated with observation only.
    - Surgery is considered when a patient experiences pain

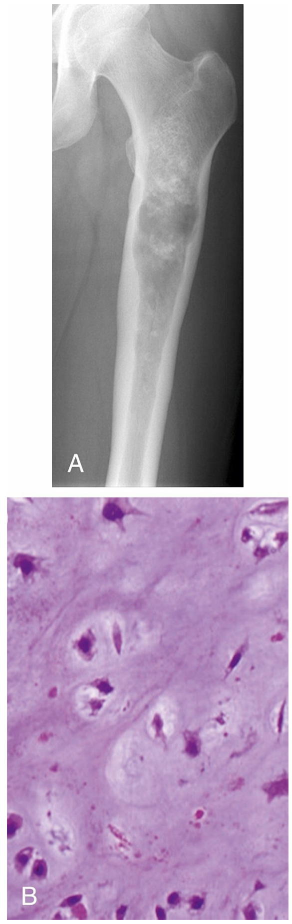
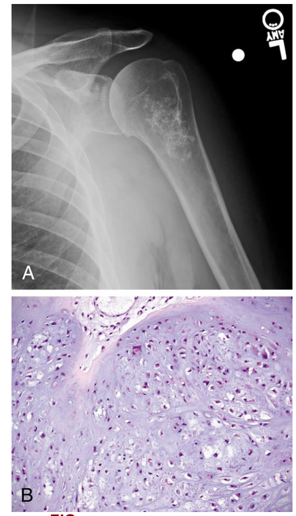
secondary to muscle irritation, mechanical trauma (contusions), or an inflamed bursa over the lesion.

- Differential diagnosis: Parosteal osteosarcoma, heterotopic ossification
- Other features
  - Malignant transformation (<1% of cases) to a "secondary chondrosarcoma"

Table 9.22

Cartilage Tumors

	Enchondroma	Osteochondroma
Patient age (yr)	Any	Any
Symptoms	Incidental	Mechanical
Imaging	No change in bone architecture No endosteal scalloping or erosion	Sessile or pedunculated lesion is confluent with the intramedu canal
Pathology	Bland cartilage with minimal cellular elements	Mature bone stalk with a benign mature cartilage cap
Treatment	Observation	Observation unless mechanical p significant
Caveats	Pathology may have high degree of cellularity in the hands and feet and can be confused with chondrosarcoma	Lesions should mature with the a cartilage cap >2 cm require observation
Syndrome association	Ollier disease Maffucci syndrome	MHE
Image		
Description		

	 FIG. 9.16 Central (intramedullary) chondrosarcoma of the proximal femur. (A) Radiograph shows an expansile lytic lesion in the proximal femur with stippled calcifications. (B) Higher-power photomicrograph shows cellular cartilage.	 FIG. 9.17 Enchondroma of the proximal humerus. (A) Radiograph shows an intramedullary lesion with stippled calcifications. (B) Photomicrograph shows bland binucleate chondrocytes in lacunae.

- Pain in the absence of mechanical factors warns of malignant change.
- Destruction of the subchondral bone, mineralization of a soft tissue mass, and an inhomogeneous appearance are radiographic changes of malignant transformation.
- A low-grade chondrosarcoma is usually present, although a dedifferentiated chondrosarcoma may occur in rare cases.
- The prognosis is excellent; these low-grade tumors rarely metastasize.

▪ **Multiple hereditary exostoses**

□ **The osteochondromas in MHE are often sessile and large. This is an autosomal dominant condition with mutations in the *EXT1* and *EXT2* gene loci. In approximately 10% of patients with multiple exostoses, a**

secondary chondrosarcoma develops. The *EXT1* mutation is associated with a greater burden of disease and higher risk of malignancy.

- **Chondroblastoma**
  - Centered in the epiphysis in young patients, usually with open physes; it may also occur in an apophysis
  - Presentation
    - Pain referable to the involved joint
    - The most common locations are the distal femur, proximal tibia, and proximal humerus.
  - Imaging
    - Shows a central region of bone destruction that is usually sharply demarcated from the normal medullary cavity by a thin rim of sclerotic bone (Fig. 9.19 in Table 9.23).
    - Mineralization may or may not occur within the lesion.
  - Histology
    - The basic proliferating cells are thought to be chondroblasts.
    - Scattered multinucleated giant cells are found throughout the lesion.
    - Zones of chondroid are present.
    - Mitotic figures may be found.
  - Treatment: Intralesional resection with curettage and reconstruction
  - Differential diagnosis: Brodie's abscess and giant cell tumor of bone (Fig. 9.20 in Table 9.23).
  - Other features: Less than 5% metastasize to the lungs.
- **Chondromyxoid fibroma**
  - Rare, benign cartilage tumor that contains variable amounts of chondroid, fibromatoid, and myxoid elements
  - Presentation
    - Focal pain
    - Pathognomonic location is the tibia; may also be found in the pelvis and distal femur.
  - Imaging: A lytic, destructive lesion that is eccentric and sharply demarcated from the adjacent normal bone
  - Histology: This lesion grows in lobules, and there is often a concentration of cells at the periphery of the lobules.
  - Treatment: Intralesional curettage
- **Chondrosarcoma**
  - Intramedullary chondrosarcoma
    - Presentation
      - Pain or a mass in adults over 50 years old
      - Most common locations include flat bones (e.g., the scapula), pelvis, and spine.
    - **Imaging**

- **Radiographs usually yield diagnostic findings, with bone destruction, thickening of the cortex, and mineralization consistent with cartilage within the lesion (see Fig. 9.16).**
        - Prominent cortical changes (endosteal scalloping and erosion) are present in 85% of affected patients.
    - Histology
        - Differentiating malignant cartilage may be extremely difficult on the basis of histologic features alone.
        - The clinical, radiographic, and histologic features must be considered in combination for an accurate diagnosis. Criteria for the diagnosis of malignancy include the following:
        - Many binucleate cells with plump nuclei
        - Particularly large cartilage cells with large single or multiple nuclei containing clumps of chromatin
        - Infiltration of the bone trabeculae
        - Chondromas of the hand (enchondromas)—the lesions in patients with Ollier disease and Maffucci syndrome—and periosteal chondromas may have atypical histopathologic features.
    - Treatment
        - Wide surgical resection
        - Chemotherapy has not been shown to improve survival.

□ Dedifferentiated chondrosarcoma: The most malignant cartilage tumor

- Presentation
    - Pain and decreased motion.
    - Most common locations include the distal and proximal femur and the proximal humerus.
- Imaging: Biomorphic appearance with that of a typical chondrosarcoma with a superimposed, highly destructive area
- Histology: Low-grade cartilage component that is intimately associated with a high-grade spindle cell sarcoma (osteosarcoma, fibrosarcoma, MFH)
- **Treatment: Wide-margin surgical resection and multiagent chemotherapy**
- **Other features: Prognosis is poor, and rate of long-term survival is less than 10%.**

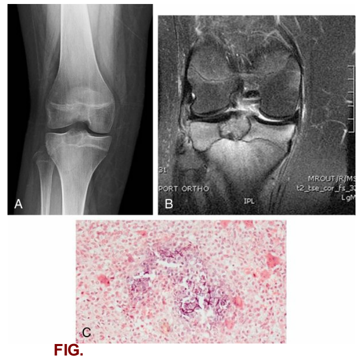
Fibrous Lesions

- **Nonossifying fibroma (also known as metaphyseal fibrous defect, nonosteogenic fibroma, and xanthoma)**
    - Presentation
        - Asymptomatic, incidentally found lesion in a young patient
        - Most common locations are the distal femur, distal tibia, and proximal tibia.
    - Imaging
        - Characteristic radiographic appearance: A lucent lesion that is metaphyseal, eccentric, and surrounded by a sclerotic rim (Fig. 9.21)
        - The overlying cortex may be slightly expanded and thinned.
    - Histology: Cellular, fibroblastic connective tissue background, with the cells arranged in whorled bundles
    - Treatment
        - Asymptomatic lesions: Observation if the radiographic appearance is characteristic and there is no risk of pathologic fracture. Lesions resolve spontaneously and are not true neoplasms.

Table 9.23

Epiphyseal Lesions—Chondroblastoma Versus Giant Cell Tumor

	Chondroblastoma	**Giant Cell Tumor**
Patient age (yr)	<30	>30
Imaging	Plain film: Skeletally immature Well-circumscribed lytic lesion Stippled calcifications MRI: Edema surrounding lesion is greatly out of proportion to the lesion	Plain film: Skeletally matu Poorly circumscribed ecce lytic lesion MRI: lesion may contain fl fluid levels (ABC collisi tumor)
Histology	Chondroblasts “Chicken-wire” calcifications in a lacelike pattern	Multinucleated giant cells a background of mono stromal cells Frequent ABC component
Biology	Lung metastases in <1% of patients	Lung metastases in 5% of pati
Treatment	Intralesional curettage	Intralesional curettage For pathologic fracture, OI resection and reconstru
Image		

Description	 **FIG. 9.19** Chondroblastoma of the proximal femur. (A) Radiograph shows a well-circumscribed lytic lesion with a sclerotic rim in the proximal tibial epiphysis. (B) T2-weighted fat saturation MR image shows the epiphyseal lesion with an extraordinary amount of intraosseous edema. (C) Photomicrograph showing chicken-wire calcification (centrally) within chondroid matrix and surrounding chondroblasts and osteoclast-like giant cells.	 **FIG. 9.20** Giant cell tumor of the distal radius. (A) Radiograph shows a well-circumscribed lytic, expansile lesion involving both the epiphysis and the metaphysis. (B) Higher-power photomicrograph shows giant cells and mononuclear cells.

- Symptomatic lesions: Curettage and fixation are performed.

- **Desmoplastic fibroma: Rare and low-grade but aggressive fibrous tumor of bone**
  - Presentation: Pain
  - Imaging: Lesion is purely lytic. When process is low grade, residual or reactive trabeculated (or corrugated) bone is often present.
  - Histology: Lesion is composed of abundant collagen and mature fibroblasts with no cellular atypia.
  - Treatment: With wide-margin surgical resection, the risk of local recurrence is low.

Notochordal Tissue Tumors

- **Chordoma is a malignant neoplasm in which the cell of origin is derived from primitive notochordal tissue.**
- **Presentation**
  - Patients present with an insidious onset of pain. Lesions in the sacrum may manifest as pain in the pelvis, low back, or hip or with primarily gastrointestinal symptoms (obstipation, constipation, loss of rectal tone). When vertebral bodies are involved, neurologic symptoms may vary widely because of nerve compression.

- Occurs predominantly at the ends of the vertebral column clivus of the skull or sacrum (sacrococcygeal)
- About 10% of chordomas occur in the vertebral bodies (cervical, thoracic, and lumbar regions).

- **Imaging**
  - Radiographs often do not reveal the true extent of sacrococcygeal chordomas.
  - MRI shows midline bone destruction and a soft tissue mass (Fig. 9.22).
  - Other MRI findings
    - Low signal on T1-weighted images
    - Very bright signal on T2-weighted images
    - Sacrum is often expanded, and the soft tissue mass may exhibit irregular mineralization.
- **Histology**
  - The tumor grows in distinct lobules.
  - Chordoma cells sometimes have a vacuolated appearance and are called *physaliferous* cells.
- **Treatment**
  - Wide-margin surgical resection
  - Radiation therapy may be added if a wide margin is not achieved.
- **Other features: Chordomas metastasize late in the course of disease, and local extension can be fatal.**

Vascular Tumors

- **Vascular malformation, a.k.a. hemangioma.**
  - Presentation
    - Patients may present with pain or pathologic fracture (often asymptomatic).
    - These tumors usually occur in vertebral bodies.
  - Imaging
    - Vertebral hemangiomas have a characteristic appearance, with lytic destruction and vertical striations or a coarsened honeycomb appearance.
    - On occasion, more than one bone is involved.
  - Histology: There are numerous blood channels. Most lesions are cavernous, although some may be a mixture of capillary and cavernous blood spaces.
  - Treatment: Symptomatic lesions may undergo fixation; asymptomatic lesions may be monitored.
- **Hemangioendothelioma**
  - Presentation

- Pain in any age group
- Multifocal involvement of the bones of the same extremity is common

□ Imaging: Predominantly oval lytic lesion with no reactive bone formation

□ Histology

□ Treatment: Low-grade multifocal lesions may be treated with irradiation alone.

Hematopoietic Tumors

- **Hematopoietic tumors are small round blue cell tumors often difficult to distinguish from a number of small round blue cell tumors—a comparison is given in** Table 9.24).

FIG. 9.21 Metaphyseal fibrous defect (nonossifying fibroma) of the proximal fibula. (A) Radiograph shows a scalloped, well-circumscribed lesion with a sclerotic rim in the proximal fibula. (B) Low-power photomicrograph shows spindle cells in a storiform pattern and occasional multinucleated giant cells.

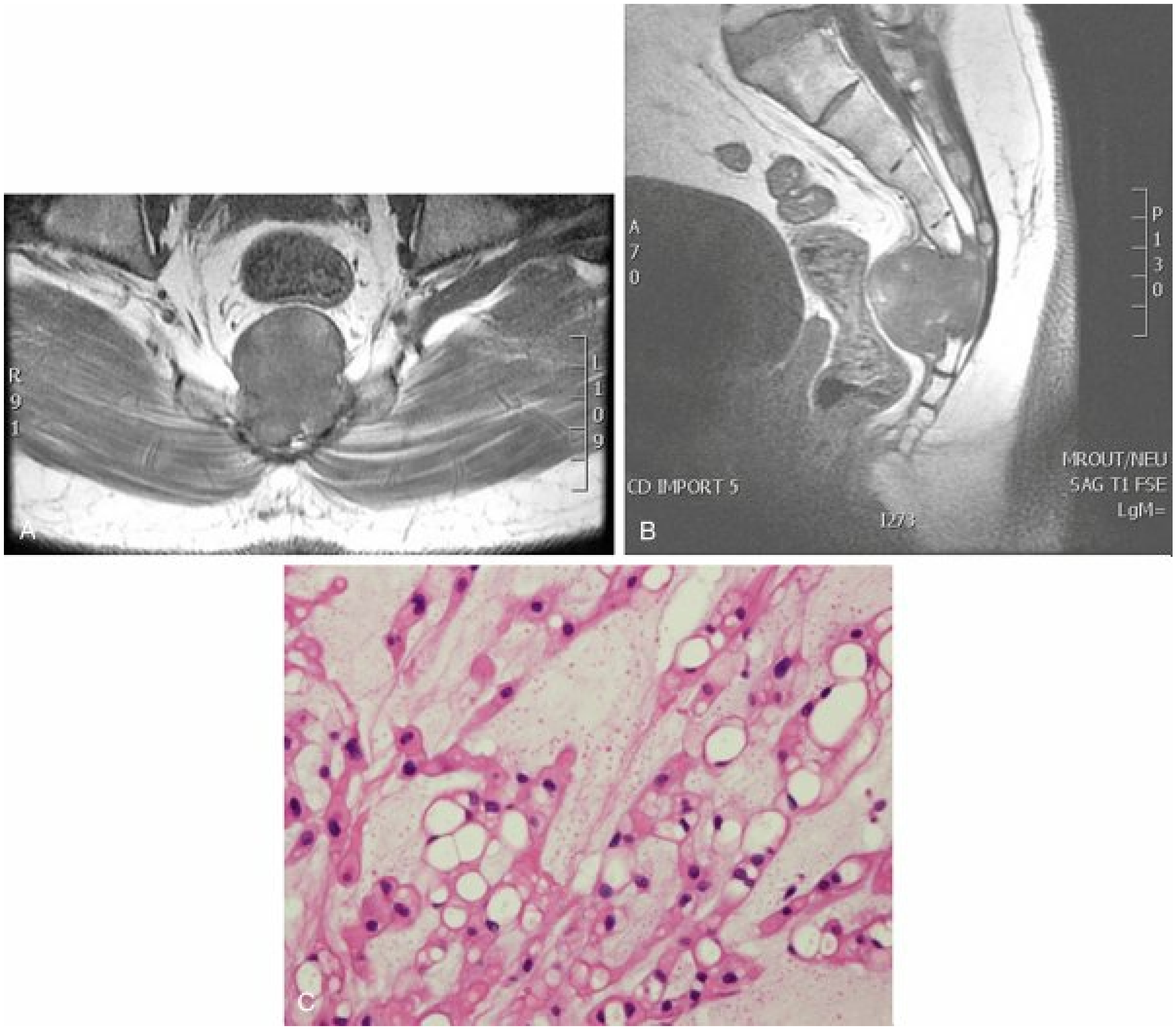


FIG. 9.22 Chordoma of the sacrum. (A) Axial T1-weighted MR image of the pelvis shows a central well-circumscribed lesion extending from the sacrum anteriorly. (B) Sagittal T1-weighted image shows a lesion emanating from the sacrum. (C) High-power photomicrograph shows nests of physaliferous cells.

- **Lymphoma of bone (non-Hodgkin lymphoma)**
  - □ Presentation
    - Pain in patients of all ages.
    - The most common locations include the distal femur, proximal tibia, pelvis, proximal femur, vertebra, and shoulder girdle.
  - □ Imaging
    - Images often show a lesion that involves a large portion of the bone (Fig. 9.23).
    - Bone destruction is common and often has a mottled appearance.
    - A large soft tissue mass out of proportion to the amount of bone destruction is characteristic of lymphoma of bone.
  - □ Histology
    - A mixed cellular infiltrate is usually present. Most lymphomas of bone are diffuse, large B-cell lymphomas.
    - IHC: CD45 and leukocyte common antigen (LCA) positive.

- Treatment
  - **Multiagent chemotherapy ([CHOP]) is curative.**
  - **Surgery is used only to stabilize fractures.**

▪ **Myeloma**

- Plasma cell dyscrasias represent a wide range of conditions from monoclonal gammopathy of undetermined significance (MGUS; Kyle disease) to multiple myeloma.
- Three plasma cell dyscrasias pertain to orthopaedic surgery: multiple myeloma, solitary plasmacytoma of bone, and osteosclerotic myeloma.
- Multiple myeloma
  - Malignant plasma cell disorder that commonly occurs in patients between 50 and 80 years of age
  - Presentation: Manifests with bone pain, usually in the spine and ribs, or as a pathologic fracture
    - Fatigue is a common complaint secondary to the associated anemia.
    - Symptoms may be related to complications such as renal insufficiency, hypercalcemia, and the deposition of amyloid.
    - Serum creatinine values are elevated in about 50% of affected patients.
    - Hypercalcemia is present in about 33% of affected patients.

Table 9.24

Blue Cell Tumors: Mnemonic LERNM ("Learn 'em") [a]

Tumor	Molecular Marker	Patient Age (YR)	Imaging
Lymphoma	CD45+ CD20+ LCA+	>30	Plain film: Minimal bone destruction MRI: Large soft tissue mass out of proportion to bone destruction
Ewing sarcoma	CD99+ FLI-1+t(11;22) translocation	<30	Plain film: Onion-skinning and Codman triangle MRI: Large soft tissue mass out of proportion to bone destruction
Rhabdomyosarcoma	Desmin positivity	<30	Plain film: Normal MRI: Soft tissue mass
Neuroblastoma	Neuron-specific enolase positivity	<30	Plain film: Normal MRI: Soft tissue mass
Myeloma	Kappa/lambda light chain+ Monoclonal spike on SPEP/UPEP CD138+	>30	Plain film: Punched-out bone lesion with no host response MRI: Visible lesion with small zone of surrounding edema

[a] Histologically, these tumors appear as small blue cells on hematoxylin-eosin staining because they have prominent nuclei and small amounts of surrounding cytoplasm. Molecular markers are utilized to distinguish tumor type.

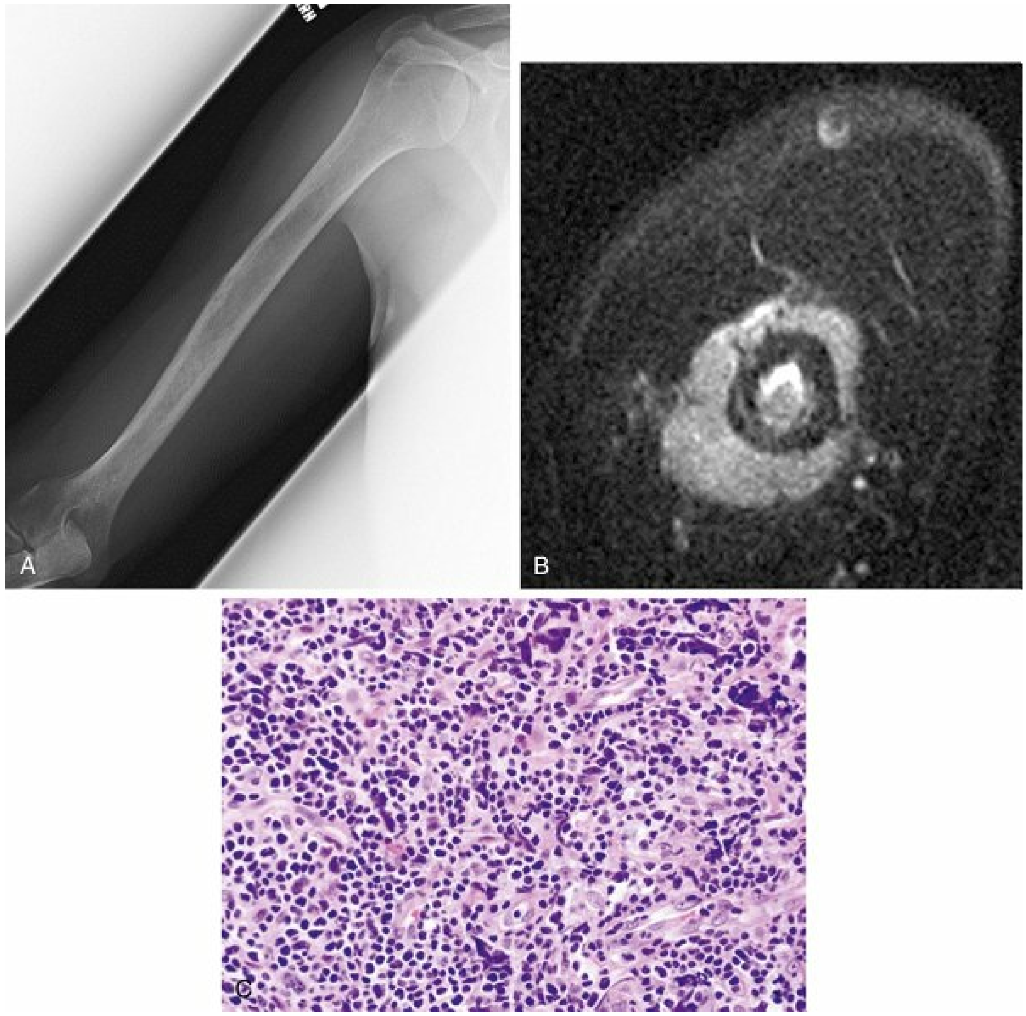


FIG. 9.23 Lymphoma of bone. (A) Radiograph shows a poorly circumscribed lytic lesion in the diaphyseal humerus. (B) Axial T2-weighted MR image shows a massive soft tissue mass out of proportion to the minimal destruction of the cortex seen on plain radiograph. (C) Higher-power photomicrograph (×400) shows a uniform population of small round blue cells within an intramedullary space.

- Imaging: Radiographic appearance is of punched-out, lytic lesions (see Fig. 9.13), which may show expansion and a “ballooned” appearance.
- Histology
- Sheets of plasma cells that appear monoclonal with immunostaining
- Well-differentiated plasma cells have eccentric nuclei that have peripherally clumped, chromatic “clock faces.”
- Treatment
    - Systemic therapy and bisphosphonates
    - Surgical stabilization with irradiation is used for pathologic fractures.
    - Radiotherapy is also used for palliation of pain and treatment of neurologic symptoms.
    - The prognosis is related to the stage of disease; the overall median survival time is 18–24 months.

- **Solitary plasmacytoma of bone**
  - It is important to differentiate solitary myeloma from multiple myeloma because of the more favorable prognosis in patients with the solitary form. Diagnostic criteria include the following:
    - A solitary lesion on skeletal survey
    - Histologic confirmation of plasmacytoma
    - Bone marrow plasmacyte count of 10% or less
    - Patients with serum protein abnormalities and Bence Jones proteinuria (protein levels <1 g/24 hr) at presentation are not excluded if they meet the aforementioned criteria.
  - Treatment
    - External beam irradiation of the lesion (4500–5000 cGy)
    - When necessary, prophylactic internal fixation
  - In approximately 50%–75% of affected patients, solitary myeloma progresses to multiple myeloma.
- **Osteosclerotic myeloma**
  - Rare variant in which bone lesions are associated with a chronic inflammatory demyelinating polyneuropathy.
  - Diagnosis of osteosclerotic myeloma is not generally made until the polyneuropathy is recognized and evaluated.
  - Presentation
    - Sensory symptoms (tingling, pins and needles, coldness) are noted first, followed by motor weakness.
    - Sensory and motor changes begin distally, are symmetric, and proceed proximally.
    - Severe weakness is common, but bone pain is not characteristic.
    - Affected patients may have abnormalities outside the nervous system and may have a constellation of findings termed the *POEMS* (polyneuropathy, organomegaly, endocrinopathy, M protein, and skin changes) syndrome.
  - Imaging
    - Radiographs may show a spectrum from pure sclerosis to a mixed pattern of lysis and sclerosis.
    - The lesions usually involve the spine, pelvic bones, and ribs; the extremities are generally spared.
  - Treatment: A combination of chemotherapy, radiotherapy, and plasmapheresis. The neurologic changes may not improve with treatment.

Tumors of Unknown Origin

- **Giant cell tumor of bone**
  - Presentation
    - Pain and pathologic fracture
    - Patients over 30 years old with closed physes
    - **Most common in the epiphysis and metaphysis of long bones, and about 50% of lesions occur about the knee; the vertebra, sacrum, and distal radius are involved in about 10% of cases.**
    - **The sacrum is the most common axial location of giant cell tumors of bone.**
  - **Imaging: A purely lytic destructive lesion in the metaphysis that extends into the epiphysis and often borders the subchondral bone** (see Fig. 9.20).
  - **Histology**
    - **Basic proliferating cell has a round to oval or even spindle-shaped nucleus, and the multinucleated giant cells appear to have the same nuclei as the proliferating mononuclear cells. The stromal cell directs the multinucleated giant cell**.
    - **Stromal malignant cells produce RANKL (receptor activator for nuclear factor κB ligand).**
    - **Multinucleated giant cells express RANK and are responsible for the osteolytic aspect of GCT**.
  - **Treatment**
    - **Aimed at removing the lesion, with preservation of the involved joint**
    - **Denosumab (Prolia), a human monoclonal antibody that binds RANKL, thereby inhibiting the maturation of osteoclasts**.
    - Extensive intralesional resection (removal of a large cortical window over the lesion) is performed using curettage with manual and power instruments.
    - Chemical cauterization may be used (phenol, peroxide).
    - Area of defect is usually reconstructed with subchondral bone grafts, methylmethacrylate, or both.
    - Local control with this treatment regimen has a success rate of 85%–90%.
  - Other features: GCT is described as benign but is aggressive, because in rare cases (<5%) it metastasizes to the lungs.
- **Ewing sarcoma**
  - Presentation
    - Patient age less than 30 years
    - Pain and fever may be present; the presentation can be similar to that in an infection.

- Patients may exhibit elevated ESR, leukocytosis, anemia, and elevated WBC count.
- Most common locations include the pelvis, distal femur, proximal tibia, femoral diaphysis, and proximal humerus.

□ Imaging

- Radiographs often show a large, destructive lesion that involves the metaphysis and diaphysis.
- The lesion may be purely lytic or may have variable amounts of reactive new bone formation (Fig. 9.24).
- The periosteum may be lifted off in multiple layers, producing a Codman triangle and an onion-skin appearance.
- The soft tissue component is distinctively large.

□ Histology

- Small round blue cells with minimal cytoplasm, pseudorosettes (attempted formation of vascular channels)
- ICH: CD99 positivity.
- **A classic 11:22 chromosomal translocation produces the *EWS-FLI1* fusion gene.**
- **Bone marrow biopsy is performed for staging purposes**.

□ Treatment: A multimodality approach with multiagent chemotherapy, irradiation, and surgical resection

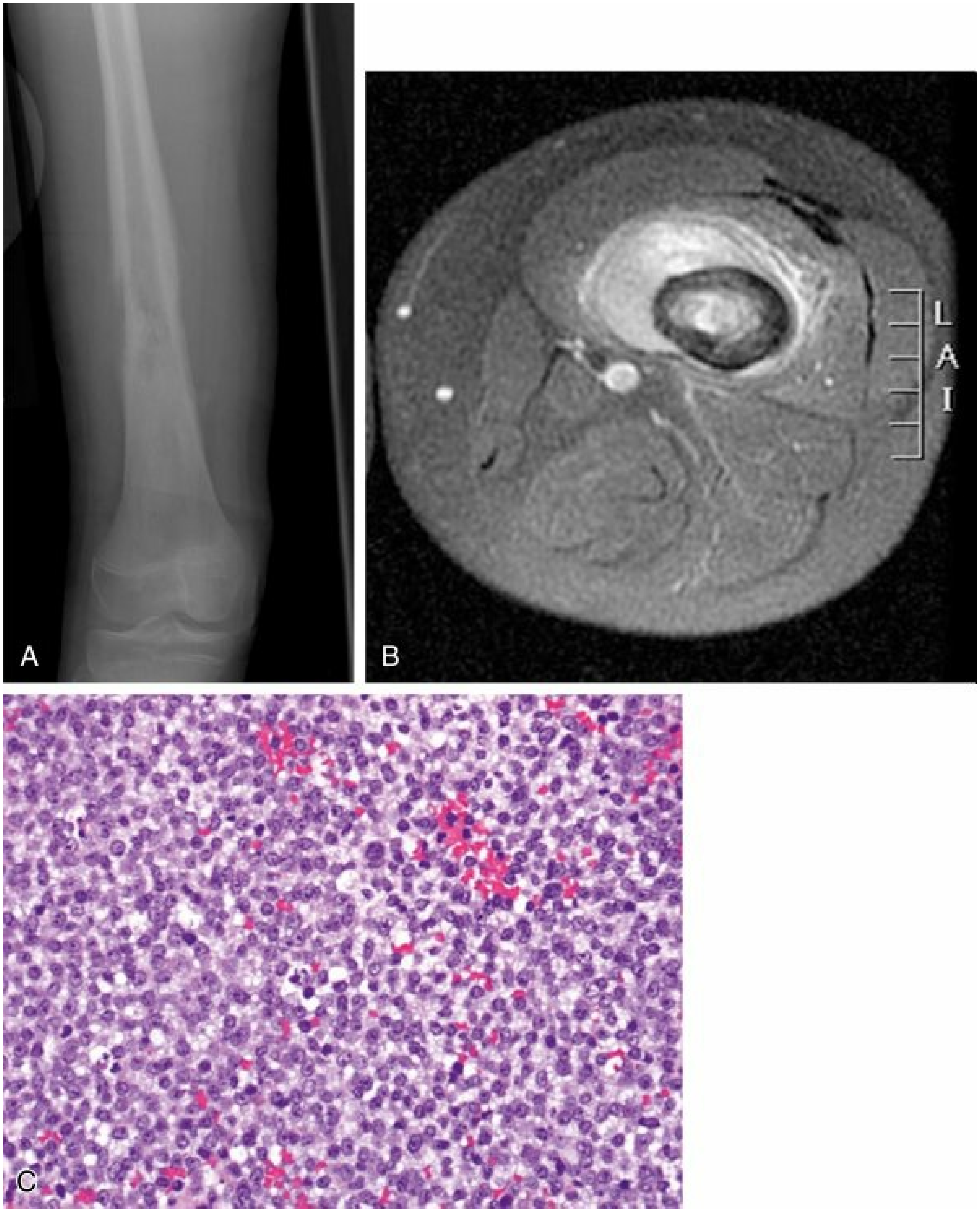


FIG. 9.24 Ewing sarcoma of the distal femur. (A) Radiograph shows a destructive expansile lesion in the distal femur with a Codman triangle on the medial side. (B) Axial MR image shows a large soft tissue mass with serial periosteal elevation, also known as "onion skinning." (C) Higher-power photomicrograph shows sheets of monotonous small round blue cells.

- Standard treatment includes chemotherapy.
- Standard for local tumor control is surgery.
- Radiation therapy may be used primarily for pelvic and spine disease, where resection would be morbid, or as an adjunct to surgery to maintain function while sparing critical

structures.

- ◻ Differential diagnosis: When a small blue cell tumor is found in a child younger than 5 years, metastatic neuroblastoma and leukemia should be considered.
- ◻ Other features
  - Survival
    - The rate of long-term survival with multimodality treatment may be as high as 60%–70%.
    - There is a consistent chromosomal translocation (11;22) with the formation of a fusion protein (EWS-FLI1).
    - Metastatic disease involves the lungs (50%), bone (25%), and bone marrow (20%).
  - Poor prognostic factors include the following:
    - Spine and pelvic tumors
    - Tumors greater than 100 cm^3 in diameter
    - A poor response to chemotherapy (<90% tumor cell necrosis)
    - Elevated serum LDH (Temple)
    - The *p53* mutation and gene fusion products other than EWS-FLI1

▪ **Adamantinoma**

- ◻ Rare low-grade, malignant tumor of long bones that contains epithelium-like islands of cells
- ◻ Presentation
  - Patient less than 30 years old with prolonged periods of pain
  - The tibia is the most common site; other long bones can be but rarely are involved (fibula, femur, ulna, radius).
- ◻ Imaging: Radiographic appearance: multiple, sharply circumscribed, “soap bubble”–looking lucent defects of different sizes, with sclerotic bone interspersed between the zones and extending above and below the lucent zones (see Fig. 9.28 in Table 9.26); one of the lesions in the midshaft is the largest and is associated with cortical bone destruction.
- ◻ Histology: Cells have an epithelial quality and are arranged in a palisading or glandular pattern; the epithelial cells occur in a fibrous stroma.
- ◻ Treatment: Wide-margin surgical resection
- ◻ Other features: Tumor may metastasize either early or after multiple failed attempts at local control.

Tumorlike Conditions

- **Many lesions simulate primary bone tumors and must be considered in the differential diagnosis. They range from metastases to reactive conditions (** Table 9.25).
- **Aneurysmal bone cyst**
  - Nonneoplastic reactive condition that may be aggressive in its ability to destroy normal bone and expand into the soft tissues
  - Presentation: Patients are less than 30 years old and present with pain and swelling.
  - **Imaging**
    - **Characteristic radiographic finding: an eccentric, lytic, expansile area of bone in the metaphysis with a thin rim of periosteal new bone surrounding the lesion. The lesion is wider than the physis of the bone it is closest to (Fig. 9.25 in Table 9.25).**
    - MRI usually shows the periosteal layer surrounding the lesion.

Table 9.25

Aneurysmal Bone Cyst Versus Unicameral Bone Cyst

Aneurysmal Bone Cyst	**Unicameral Bone Cyst**
Occurs with other lesions; "collision tumor"	Does *not* occur with other lesions
***No* fallen leaf sign**	Fallen leaf sign
Radiograph: **Eccentric** **Width of the tumor is greater that the width of the physis**	Radiograph: Central Width of the tumor is *not* greater that the width of the physis
Initial treatment: *Open* curettage	Initial treatment: Aspiration/injection

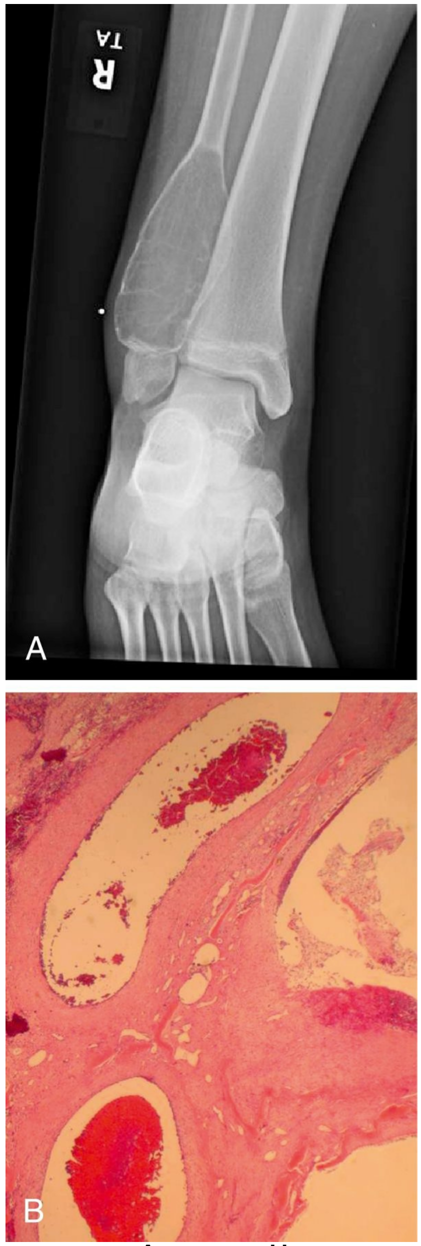


FIG. 9.25 **Aneurysmal bone cyst of the distal fibula. (A) Radiograph shows a lesion that has expanded to be wider than its closest physis; small, thin trabeculae of bone can be seen within the well-defined lytic lesion in the posterior tibial metaphysis. (B) Photomicrograph shows blood-filled lakes, the wall of the cyst, with fibroblasts and occasional multinucleated giant cells.**

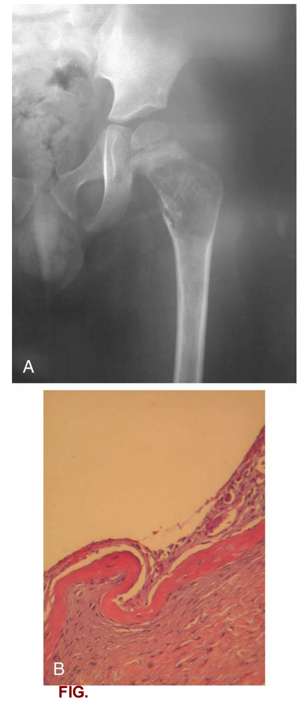


FIG. 9.26 Unicameral bone cyst of the proximal femur. (A) Radiograph shows a symmetric, midline, well-circumscribed lytic lesion in the femoral metaphysis. (B) Photomicrograph shows the fibrous tissue membrane, with reactive bone and occasional multinucleated giant cells.

- Fluid-fluid levels visible on T2-weighted MRI are characteristic of, but not exclusive to, ABC.

□ Histology

- Cavernous blood-filled spaces without an endothelial lining.
- Thin strands of bone are present in the fibrous tissue of the septa.

        - Benign giant cells may be numerous.
    - Treatment: Curettage and reconstruction, which may include bone grafting or fixation in the setting of a fracture.
    - Differential diagnosis: Unicameral bone cyst, telangiectatic osteosarcoma
    - Other features
        - Local recurrence is common in children with open physes.
        - ABC may arise primarily in bone or may be found in association with other tumors, such as giant cell tumor, chondroblastoma, chondromyxoid fibroma, and fibrous dysplasia.
- **Unicameral bone cyst (a.k.a. simple bone cyst)**
    - Presentation
        - Patient less than 30 years old presents with pain, usually after a fracture caused by minor trauma (e.g., sporting event, throwing a baseball, wrestling).
        - Occurs most often in the proximal humerus; other sites are the proximal femur and distal tibia.
    - Imaging
        - Symmetric cystic expansion with thinning of the involved cortices (Fig. 9.26 in Table 9.25)
        - Affected bone is often expanded; however, the bone is generally no wider than the physis.
        - Often appears trabeculated
        - When the cyst abuts the physeal plate, the process is called *active;* when normal bone intervenes, the cyst is termed *latent.*
    - Histology: Thin, fibrous lining contains fibrous tissue, giant cells, hemosiderin pigment, and a few chronic inflammatory cells.
    - Treatment
        - Asymptomatic: Observation
        - Symptomatic: Aspiration and injection (bone aspirate, bone graft substitute, or methylprednisolone acetate may be used)
        - Unicameral bone cysts in high-stress areas (e.g., proximal femur) are often treated with curettage, grafting, and internal fixation to avoid fracture and osteonecrosis.
- **Langerhans cell histiocytosis**
    - Occurs as three entities:
        - LCH monostotic, also known as eosinophilic granuloma. Only a single bone or, on occasion, multiple bones involved. Most common.
        - LCH polyostotic plus visceral disease, or Hand-Schüller-Christian disease

- LCH polyostotic plus visceral disease in an infant, or Letterer-Siwe disease

□ **The cellular abnormality is a proliferation of the Langerhans cells of the dendritic system.**

□ LCH monostotic
- Presentation: Pain and swelling
- Imaging
  - The lesion is lytic and has well-defined margins, described as "punched out" (Fig. 9.27).
  - Cortex may be destroyed, and a periosteal reaction with a soft tissue mass simulating a malignant bone tumor may be present.
  - Often there are different amounts of bone destruction of the involved cortices, resulting in the appearance of a bone within a bone.
  - There may be expansion of the involved bone.
  - Any bone may be involved.
- Histology
  - The proliferating Langerhans cell, with an indented or grooved nucleus, is the characteristic cell.
  - Cytoplasm is eosinophilic.
  - Nuclear membrane has a crisp border.
  - Mitotic figures may be common.

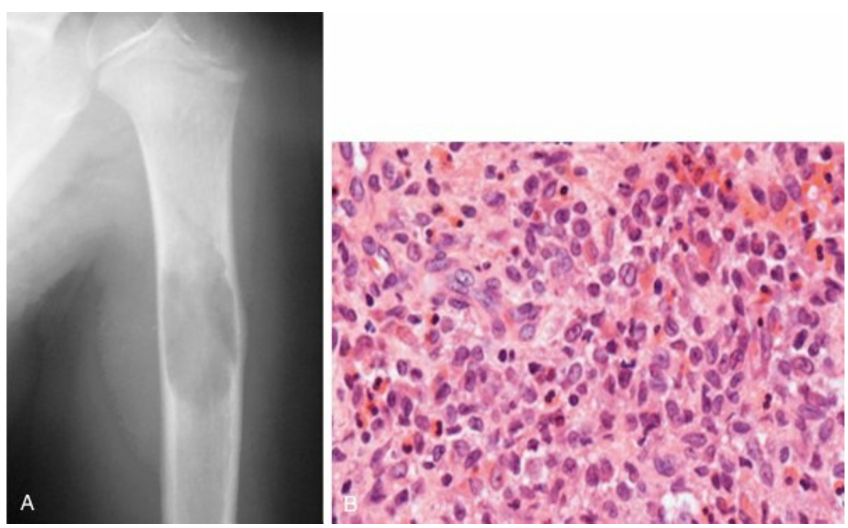


FIG. 9.27 Eosinophilic granuloma of the proximal humerus. (A) Radiograph shows a well-circumscribed lesion with a sclerotic rim in the humeral diaphysis. (B) Higher-power photomicrograph shows eosinophils, histiocytes, and nests of Langerhans histiocytes.

  - Bilobed eosinophils with bright, granular, eosinophilic cytoplasm are present in large

numbers.
      - Electron microscopy shows a tennis racquet–shaped Birbeck granule.
    - Treatment: LCH is a self-limiting process that often resolves after biopsy and/or curettage.
  - LCH polyostotic plus visceral disease: Hand-Schüller-Christian disease
    - Bone lesions and visceral involvement
    - Classic triad, which occurs in fewer than one fourth of patients, consists of exophthalmos, diabetes insipidus, and lytic skull lesions.
    - **Multifocal disease is usually treated with chemotherapy.**
  - Letterer-Siwe disease occurs in young children and is usually fatal.
- **Fibrous dysplasia**
  - Developmental abnormality of bone that is characterized by monostotic or polyostotic involvement and is the failure of the production of normal lamellar bone.
  - Presentation
    - Pain from a fracture or stress fracture; or an incidental finding if asymptomatic; café au lait spots with irregular borders (resembling the coast of Maine) may accompany the bone lesions.
    - Any bone may be involved; the proximal femur is the most commonly affected.
  - Imaging: Variable appearance that can look highly lytic or like ground glass (Fig. 9.29)
  - Histology
    - Well-defined rim of sclerotic bone
    - Proliferation of fibroblasts (produces a dense collagenous matrix)
    - **Trabeculae of osteoid and bone within the fibrous stroma are present in a disorganized manner, and their appearance has been likened to “alphabet soup” and “Chinese letters.”**
  - Treatment
    - Predicated on the presence of symptoms and the risk of fracture
    - Internal fixation and bone grafting are used in areas of high stress in which nonoperative treatment would not be effective.
    - Most affected patients do not need surgical treatment.
    - **Autogenous cancellous bone grafting is never used because the transplanted bone is quickly transformed into the woven bone of fibrous dysplasia.** Cortical or cancellous allografts are usually used.

- Bisphosphonate therapy has been shown to be effective in decreasing pain and reducing bone turnover in patients with polyostotic fibrous dysplasia.
- □ Other features
  - Genetic mutation is an activating mutation of the GSα surface protein (*GNAS*)
  - Increased production of cAMP
  - When endocrine abnormalities (especially precocious puberty) accompany multiple bone lesions and skin abnormalities, the condition is called *McCune-Albright syndrome.*

- **Osteofibrous dysplasia (also called *ossifying fibroma* or *Jaffe-Campanacci lesion*)**
  - □ Presentation: Patients present before 30 years of age, commonly with tibial disease in which bowing is very common, and affected children may experience pathologic fractures.
  - □ **Imaging: Primarily involves the tibia and is usually confined to the anterior tibial cortex (Fig. 9.30).**
  - □ **Histology: Fibrous tissue stroma and a background of bone trabeculae *with* osteoblastic rimming**.
  - □ **Treatment**
    - Nonoperative treatment is preferred until the child reaches maturity.
    - Resection or fixation or both may be required.
- **Fibrous dysplasia, osteofibrous dysplasia, and adamantinoma are compared in** Table 9.26 and Figs. 9.28, 9.29, and 9.30.
- **Paget disease of bone**
  - □ Characterized by abnormal bone remodeling
  - □ Presentation
    - Patient over 50 years old presenting **with pain.**
    - Patient may present with degenerative joint disease, fracture, or neurologic encroachment; joint degeneration is common in the hip and knee.
    - Monostotic or polyostotic
  - □ Imaging: Radiographs demonstrate coarsened trabeculae and remodeled cortices. Coarsened trabeculae give the bone a blastic appearance.
  - □ Histology: Characteristic features are irregular, broad trabeculae; reversal or cement lines; osteoclastic activity; and fibrous vascular tissue between the trabeculae.
  - □ Treatment
    - Aimed at retarding the activity of the osteoclasts
    - Agents used include diphosphonates and calcitonin (pamidronate and zoledronic acid).

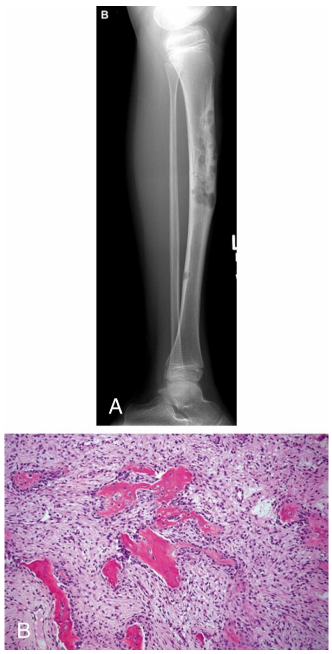
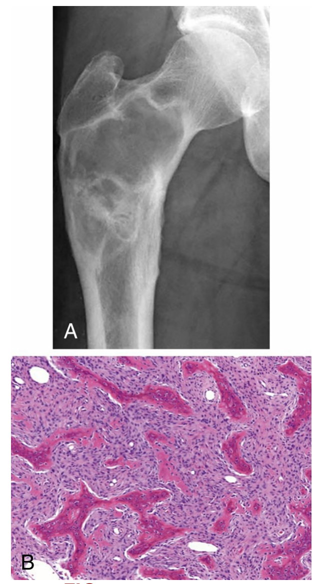
- Patients undergoing arthroplasty should be treated with bisphosphonates to decrease bleeding at the time of surgery.
  - Other features
    - Fewer than 1% of patients with Paget disease experience malignant degeneration with the formation of sarcoma within a focus of a Paget lesion.
      - Symptoms of Paget sarcoma are the abrupt onset of pain and swelling.
      - Radiographs usually demonstrate cortical bone destruction and the presence of a soft tissue mass.
      - Paget sarcoma is a deadly tumor with a poor prognosis (rate of long-term survival is <20%).

- **Osteomyelitis**
  - Bone infections often simulate primary tumors.
  - Presentation: Patient of any age may present with fever, chills, bone pain, or a combination of these symptoms.
  - Imaging
    - Bone destruction and formation are the characteristic findings of chronic infections.
    - Acute infections often produce cortical bone destruction and periosteal elevation.
    - **Serpiginous tracts and irregular areas of bone destruction are suggestive of infection rather than neoplasm.**
  - Histology: A mixed-cell population of inflammatory cells, plasma cells, polymorphonuclear leukocytes, eosinophils, lymphocytes, and histiocytes
  - Treatment: Resection of necrotic bone and appropriate antibiotic therapy
  - Other features: A chronic infection with long-standing wound drainage is occasionally complicated by squamous cell carcinoma.

Table 9.26

Osteofibrous Dysplasia, Fibrous Dysplasia, and Adamantinoma

	Osteofibrous Dysplasia	Fibrous Dysplasia	Adamantino
Patient age (yr)	<30	Any	<30
Imaging	Multilocular, eccentric lytic defects of cortex with a well-defined sclerotic border	"Ground-glass" appearance Bone deformity/bowing	Lytic, mixed l based lesic

Location	Tibia common	Any bone	Tibia characte
Histology	Fibroosseous lesion *with* rimming osteoblasts	Fibro-osseous lesion *without* rimming osteoblasts	Nests of epith backgrour
Biology	Benign	Benign	
Treatment	Observation	Observation Pathologic fractures treated surgically	Wide excision
Image			
Description	 **FIG. 9.30** Osteofibrous dysplasia of the diaphyseal tibia. (A) Plain radiograph shows a cortically based lesion with lytic areas that have sclerotic rimming. (B) Histologic specimen shows osteoid lakes in a fibrous stroma *with* rimming osteoblasts.	 **FIG. 9.29** Fibrous dysplasia of the proximal femur. (A) Radiograph shows a lesion of the proximal femur with a ground-glass appearance. (B) Higher-power photomicrograph shows osteoid *without* rimming osteoblasts surrounded by bland fibrous tissue	F 9 O F b ly ti F s d s e A p s s e k

Metastatic Bone Disease

- **Most common entity that destroys the skeleton in older patients**
- **Presentation**
    - **When a destructive bone lesion is found in a patient older than 50**

years, metastases must be considered first.

- **The five carcinomas that are most likely to metastasize to bone are those of the breast, lung, prostate, kidney, and thyroid. (Mnemonic: "BLT and a kosher pickle" or PT Barnum Likes Kids)**

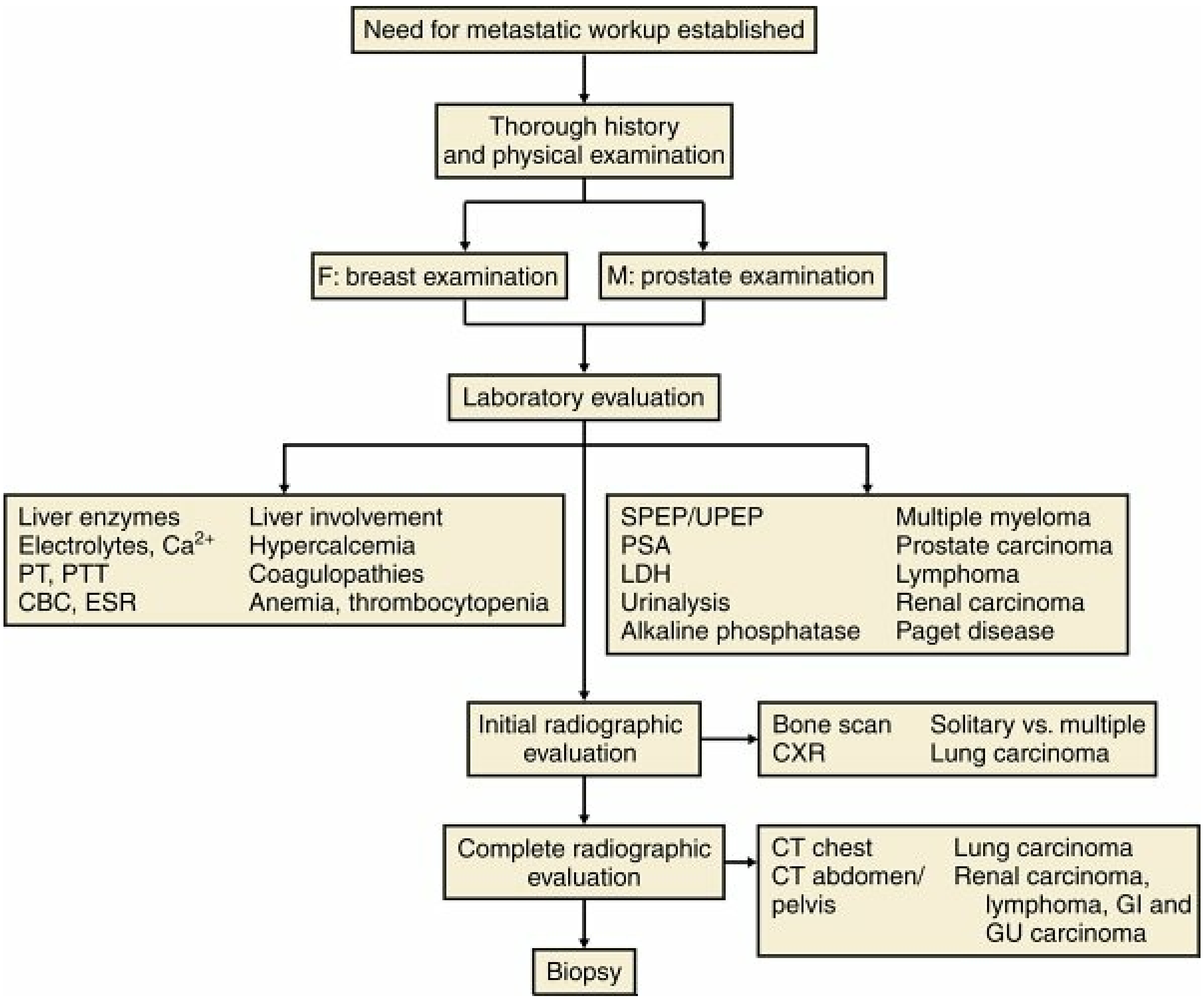


FIG. 9.31 Algorithm showing the evaluation of the older patient with a single bone lesion and suspected metastases of unknown origin. *CXR,* Chest radiograph; *F,* female patient; *M,* male patient; *PT,* prothrombin time; *PTT,* partial thromboplastin time.

From Damron TA: *Orthopaedic surgery essentials, oncology and basic science,* Philadelphia, 2008, Lippincott Williams & Wilkins, p 233.

- **In a patient older than 50 years with a single destructive bone lesion but without a known primary tumor, metastatic disease must be considered present. Simon outlined a diagnostic strategy that identifies the primary lesion in up to 80%–90% of patients (Fig. 9.31).**
- Most common locations of metastasis are the pelvis, vertebral bodies, ribs, and proximal limb girdles.
  - Pathologic fractures secondary to metastatic disease occur most commonly in the proximal femur.

- **Pathogenesis: probably related to Batson vertebral vein plexus.**
  - Venous flow from the breast, lung, prostate, kidney, and thyroid drains into the vertebral vein plexus (Fig. 9.32).

- The plexus has intimate connections to the vertebral bodies, pelvis, skull, and proximal limb girdles.

- **Imaging: Destructive lesion that may be purely lytic, may have a mixed pattern of bone destruction and formation, or may be purely sclerotic (** Fig. 9.33).
- **Histology**
  - Appearance of epithelial cells in a fibrous stroma; the epithelial cells are often arranged in a glandular pattern.
  - Histologically confirmed metastatic cancer for which a definitive primary site is not identified after a detailed medical examination is known as a *carcinoma, unknown primary.*
- **Treatment**
  - Overall treatment aimed at controlling pain and maintaining the independence of the patient
  - Prophylactic internal fixation is performed when impending fracture is deemed likely.

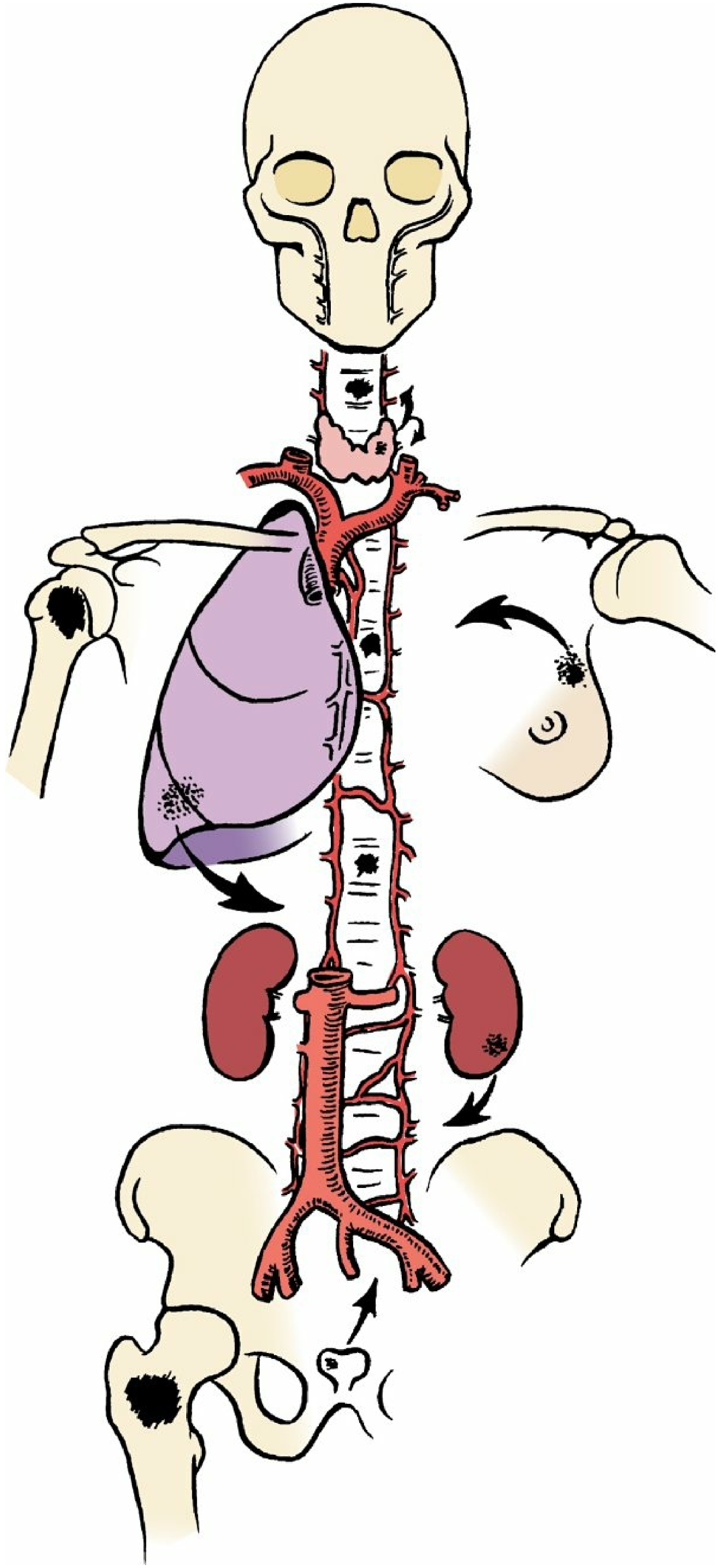


FIG. 9.32 Batson venous plexus. This plexus is longitudinal and valveless and extends from the sacrum to the skull. The breast, lung, kidney, prostate, and thyroid glands connect to this system. Tumor cells can enter this system and spread to the vertebrae, ribs, pelvis, and proximal limb girdle.

From McCarthy EF, Frassica FJ: *Pathology of bone and joint disorders,* Philadelphia, 1998, WB Saunders.

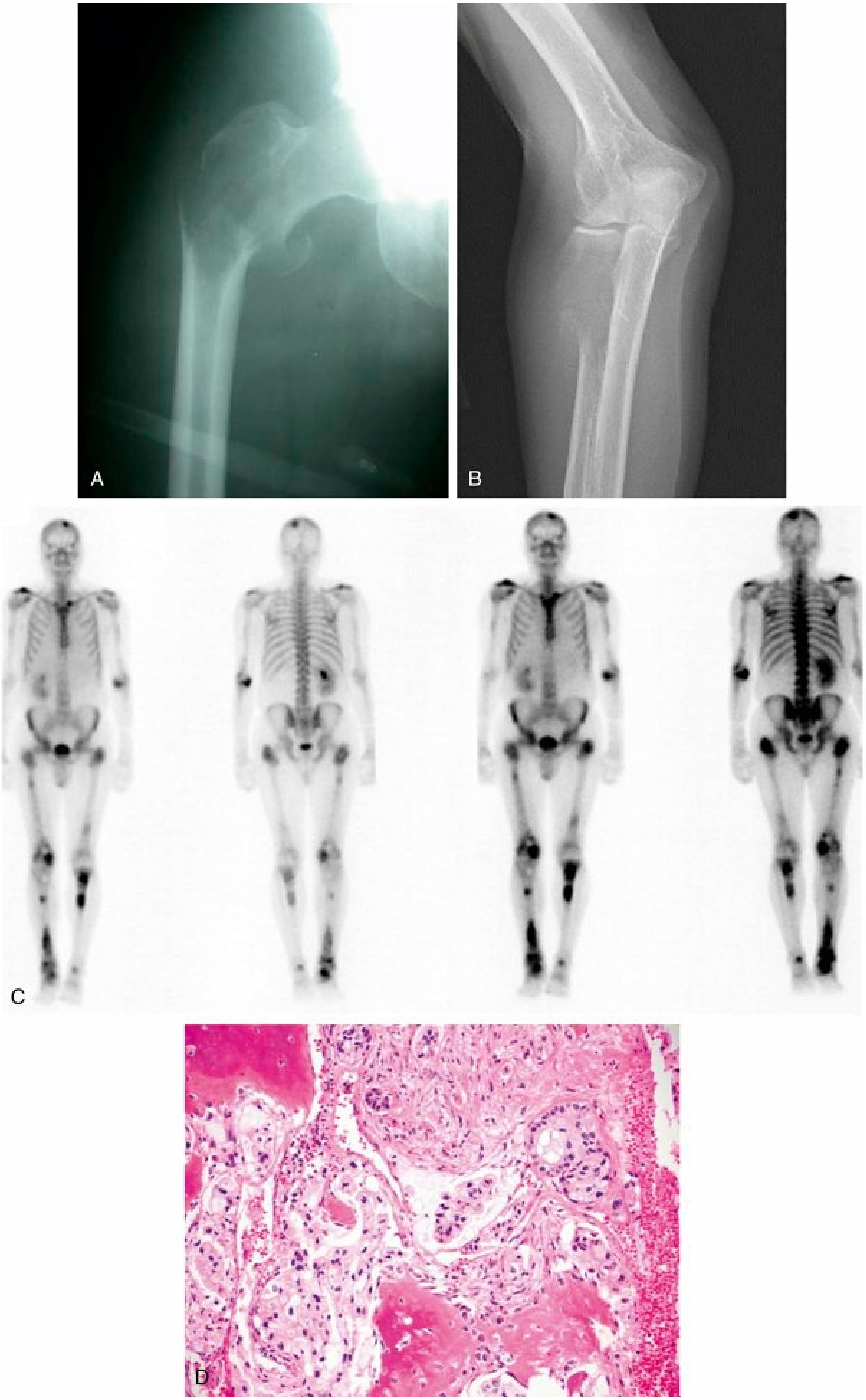


FIG. 9.33 Metastatic carcinoma. (A) Radiograph shows a lytic lesion in the femoral neck with a displaced pathologic fracture. (B) Radiograph shows a lytic destructive lesion of the proximal radius. (C) Whole-body bone scan shows multiple lytic

lesions with increased uptake of radioactive material. (D) Photomicrograph shows the glandular arrangement of cells in the marrow space.

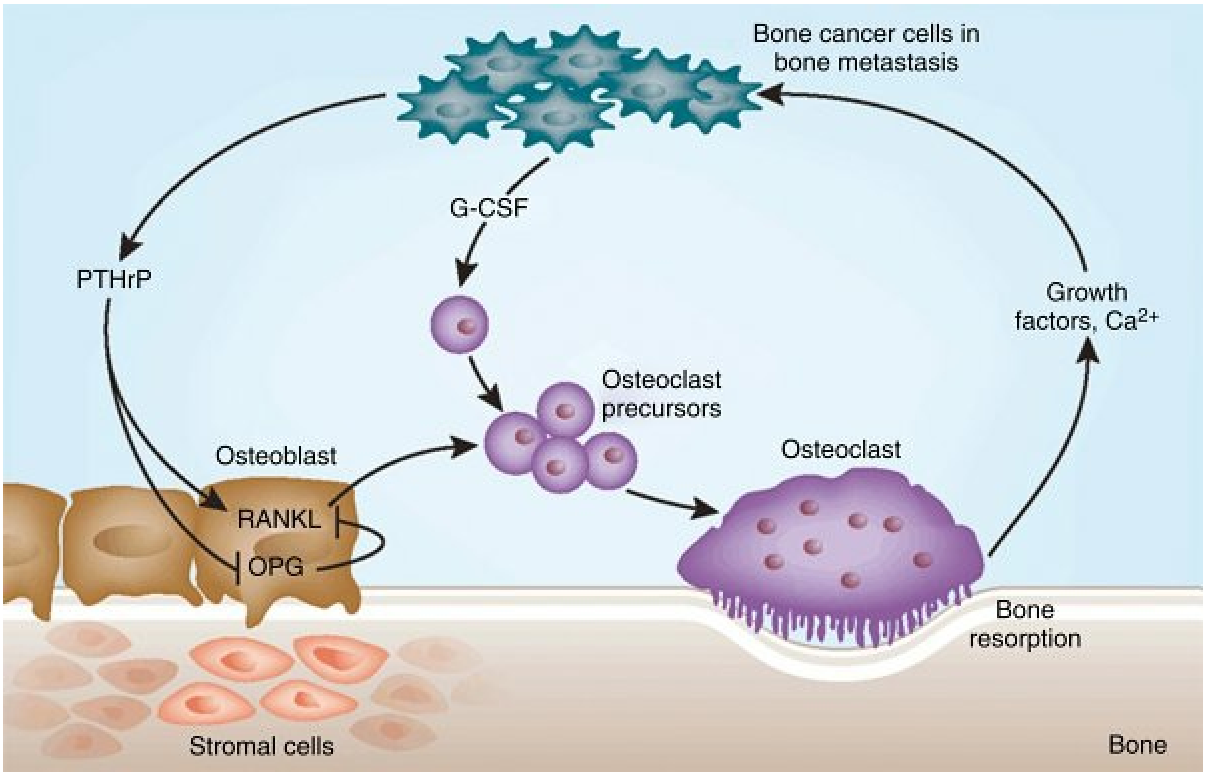


FIG. 9.34 Breast cancer cells produce factors such as PTHrP and G-CSF, which enhance the formation of osteoclasts. *OPG*, Osteoprotegerin.
From Roodman GD: Bone-breaking cancer treatment, *Nat Med* 13:25-26, 2007, Fig. 9.1.

- In comparison with treatment of completed pathologic fractures, prophylactic fixation results in less blood loss, shorter hospital stays, greater likelihood of discharge to home, and greater likelihood of independent ambulation.

- **There are many suggested criteria for fixation. The following conditions put the patient most at risk for fracture:**
  - **More than 50% destruction of the diaphyseal cortices**
  - **Permeative destruction of the subtrochanteric femoral region**
  - **More than 50%–75% destruction of the metaphysis**
  - **Persistent pain after irradiation**
  - **Pain on weight bearing (especially in lower extremity with every footstep)**
- **Treatment of pathologic fractures is almost always surgical, inasmuch as these fractures rarely have the potential to heal.**
- **Surgical procedures should not rely on bony healing.**
  - Most proximal femur fractures should be treated with an endoprosthesis, to protect the femoral shaft in patients with relatively long life expectancy.
  - Risk factors for sudden death during insertion of a long-stem

prosthesis: presence of breast cancer, hypovolemia, reduced pulmonary function

- **Other features**
  - Bone destruction in metastatic disease is termed a "vicious circle."
  - **The bone destruction is caused by activation of osteoclasts (Fig. 9.34).**
    - Tumor cells secrete parathyroid hormone–related peptide (PTHrP), which stimulates the release of RANKL from the osteoblasts and marrow stromal cells.
    - RANKL attaches to the RANK receptor on the osteoclast precursor cells.
    - In the presence of granulocyte colony–stimulating factor (G-CSF), the osteoclast precursor cells differentiate into active osteoclasts that resorb the trabecular and cortical bone.
    - With bone resorption, transforming growth factor-β, insulin-like growth factor-1, and calcium are released, and these factors stimulate the tumor cells to multiply and release more PTHrP.
  - To combat the osteoclastic bone destruction, many patients are now treated with antiresorptive agents (bisphosphonates), such as intravenous pamidronate and zoledronic acid.

Testable Concepts

Section 1 principles Of Practice

- Prognostic factors in bone tumor staging, in order, are presence of metastases, discontinuous tumor, grade, and size.
- Prognostic factors in soft tissue tumor staging, in order, are presence of metastases, grade, and size.
- The most common site to which bone and soft tissue sarcomas metastasize is the lung.
- Chemotherapy is used to reduce or eliminate pulmonary metastases by inducing programmed cell death (apoptosis).
- Chemotherapy is commonly used with limb salvage surgery for osteosarcoma and Ewing sarcoma.
- Rhabdomyosarcoma and synovial sarcoma are two soft tissue tumors for which chemotherapy is indicated.
- Radiotherapy is used to reduce or eliminate local recurrence by inducing DNA damage.
- Irradiation is used in combination with limb salvage surgery for soft tissue sarcomas and alone for metastatic bone disease, lymphoma, and myeloma and for select cases of Ewing sarcoma. Radiation therapy is associated with late stress fractures and postradiation sarcoma.

- Irradiation may be administered preoperatively or postoperatively. Postoperative external beam irradiation yields local control rates equal to those of preoperative treatment, with a lower rate of postoperative wound complications but a higher incidence of postoperative fibrosis.
- Wide excision alone is used for chondrosarcoma, adamantinoma, parosteal osteosarcoma, and chordoma.
- Intralesional resection/curettage is used for GCT, ABC, nonossifying fibroma, LCH, osteoblastoma, and chondroblastoma.
- Benign bone tumors in children are most commonly incidental findings.
- Different lesions occur in typical age ranges. Classic patient age associations are as follows:
    - Age less than 5 years: rhabdomyosarcoma, osteofibrous dysplasia, leukemia
    - Age less than 30 years: metaphyseal fibrous defect (nonossifying fibroma), enchondroma, unicameral bone cyst, osteosarcoma, Ewing sarcoma, osteoid osteoma, chondroblastoma, fibrous dysplasia, giant cell tumor
    - Age over 50 years: metastatic bone disease, fibrosarcoma, MFH, metastatic bone disease, myeloma, lymphoma, chondrosarcoma, Paget disease
- Some lesions have classic anatomic locations:
    - Anterior cortex of tibia: adamantinoma, osteofibrous dysplasia
    - Posterior cortex of distal femur: parosteal osteosarcoma
    - Epiphysis: GCT, chondroblastoma, osteomyelitis (Brodie abscess), clear cell chondrosarcoma (femoral head)
    - Metaphysis: metaphyseal fibrous defect (nonossifying fibroma), ABC, GCT, osteosarcoma
    - Diaphysis: Ewing sarcoma, fibrous dysplasia, eosinophilic granuloma (histiocytosis), multiple myeloma, osteoid osteoma/osteoblastoma, infection
    - Principles of biopsy:
    - Use of longitudinal incisions and so biopsy tracts may be excised with a future resection
    - Approaching lesions through muscles wherever possible
    - Avoidance of functionally important structures and neurovascular structures
    - Maintenance of meticulous hemostasis
    - Biopsy of the soft tissue component of a bone tumor when possible
    - Culture of what is biopsied and biopsy of what is cultured.
- There are four surgical margins of tumor excision: intralesional, marginal (through reactive zone), wide (including a cuff of normal tissue), and radical (entire tumor and its compartment, including surrounding muscles, ligaments, and connective tissues).

- Two essential criteria for limb salvage surgery: local control is at least equal to that of amputation; the residual limb must be functional.
- Common tumor-associated genetic associations:
    - Osteosarcoma: tumor suppressor genes *Rb* (retinoblastoma) and *p53* (Li-Fraumeni syndrome)
    - Ewing sarcoma: t(11;22); gene product is *EWS-FLI1*
    - Synovial sarcoma: t(X;18); gene products are *SYT-SSX1* and *SYT-SSX2*
    - Myxoid liposarcoma: t(12;16); gene product is *FUS-CHOP*
    - Alveolar rhabdomyosarcoma: t(2;13); gene product is *PAX3-FKHR*
    - Fibrous dysplasia: *GNAS*

SECTION 2 Soft Tissue Tumors

Introduction

- The most common presentation of a soft tissue sarcoma is an enlarging painful or painless soft tissue mass.
- Any large (>5 cm) soft tissue mass deep to fascia should be considered a sarcoma.
- Soft tissue sarcomas have low intensity on T1-weighted MR images and high intensity on T2-weighted images.
- Metastatic workup for soft tissue sarcoma includes CT of the chest.
- Unplanned removal of a soft tissue sarcoma is the most common error of treatment. Residual tumor may exist, and repeat excision should be performed.
- The most common soft tissue sarcoma of the hand is epithelioid sarcoma.
- The most common soft tissue sarcoma of the foot is synovial sarcoma.
- The primary site of metastases from soft tissue sarcomas is the lung.
- Lymphatic metastasis occurs in 5% of cases; tumors with a predilection for lymph node metastases are epithelioid sarcoma, synovial sarcoma, angiosarcoma, rhabdomyosarcoma, clear cell sarcoma (ESARC), and they are the most common.

Tumors of Fibrous Tissue

- Extraabdominal desmoid tumors are "rock-hard." Patients with Gardner syndrome (familial adenomatous polyposis) have a 10,000-fold increased risk for such tumors. Estrogen receptor β inhibitors can be used for treatment.
- Nodular fasciitis is a painful, rapidly enlarging mass in a person less than 30 years of age. Treatment is marginal margin.
- Undifferentiated pleomorphic sarcoma, previously known as malignant fibrous histiocytoma, is the most common malignant sarcoma of soft tissue in adults. It appears on MRI as a deep-seated, inhomogeneous mass that has a low signal on T1-weighted images and a high signal on T2-weighted images. Treatment is with wide-margin local excision and adjuvant radiotherapy.
- Fibrosarcoma follows the same imaging patterns on MRI scan and has the same

treatment as any high-grade soft tissue sarcoma—limb salvage surgery, perioperative radiotherapy, and long-term surveillance.

Tumors of Fatty Tissue

- Lipomas appear on MRI as well-demarcated lesions with the same signal characteristics as those of mature fat on all sequences. On fat suppression sequences, lipoma has a uniformly low signal. Treatment of asymptomatic lesions is observation, whereas that for expanding or symptomatic lesions is marginal excision.
- Myxoid liposarcoma has a classic 12;16 chromosomal translocation.
- Liposarcoma is the second most common soft tissue sarcoma in adults. It virtually never occurs in the subcutaneous tissues. MRI demonstrates thicker and more irregular septa than in lipomas, which also appear bright on T2-weighted images.

Tumors of Neural Tissue

- Neurofibromatosis can manifest with more than one neurofibroma or one plexiform neurofibroma, with café au lait spots, with Lisch nodules (melanocytic hamartomas in the iris), and with anterolateral tibial bowing.
- Patients with NF1 have a 5% chance of malignant degeneration of a neurofibroma to an MPNST.
- MPNST follows the same imaging patterns on MRI and has the same treatment as any high-grade soft tissue sarcoma—limb salvage surgery, perioperative radiotherapy, and long-term surveillance.

Tumors of Muscle Tissue

- Rhabdomyosarcoma is the most common soft tissue sarcoma in children. It most commonly manifests in the head and neck, genitourinary tract, and retroperitoneum. Extremity involvement is associated with the alveolar subtype; it involves a translocation of chromosomes 2 and 13, and the gene product is *PAX3-FKHR.*
- Rhabdomyosarcomas are sensitive to multiagent chemotherapy. Wide-margin surgical resection and irradiation are used in treatment.
- Leiomyosarcoma follows the same imaging patterns on MRI and has the same treatment as any high-grade soft tissue sarcoma—limb salvage surgery, perioperative radiotherapy, and long-term surveillance.

Vascular Tumors

- Vascular malformations are common in children and adults. Radiographs may reveal phleboliths. Multiple hemangiomas are associated with Maffucci syndrome.

- Angiosarcoma is associated with Stuart-Treves syndrome as well as cutaneous and lymph node metastases (ESARC). It is treated with irradiation and wide surgical excision.

Synovial Disorders

- PVNS most commonly affects the knee, followed by the hip and shoulder. Recurrent, atraumatic hemarthrosis with associated pain is the most common manifestation. Radiographs may show cystic erosions on both sides of the joint. Histologic study reveals highly vascular villi lined with plump, hyperplastic synovial cells; hemosiderin-stained, multinucleated giant cells; and chronic inflammatory cells.
- On both T1- and T2-weighted MRI sequences, PVNS appears as a low-signal lesion.
- Treatment of PVNS is complete synovectomy for diffuse disease and local resection for focal nodular PVNS.

Other Rare Sarcomas

- Synovial sarcoma does not originate from an intraarticular location. It most commonly occurs about the knee and is the most common sarcoma of the foot. Spotty mineralization on radiographs is highly characteristic.
- Histologic study of synovial sarcoma reveals a biphasic pattern: epithelial cells (resembling carcinoma) and spindle cells (resembling fibrosarcoma).
- All cells of synovial sarcomas have a translocation between chromosome 18 and the X chromosome that produces two gene fusion products (*SYT-SSX1* and *SYT-SSX2*). Staining of tumor cells yields positivity for keratin and EMA.
- Epithelioid sarcoma is the most common sarcoma of the hand. Lymph node metastases are common.
- Clear cell sarcoma is a melanin-producing lesion, but its cells have a t(12;22) translocation not present in melanoma cells. Lymph node metastases are common.

Posttraumatic Conditions

- Sarcomas may spontaneously hemorrhage. On advanced imaging, the appearance of “hematomas” should show fascial plane tracking or subcutaneous ecchymosis. Clinical awareness of the spontaneous hematoma should be high, because it can be a sarcoma.
- In myositis ossificans, radiography reveals peripheral mineralization with a central lucent area.

SECTION 3 Bone Tumors

Presentation

- Malignant bone tumors manifest most commonly with pain, in contrast to soft tissue tumors, which most commonly manifest as painless masses.
- Bone sarcomas metastasize primarily via the hematogenous route. The lung is the most common site of metastasis.
- Osteosarcoma and Ewing sarcoma commonly metastasize to other bone sites.

Bone-Producing Lesions

Osteoid Osteoma

- Classically manifests with increasing pain that is relieved by salicylates and other NSAIDs.
- Radiographs of an osteoid osteoma show intensely reactive bone and a radiolucent nidus. CT provides better contrast between the lucent nidus and the reactive bone than does MRI.
- This lesion may produce a painful nonstructural scoliosis, which leads to a curve with the osteoid osteoma on the concave side and is thought to result from marked paravertebral muscle spasm.
- CT-guided radiofrequency ablation is the standard method of treatment; however, in 50% of patients treated with NSAIDs alone, the symptoms resolve.
- Osteoblastoma may be confused with osteoid osteoma—the self-limited nidus is less than 1 cm in osteoid osteoma and greater than 2 cm in osteoblastoma, with unlimited growth and pain not relieved by salicylates/NSAIDS; the two tumors have the same histology.

Osteosarcoma

- Osteosarcoma is the most common malignant bone tumor in children.
- There are many types of osteosarcoma. The most commonly recognized are high-grade intramedullary osteosarcoma (ordinary or classic osteosarcoma), parosteal osteosarcoma, periosteal osteosarcoma, telangiectatic osteosarcoma, osteosarcoma occurring with Paget disease, and postradiation osteosarcoma.
- Classic high-grade intramedullary osteosarcoma is the most common type and usually occurs about the knee in children and young adults, but its incidence has a second peak in late adulthood.
    - Treated with neoadjuvant chemotherapy, followed by resection of the tumor and adjuvant chemotherapy.
    - Chemotherapy both kills the micrometastases that are present in 80%–90% of affected patients at presentation and sterilizes the reactive zone around the tumor.

- The rate of long-term survival is approximately 60%–70%.
- Parosteal osteosarcoma is a low-grade osteosarcoma. It most commonly arises on the posterior aspect of the distal femur.
    - Treatment is by wide-margin surgical resection. Because this lesion is low grade, chemotherapy is not required.
    - Long-term survival is 95%.
- Periosteal osteosarcoma is a surface form that appears radiographically as a sunburst-type lesion resting on a saucerized cortical depression.
    - Treatment is chemotherapy and wide surgical resection.
    - Long-term survival is 85%.
- Telangiectatic osteosarcoma is described as a "bag of blood."
- Radiographic features are similar to those of aneurysmal bone cysts. Treatment is chemotherapy and wide-margin surgical resection.

Chondrogenic Lesions

Chondroma

- Benign cartilage tumors on the surface of bone are called *periosteal chondromas.* When they are in the medullary cavity, they are called *enchondromas.*
- Enchondromas appear radiographically as areas of stippled calcifications. The radiographic distinction between low-grade chondrosarcoma and enchondroma can be difficult; serial plain radiographs show cortical bone changes or lysis of the previously mineralized cartilage in chondrosarcoma. Patients with chondrosarcoma have pain.
- Most enchondromas necessitate no treatment.
- Syndromes of multiple enchondromas include Ollier disease and Maffucci syndrome.
    - Ollier disease:
    - Multiple enchondromas
    - Dysplastic bones (particularly a shortened ulna)
    - A 30% risk of transformation to chondrosarcoma
    - Random spontaneous mutation
    - Maffucci syndrome:
    - Multiple enchondromas and soft tissue hemangiomas (extremity and visceral)
    - A 100% risk of malignancy

Osteochondroma

- Characteristic appearance is a surface lesion in which the cortex of the lesion and the underlying cortex are confluent and the medullary cavity of the host bone also flows into (is continuous with) the osteochondroma.

- When asymptomatic, these lesions are treated with observation only.
- Malignant transformation into a secondary chondrosarcoma is rare, occurring in far fewer than 1% of cases. Thickness of the cartilage cap (>2 cm) may increase the risk of malignancy.
- Multiple hereditary exostoses is an autosomal disorder manifesting in childhood with multiple osteochondromas. Mutations are found in the *EXT1, EXT2,* and *EXT3* gene loci; the *EXT1* mutation is associated with a greater burden of disease and higher risk of malignancy. Approximately 5%–10% of affected patients a secondary chondrosarcoma develops, which is low grade.

Chondroblastoma

- Centered in the epiphysis in young patients, usually with open physes
- Radiographs show a central region of bone destruction that is usually sharply demarcated from the normal medullary cavity by a thin rim of sclerotic bone. MRI shows edema far out of proportion to the lesion.
- Treatment is with intralesional resection and curettage.

Chondrosarcoma

- Occurs in patients over 50 years old, and the pelvis is the most common location
- May be primary or may arise secondarily in a previous lesion (enchondroma, osteochondroma)
- It may be extremely difficult to differentiate malignant cartilage on the basis of histologic features alone. The clinical, radiographic, and histologic features of a particular lesion must be considered in combination to avoid incorrect diagnosis.
- Treatment consists of wide-margin surgical resection.
- Chemotherapy is used only as an adjunct for dedifferentiated and mesenchymal chondrosarcomas.
- Dedifferentiated chondrosarcoma, which is the most malignant cartilage tumor, has a biomorphic histologic and radiographic appearance. In typical cases, a high-grade spindle cell sarcoma is intimately associated with the low-grade cartilage component. Treatment is with wide-margin surgical resection and chemotherapy.

Fibrous Lesions

- Metaphyseal fibrous defect (nonossifying fibroma) is an extraordinarily common lesion, occurring in approximately 30%–40% of children. The characteristic radiographic appearance is that of a lucent lesion that is metaphyseal, eccentric, and surrounded by a sclerotic rim. The overlying cortex may be slightly expanded and thinned.
- Treatment is with observation. Curettage and bone grafting are indicated in

symptomatic lesions (painful or fractured) with more than 50% of cortical involvement.

Notochordal Tissue Tumors

- Chordoma is a malignant neoplasm that arises from primitive notochordal tissue.
- The most common location is the sacrococcygeal region, and the second most common is the sphenooccipital region.
- CT scans show a midline bone mass.

Hematopoietic Tumors

- Multiple myeloma is the most common primary tumor of bone.
- Light-chain subunits of immunoglobulins G and A are found in the urine.
- Radiographic appearance of multiple myeloma is punched-out lytic lesions.
- The classical histologic appearance is sheets of plasma cells that appear monoclonal with immunostaining. Well-differentiated plasma cells have eccentric nuclei that have peripherally clumped, chromatic “clock faces.”
- Treatment is multimodal and includes chemotherapy, radiation therapy, and surgery.

Tumors of Unknown Origin

Giant Cell Tumor

- GCT is a benign but aggressive neoplasm that in rare cases metastasizes to the lung.
- It most commonly occurs about the knee and sacrum. Pain is referred to the involved joint.
- Radiographs demonstrate a purely lytic destructive lesion in the metaphysis that extends into the epiphysis and often borders the subchondral bone.
- Treatment is aimed at removal of the lesion with preservation of the involved joint. Curettage and subsequent reconstruction with subchondral bone grafts or methylmethacrylate is frequently performed.

Ewing Sarcoma

- A distinctive small, round cell sarcoma that occurs most often in children and young adults; most affected children are older than 5 years.
- Radiographs show a large destructive lesion that involves the metaphysis and diaphysis. Periosteum may be lifted off in multiple layers, resulting in a characteristic but uncommon onion-skin appearance.
- Immunohistochemistry studies reveal CD99 positivity. There is a consistent

chromosomal translocation—t(11;22)—with the formation of a fusion protein (*EWS-FLI1*).
- Bone marrow biopsy is performed for staging purposes.
- Most lesions are treated with chemotherapy and surgery; irradiation may be used where surgical resection is not feasible (sacrum/spine).
- Metastatic disease occurs in the lung (50%), bone (25%), and bone marrow (20%).

Adamantinoma

- Adamantinoma is a rare tumor that classically manifests in the anterior cortex of the tibial diaphysis. Treatment is with wide-margin surgical resection.

Tumorlike Conditions

Aneurysmal Bone Cyst

- ABC is nonneoplastic but aggressive in its ability to destroy normal bone and extend into the soft tissues.
- Characteristic radiographic finding is an eccentric, lytic, expansile area of bone destruction in the metaphysis. Fluid-fluid levels are characteristically visible on T2-weighted MRI.
- Treatment is with curettage and bone grafting. Local recurrence is common in children.

Unicameral Bone Cyst (Simple Bone Cyst)

- Unicameral bone cyst most commonly involves the proximal humerus and manifests either with pain or with a pathologic fracture.
- Characteristic radiographic finding is symmetric cystic expansion with thinning of the involved cortices.
- Comparison of ABC and unicameral bone cyst (simplified):
- ABC manifests with pain and swelling. Unicameral bone cyst manifests with pathologic fracture and pain.
- ABC is eccentric and can expand wider than the growth plate. Unicameral bone cyst is central and does not expand wider than the growth plate.

Langerhans Cell Histiocytosis (Histiocytosis X)

- This lesion manifests as three entities:
    - LCH monostotic/eosinophilic granuloma
    - Monostotic
    - Highly destructive lesion with well-defined margin
    - Self-limiting

- Hand-Schüller-Christian disease
- Multiple bone lesions and visceral disease (skull defects, exophthalmos, and diabetes insipidus)
- Letterer-Siwe disease (a fulminating condition in young children)
- Typically fatal

Fibrous Dysplasia

- This condition is caused by a genetic activating mutation of the GSα surface protein, which results in increased production of cAMP.
- Its radiographic appearance is variable but classically referred to as "ground glass."
- Its histologic appearance has been likened to "alphabet soup" and "Chinese letters."
- Autogenous cancellous bone grafting is never used for this disorder because the transplanted bone is quickly transformed into the woven bone of fibrous dysplasia.
- Polyostotic fibrous dysplasia is less common but more symptomatic and is diagnosed earlier (before the age 10 years) than monostotic fibrous dysplasia.
- Polyostotic fibrous dysplasia with endocrinopathy is termed *McCune-Albright syndrome* (café au lait spots, precocious puberty, and polyostotic fibrous dysplasia).

Osteofibrous Dysplasia

- This condition manifests in a manner similar to that of fibrous dysplasia but in children younger than 10 years.
- The tibia is its characteristic location.

Paget Disease

- This disorder is characterized by abnormal bone remodeling, which results in coarsened trabeculae and remodeled cortices.
- Medical treatment of Paget disease is aimed at retarding the activity of the osteoclasts. Agents used include bisphosphonates and calcitonin.
- Fewer than 1% of patients with Paget disease experience malignant degeneration with the formation of a sarcoma within a focus of Paget disease.
- Paget sarcomas are deadly tumors with a poor prognosis (the rate of long-term survival is <20%).

Metastatic Bone Disease

- The patient over 50 years old with a destructive bone lesion should be presumed to have metastatic disease.

- History, physical examination, and radiographic staging (CT of chest, abdomen, and pelvis) identify the primary source of metastasis in 85% of cases; biopsy is necessary for definitive diagnosis.
- The five carcinomas that are most likely to metastasize to bone are those of the prostate, thyroid, breast, lung, and kidney.
- Pathologic fractures secondary to metastatic disease occur most commonly in the spine.
- Histologic hallmark is the appearance of epithelial cells in a fibrous stroma; the epithelial cells are often arranged in a glandular pattern.
- Bone destruction in metastatic disease results from activation of osteoclasts. Tumor cells secrete PTHrP, which stimulates RANKL release and results in activation of osteoclasts.

Chapter 9 Review Questions

1. The plain radiograph and biopsy specimen of a 14-year-old boy reveal a conventional osteosarcoma. The most appropriate next diagnostic steps should include which of the following?

A. A bone scan, MRI of the femur, and CT of the chest.

B. A bone scan; MRI of the femur; and CT of the chest, abdomen, and pelvis.

C. A bone marrow aspirate; CT of the chest, abdomen, and pelvis; and a bone scan.

D. A bone marrow biopsy; CT of the chest, abdomen, and pelvis; MRI of the femur; and a bone scan.

E. Nothing further; a biopsy should be adequate to stage this disease.

ANSWER 1: **A.** The staging of osteosarcoma of bone consists of local imaging of the affected extremity with radiographs and MRI, CT of the chest, and a whole-body bone scan. Osteosarcomas and Ewing sarcoma have a predilection for osseous metastases so a bone scan is indicated. Because the treatment of osteosarcoma begins with neoadjuvant chemotherapy, immediate referral to a pediatric oncologist is critical. A CT scan of the abdomen and pelvis is not indicated in primary bone sarcomas, but it may have a role in the staging of some soft tissue sarcomas. Bone marrow biopsy is not a component of osteosarcoma staging but is used in the staging of Ewing sarcoma of bone.

2. Which of the following tumors is most likely to occur in a patient more than 50 years of age?

A. Ewing sarcoma

B. Chondrosarcoma

C. Rhabdomyosarcoma

D. Osteosarcoma

E. Langerhans cell histiocytosis

ANSWER 2: **B.**

Ewing sarcoma, rhabdomyosarcoma, osteosarcoma, and Langerhans cell histiocytosis are most likely to occur in patients less than 30 years of age.

3. A 65-year-old man has had thigh pain and a mass for 4 months since he pulled his groin. The presumed diagnosis, considering his clinical history and evaluation appearance was that of a high-grade sarcoma. Which of the following is true regarding an incomplete excision of a soft tissue sarcoma?

A. Physical therapy will accelerate healing and improve function.

B. This patient would benefit from a complete hematologic workup to evaluate a bleeding disorder.

C. The risk for local recurrence after tumor bed excision and irradiation is higher in a patient who undergoes an unplanned excision of a sarcoma.

D. Radiotherapy only is needed for definitive treatment of this problem.

E. Further treatment with observation and serial MRI only is appropriate.

ANSWER 3: **C.** Patients with unplanned excisions who undergo limb salvage procedures require more extensive surgical procedures involving free flaps and skin grafting; they also require more adjuvant radiotherapy and, often, amputation.

Unplanned excisions of high-grade soft tissue sarcomas result in increased rates of local recurrence but not disease-specific survival. Patients with unplanned excisions require adequate surgical excision, and irradiation alone or physical therapy cannot accelerate the healing and function in this setting. Soft tissue sarcoma is are often confused with spontaneous hematoma because of the central tumor necrosis and bleeding; therefore a hematologic evaluation in a patient with a soft tissue sarcoma is not warranted.

4. A 55-year-old woman has a soft tissue thigh mass that is isointense with muscle and hyperintense on T2-weighted MR images. Biopsy findings are consistent with a sarcoma. Which of the findings of genetic testing will help determine the definitive pathologic diagnosis of a synovial sarcoma?

A. t(X;18)

B. t(11;22)

C. HMB-45

D. *MDM2* amplification

E. Mutation in the neurofibromin-2 (*NF2*) gene

ANSWER 4: **A.** Amplification of the *MDM2* gene is seen in well-differentiated liposarcoma. Mutation in the *NF2* gene is associated with neurofibromatosis. HMB-45 positivity is seen in malignant melanoma and clear cell sarcoma. t(X;18) is the characteristic translocation in synovial sarcoma. t(11;22) is the characteristic translocation in Ewing sarcoma.

5. A 70-year-old woman with a history of breast cancer has left groin pain with ambulation. Radiographs demonstrate a destructive lesion in her left proximal femur without fracture. A bone scan reveals a solitary lesion in the left femoral neck. Following a thorough history and examination, the best next step is:

A. Referral to radiation oncology for radiotherapy.

B. Surgical prophylaxis.

C. Surgical prophylaxis followed by radiotherapy.

D. Laboratory evaluation (CBC, chemistry panel, urinalysis) followed by surgical prophylaxis.

E. Laboratory evaluation (CBC, chemistry panel, and urinalysis); CT scan of the chest, abdomen, and pelvis; and biopsy of the femoral lesion.

ANSWER 5: **E.** This clinical scenario describes a solitary bone lesion and impending fracture of the proximal femur. In a patient in this age group, the differential diagnosis includes metastatic disease to bone, multiple myeloma, and primary tumors of bone. The presurgical workup has been well described and includes laboratory evaluation (CBC, chemistry panel, and urinalysis); CT scan of the chest, abdomen, and pelvis; and biopsy of the femoral lesion. It is critical that the diagnosis be determined prior to treatment. All other responses are incorrect because they involve treatment without an established diagnosis.

6. What is the most current recommendation for definitive treatment of a 15-year-old boy who has a high-grade osteosarcoma of the distal femur?

A. Surgical resection only

B. Radiation therapy only

C. Radiation therapy and surgical resection

D. Chemotherapy only

E. Chemotherapy and surgical resection

ANSWER 6: **E.** Neoadjuvant chemotherapy has provided many improvements in treatment, including elimination of micrometastastases, necrosis of the primary tumor, reduction of tumor size and neovasculization, and aid in prevention of local recurrences. Complete surgical resection is the mainstay of treatment of osteogenic sarcoma; the addition of neoadjuvant chemotherapy has proved to be the most effective.

7. Lymphoma is distinguished from other small round blue cell tumors by which of the following?

A. *FLI1*

B. Desmin

C. NSE

D. CD45

E. Lambda light chains

ANSWER 7: **D.** The CD45 response is positive in lymphoma. *FLI1* is the fusion protein from the 11;22 chromosomal translocation in Ewing sarcoma. Desmin positivity is seen in rhabdomyosarcoma. NSE positivity is found in neuroblastoma. Lambda light chains are found in myeloma.

8. Which gene is associated with multiple hereditary exostoses?

A. *NF1*

B. *SYT*

C. *EWS*

D. *EXT1*

E. *COL1A*

ANSWER 8: **D.**

NF1 is associated with neurofibromatosis. Synovial sarcoma has an association with *SYT*. Ewing sarcoma is linked to the *EWS* gene. Osteogenesis imperfecta is associated with the *COL1A* gene.

9. A 65-year-old woman sustained a pathologic hip fracture through a femoral neck lesion. She has breast cancer and multifocal metastatic bone disease. In addition to estrogen receptor status, which other pathologic studies will assist the medical oncologist in planning this patient's treatment?

A. HER2/neu receptor status only

B. HER2/neu and VEGF receptor status

C. Progesterone receptor status only

D. Progesterone and HER2/neu receptors

E. Progesterone, VEGF, and HER2/neu receptors

ANSWER 9: **D.** Endocrine therapy and/or chemotherapy is first-line treatment in hormone receptor–positive breast cancer. Endocrine therapies in breast cancer are guided by status of estrogen, progesterone, and HER2 (human epidermal growth factor receptor 2)/neu receptors.

10. Radiography in a 73-year-old woman with a history of nonmetastatic

breast cancer and ambulatory thigh pain for 1 month shows a large subtrochanteric lytic bone lesion. A whole-body bone scan reveals radiotracer uptake localized to the proximal femur. A needle biopsy confirms metastatic breast carcinoma. What is the most appropriate treatment strategy?

A. Irradiation

B. Prophylactic internal fixation

C. Prophylactic internal fixation and irradiation

D. Proximal femur resection

E. Proximal femur resection and irradiation

ANSWER 10: **C.** This patient has a biopsy-proven osseous metastatic form of breast cancer. She has functional pain, and the lytic lesion is located in the subtrochanteric region, putting her at high risk for impending fracture. Therefore, prophylactic fixation is recommended in addition to radiotherapy for local control.

Prophylactic fixation alone does not provide local oncologic control. Without associated radiotherapy, local tumor progression would most likely result in failure of the internal fixation construct. Proximal femur resection would be a reasonable choice in isolated renal cell carcinoma metastasis, which tends to be radioresistant and for which resection has been shown to have an oncologic benefit. However, proximal femur resection is an unnecessarily aggressive surgical procedure in the setting of radiosensitive cancer. Irradiation is an effective strategy for local control of breast cancer but, without internal fixation, would not mitigate the high risk for fracture.

11. The osteoclast-like giant cells in a giant cell tumor express which of the following surface cell receptors?

A. SDF-1

B. OPG

C. RANKL

D. RANK

E. VEGF

ANSWER 11: **D.**

Stromal malignant cells produce RANKL. Giant cells express RANK. Giant cells are responsible for the osteolytic aspect of GCT. Osteoprotegerin (OPG) is a decoy receptor that binds to RANK-L, preventing it from binding to RANK. Stromal-derived factor (SDF) is a chemokine protein ubiquitously expressed. Vascular endothelial growth factor (VEGF) is a potent angiogenic growth factor.

12. A 10-year-old girl with a history of unilateral retinoblastoma presents with increasing pain in the arm. She is otherwise healthy. Images show a

metaphyseal bone-forming lesion. Treatment now consists of which of the following?

A. Amputation

B. Limb sparing surgery with reconstruction

C. Irradiation and chemotherapy

D. Chemotherapy and limb sparing surgery with reconstruction

E. Curettage and bone grafting

ANSWER 12: **D.** Chemotherapy and limb sparing surgery with reconstruction are the treatment for osteosarcoma. Retinoblastoma is a malignant tumor of the eye in children associated with the *Rb1* gene and is mutated in 35% of osteosarcomas.

13. Which of the following does not describe a characteristic of osteoid osteoma?

A. Size is less than 1 cm.

B. Pain is diurnal in nature.

C. Treatment is radiofrequency ablation.

D. Pain is alleviated by NSAIDs.

E. Growth is not self-limited.

ANSWER 13: **E.** The growth of an osteoid osteoma is self-limited and the lesion remains at 1 cm or less. The pain pattern is diurnal and is alleviated by NSAIDs, and the lesion is successfully treated by radiofrequency ablation.

14. Which of the following is the most appropriate treatment of a grade III chondrosarcoma of the scapula?

A. Chemotherapy followed by wide, negative-margin surgery

B. Irradiation followed by wide, negative-margin surgery

C. Chemotherapy and irradiation followed by wide, negative-margin surgery

D. Wide, negative-margin surgery

E. Observation

ANSWER 14: **D.**

Chemotherapy followed by wide, negative margin surgery would be appropriate for osteosarcoma and Ewing sarcoma. Irradiation followed by wide, negative-margin surgery would be appropriate for soft tissue sarcoma. Concurrent chemotherapy and irradiation followed by wide, negative-margin surgery would not be appropriate in the setting of sarcomas, as the combination of chemotherapy and irradiation has a negative synergistic effect. Observation would not be appropriate for a high-grade malignancy.

15. What is the most common site for metastases from synovial sarcoma?

A. Liver

B. Lung

C. Lymph nodes

D. Bone

E. Synovium

ANSWER 15: **B.** As with all sarcomas, metastasis occurs via a hematogenous route, with the lungs being the most common site. Special to synovial sarcoma is its propensity to metastasize to regional lymph nodes, but the most common site remains the lungs. The same is true for epithelioid sarcoma, angiosarcoma, rhabdomyosarcoma, and clear cell sarcoma (ESARC).

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CHAPTER 10

Rehabilitation

Gait, Amputations, Prostheses, Orthoses, and Neurologic Injury

Chan Gao, Gerasimos Bastas, and Nitin Jain

Section 1 Gait

Walking

- Definitions
  - *Walking* describes an energy-efficient process of controlled, reciprocal lower limb movements, used to move the body from one location to another while maintaining upright stability.
  - During walking the motion of the two legs is coordinated so that one supporting foot is in contact with the ground at all times (single-limb support), with a period when both limbs are in contact with the ground (double-limb stance support) (Fig. 10.1).
  - **A *step* is the distance between successive initial contact by the two lower limbs.**
  - ***Stride* is the distance between successive initial contact by the same lower limb.** (Fig. 10.2).
  - ***Velocity* is the ratio of distance to time. *Cadence* defines steps per unit of time.**
  - Running differs from walking in that it precludes double-limb support/stance.
- Phases: normal gait cycle is divided into stance and swing phases (see Fig. 10.1).

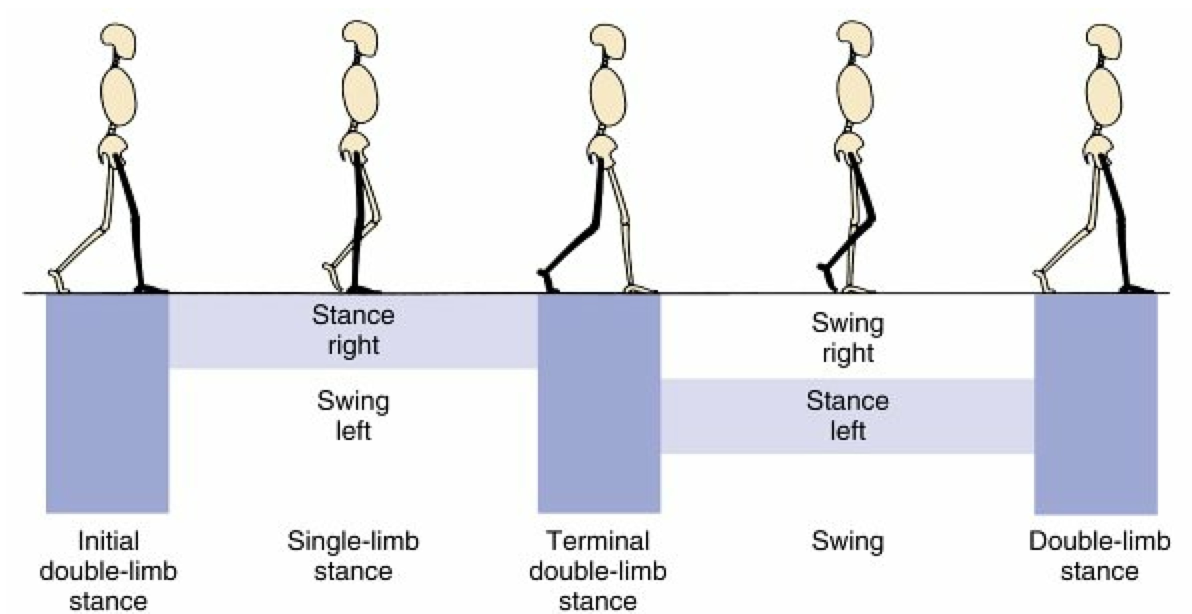


FIG. 10.1 Subdivisions of gait and their relationships to the pattern of bilateral floor contact. Adapted from Perry J: *Gait analysis: normal and pathological function,* New York, 1992, Slack Inc.

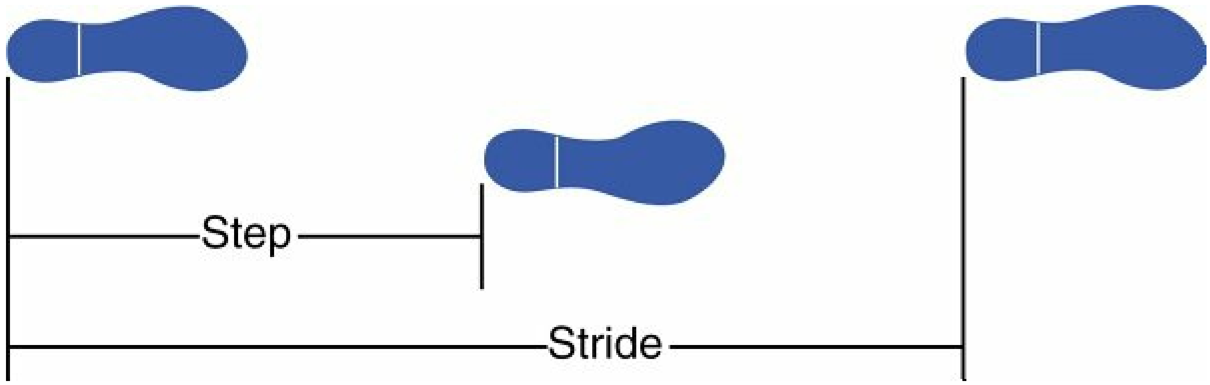


FIG. 10.2 Step versus stride.
Adapted from Perry J: *Gait analysis: normal and pathological function,* New York, 1992, Slack Inc.

- Stance phase occupies 60% of the gait cycle.
  - Initial contact (IC): the instant the reference foot contacts the ground
  - Loading response (LR) starts with initial contact of reference foot and ends with initial swing of the contralateral foot.
  - Midstance (MSt) begins with initial swing (ISw) of the advancing foot and ends when the body's center of gravity is directly over the supporting forefoot.
  - Terminal stance (TSt) begins with heel rise and continues until initial contact of the contralateral (advancing) foot.
  - Preswing (PSw) begins with initial contact of contralateral limb and ends when the stance foot lifts off the ground.
- Swing phase is 40% of the gait cycle.
  - Initial swing (ISw) begins when the reference foot leaves the ground, and ends when the swinging foot is opposite the stance foot.
  - Midswing (MSw) ends when the swinging limb is forward with the tibia perpendicular/vertical to ground.
  - Terminal swing (TSw) spans the period from when the advancing limb's tibia is perpendicular/vertical to ground to when the foot makes initial contact with the ground (Fig. 10.3).
- Important characteristics of gait cycle
  - Normal gait cycle requires stance-phase stability, swing-phase ground clearance, correct position of the foot before initial contact, and energy-efficient step length and speed.
  - There are two periods of double-limb support (during IC + LR and then PSw) ranging between 20% and 30% of the gait cycle. Time spent in these events is velocity dependent.
  - During normal walking, the body's center of gravity is subject to vertical and lateral displacement. Minimizing trunk displacement decreases energy expenditure during bipedal

gait.

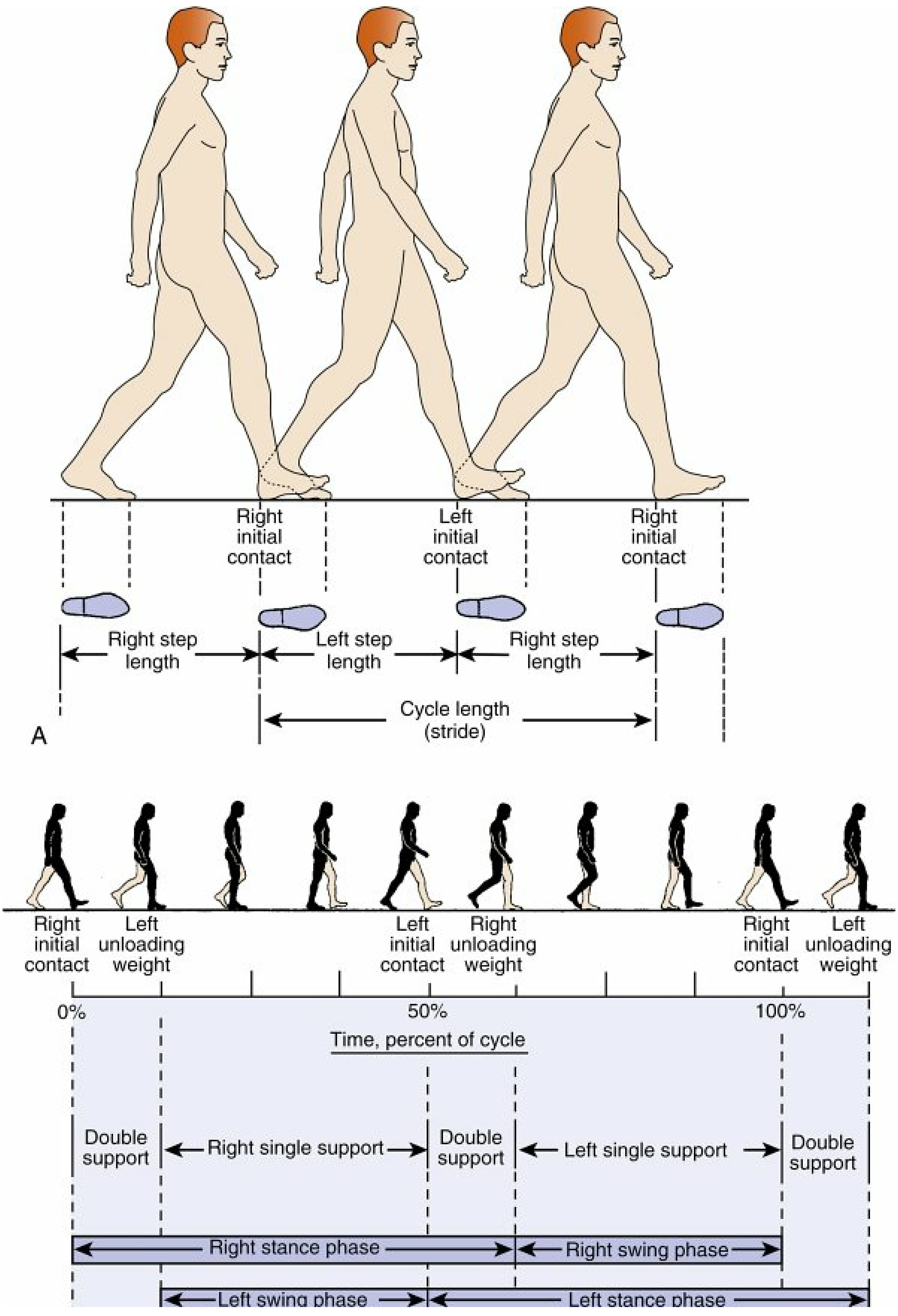
- In the sagittal plane of the body, vertical displacement follows a sinusoidal curve with an amplitude of 5 cm.
- Lateral displacement also follows a sinusoidal curve, with an amplitude of 6 cm.

Gait Dynamics (Fig. 10.4)

- The combined phases of gait contribute to an energy-efficient process by lessening excursion of the center of body mass.
- Head, neck, trunk, and arms account for 70% of body weight.
- The trunk's center of gravity is located just anterior to T10, 33 cm above the hip joints in an average-height (184 cm) individual.
- The entire body's center of mass is 2 cm anterior to S2 and provides a reference for the moment arm to the center of the joint under consideration. The resulting gait pattern resembles a sinusoidal curve.
- The *ground reaction force* (GRF) is the mean loading-bearing vector, which changes in both magnitude and direction throughout the gait cycle. Understanding its dynamic relationship with and through a given joint is crucial to understanding muscle action across the joint in question as well as for the ensemble locomotor strategy (muscle action at other joints). The GRF also determines the rotational potential, known as *moment* or *torque*, that combined forces may exert on a joint.

Determinants of Gait (Motion Patterns)

- Six principal processes have been identified as determinants of gait efficiency, working in concert to minimize vertical and lateral displacements of the center of mass during typical walking. Three occur at the pelvis, and the others involve the knee, ankle, and foot mechanisms.
  - Pelvic rotation: During forward motion, the pelvis externally rotates from IC to onset of PSw, and internally during PSw and swing. This symmetric net rotation minimizes the total vertical plane displacement needed for limb retraction and advancement in swing and stance.


Right
initial
contact
Left
initial
contact
Right
initial
contact
Right step
length
Left step
length
Right step
length
Cycle length
(stride)
A
Right
initial
contact
Left
unloading
weight
Left
initial
contact
Right
unloading
weight
Right
initial
contact
Left
unloading
weight
0%
50%
100%
Time, percent of cycle
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Right swing phase
Left swing phase
Left stance phase

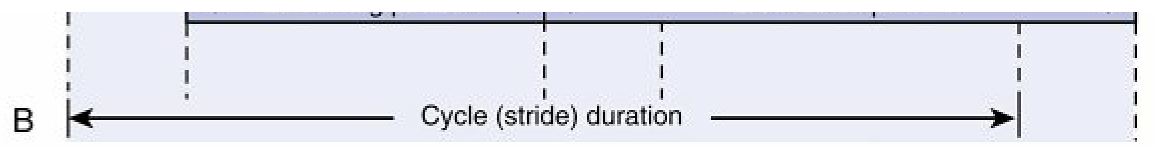
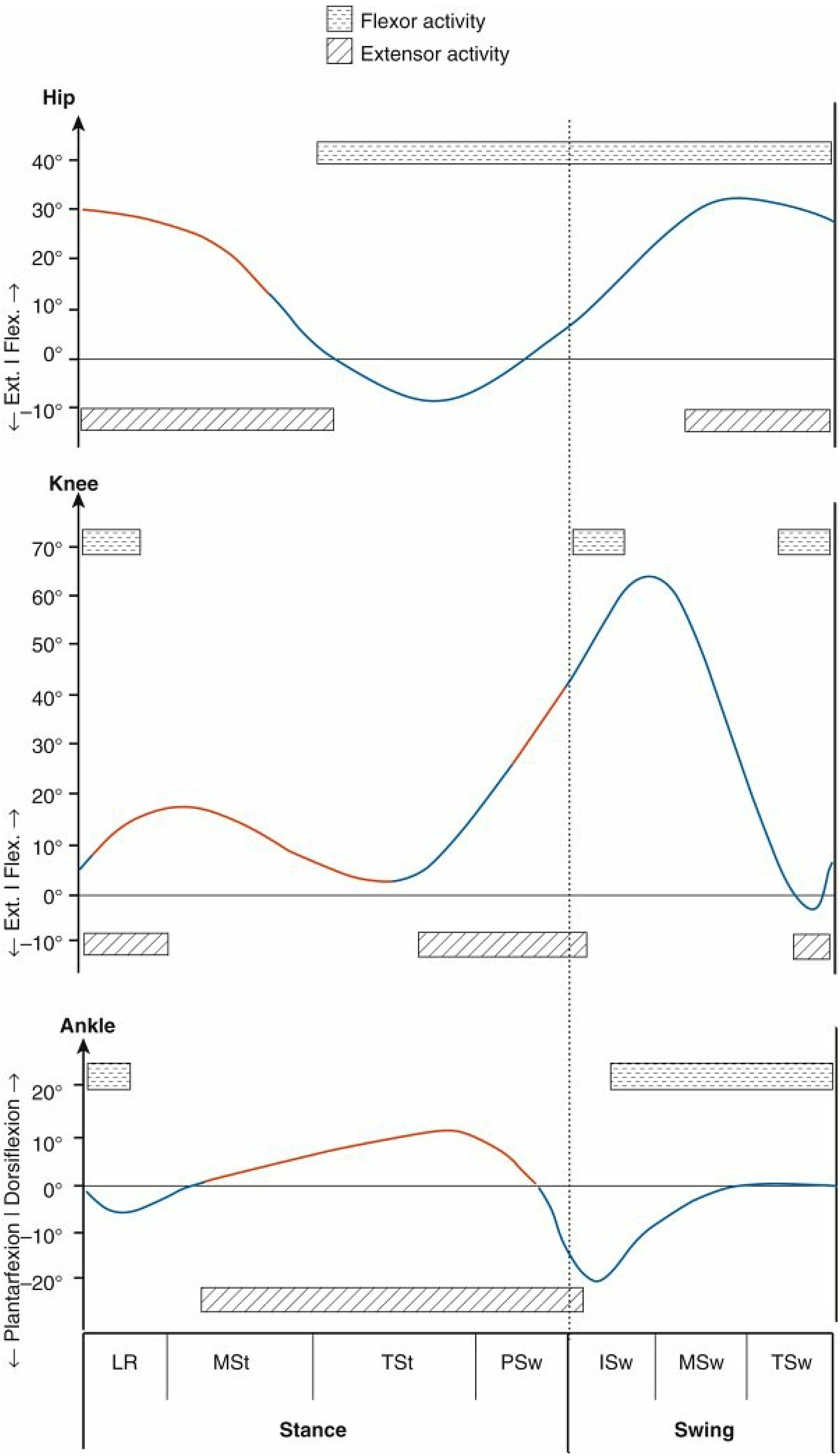


FIG. 10.3 Dimensions of the walking cycle: distance (A) and time (duration) (B).
From Inman VT et al: *Human walking*, Baltimore, 1982, Williams & Wilkins, p 26.

- Pelvic list (tilt): non–weight-bearing contralateral side drops 5 degrees, reducing superior deviation.
- Knee flexion at loading (early knee flexion): stance-phase limb is flexed 15 degrees to dampen the impact of initial loading.
- Foot and ankle motion: through subtalar joint, damping of loading response occurs, leading to stability during midstance and efficiency of propulsion at push-off.
- Knee motion: knee works in concert with foot and ankle to decrease unnecessary limb motion. The knee flexes at IC and extends at midstance.
- Control of pelvic lateral displacement: occurs during weight transfer of body onto the accepting/leading limb. Length of motion is 5 cm over the weight-bearing limb, narrowing the base of support and increasing stance-phase stability.



Flexor activity
Extensor activity
Hip
40°
30°
20°
10°
0°
−10°
← Ext. I Flex. →
Knee
70°
60°
50°
40°
30°
20°
10°
0°
−10°
← Ext. I Flex. →
Ankle
20°
10°
0°
−10°
−20°
← Plantarflexion I Dorsiflexion →
LR
MSt
TSt
PSw
ISw
MSw
TSw
Stance
Swing

FIG. 10.4 Kinetics and kinematics of gait cycle. The curves describe the hip, knee, and ankle joint positions through the gait cycle. The bars above and below the curves highlight the muscle actions across different phases. The red portions of the curves indicate the phases when ground reaction force is located anterior to the hip, posterior to knee, and anterior to the ankle, respectively, in the stance phase.

Muscle Action (see Fig. 10.4)

- Agonist and antagonist muscle groups work in concert during the gait cycle to effectively advance the limb through space.
- Most muscle activity is *e*ccentric, during which a muscle is active while lengthening (aka *e*longation), oftentimes working in concert with an antagonist muscle to control joint and limb segment motion (Table 10.1).
- In isometric contraction, muscle length remains constant during contraction.
- Some muscle activity can be concentric, in which the muscle shortens to move a joint through space.
    - **Hip flexors advance the limb forward during swing phase, and the motion trajectory of the advancing limb is fine tuned by the decelerating action of the hip extensors during terminal swing and before IC.**
    - The anterior tibialis has both eccentric (IC) and concentric (swing) muscle actions during normal gait. **The posterior tibialis inverts the hindfoot and locks the transverse tarsal joints in the terminal stance to facilitate the heel rise and toe-off by the gastrocnemius muscles.**

Table 10.1

Major Muscle Action and Function.

Muscle	Action	Function
Gluteus medius	Eccentric	Controls pelvic tilt (midstance)
Gluteus maximus	Concentric	Powers hip extension
Iliopsoas	Concentric	Powers hip flexion
Hip adductors	Eccentric	Control lateral sway (late stance)
Quadriceps	Eccentric	Stabilizes knee at initial contact and preswing
Hamstrings	Eccentric	Control rate of knee extension at swing
Tibialis anterior	Concentric	Dorsiflexes ankle at swing
	Eccentric [a]	Slows plantar flexion rate during initial contact
Gastrocnemius-soleus	Eccentric	Slows dorsiflexion rate (stance)

[a] Predominant role.

Pathologic Gait

- Factors that lead to abnormal gait include muscle weakness, neurologic conditions, pain, limb deformity, and joint disease (Table 10.2).
    - Muscle weakness or paralysis: decreases ability to control joint movement. Walking strategies develop on the basis of the specific muscle or muscle groups involved and the ability of the individual to execute adaptation—that is, effective substitutions replacing or compensating for deficient muscle action(s).
    - Neurologic conditions: may alter gait by producing muscle weakness, loss of balance, reduced coordination between agonist and antagonist muscle groups (i.e., spasticity), and joint contracture.
        - Hip scissoring is associated with overactive adductors, and knee flexion may be caused by hamstring spasticity or knee extensor weakness.
        - Equinus deformity of the foot and ankle may result in steppage gait (exaggerated knee flexion through swing, to effect clearance for the advancing limb) and hyperextension moment through the knee during stance phase.
    - Pain in a limb: creates an antalgic gait pattern in which the individual shortens stance phase to lessen the time the painful limb is loaded. The contralateral swing phase is more rapid.

Table 10.2

Gait Abnormalities.

Phase of Gait	Abnormalities	Hip	Knee	Ankle/Foot	Alignm
IC	Foot slap			Dorsiflexion weak	
IC–MS	Genu recurvatum		Quadriceps weakness or shortness or spasticity Hamstring weakness (compensated)	Achilles contracture Plantar flexor spasticity	
	Excessive foot supination			Forefoot valgus (compensated) Pes cavus	Short li
	Excessive trunk extension	Hip extensor or flexor weakness Pain	Decreased range of movement		
	Excessive trunk flexion	Gluteus maximus weakness Flexion contracture	Quadriceps weakness		
IC–PSw	Excessive knee flexion (Crouch gait)	Flexion contracture	Hamstring contracture	Increased dorsiflexion Plantar flexor weakness	Long li
	Excessive medial femur rotation		Medial hamstring tightness Opposite muscle weakness Anteverted femur shaft		
	Excessive lateral femur rotation		Lateral hamstrings tightness Opposite muscle weakness Retroverted femur shaft		
	Wide base of support	Abductor contracture	Genu valgus		Discrep Inst
	Narrow base of support	Adductor contracture	Genu varum		

LR–PSw	Excessive trunk lateral flexion	Gluteus medius weakness (ipsilateral) Pain			
	Pelvic drop	Gluteus medius weakness (contralateral)			
	Waddling gait	Gluteus medius weakness (bilateral)			
					Table Co

Phase of Gait	Abnormalities	Hip	Knee	Ankle/Foot	Alignm
MS–PSw	Excessive foot pronation			Valgus deformity of forefoot (uncompensated) Varus deformity of forefoot and hindfoot (compensated) Pes planus Decreased dorsiflexion Tibialis posterior weakness	Fem i (Tibi Lon
	Bouncing			Achilles contracture Plantar flexor spasticity	
	Insufficient push-off			Achilles rupture Plantar flexor weakness Metatarsalgia Hallux rigidus	
	Inadequate hip extension	Flexor contracture Extensor weakness			
Swing	Steppage gait (footdrop)			Dorsiflexion weakness Plantar flexor spasticity Equines deformity	
	Circumduction	Abductor shortening or overuse	Stiffness		Long li

	Hip hiking	Quadratus lumborum shortening	Hamstring weakness Stiffness		Long li

Adapted from Cuccurullo SJ, et al: *Physical medicine and rehabilitation board review*, ed 3, New York, 2015, Demos Medical.

- □ Joint abnormalities: alter gait by changing the range of motion of the affected joint or producing pain.
  - A hip and knee with arthritis may have joint contractures and reduced range of motion.
  - An anterior cruciate–deficient knee has quadriceps-avoidance gait, which represents a decreased quadriceps moment during midstance. The patient compensates with forward flexion of the trunk, plantar flexion of the ankle, and sometimes use of the hand to hyperextend the knee.
- □ Hemiplegia: characterized by prolongation of stance and double-limb support
  - Gait impairment may consist of excessive plantar flexion, weakness, and balance problems.
  - Associated problems are ankle equinus, limitation of knee flexion, and increased hip flexion.
- □ Crutches and canes: devices that ameliorate instability and pain
  - Crutches increase stability by providing two additional load points.
  - A cane helps shift the center of gravity to the affected side when the cane is used in the opposite hand. This shift decreases the joint reaction of the lower limb and reduces the pain. (See Chapter 5, Adult Reconstruction.)
- □ Arthritis: forces across knee may be four to seven times those of the body weight; 70% of load across knee occurs through medial compartment.
- □ Water walking: significant decrease in joint moments and total joint contact forces due to buoyancy

Section 2 Amputations

Introduction

- All or part of a limb may be amputated to treat peripheral vascular disease, trauma, burn, tumor, infection, or a congenital anomaly.
- Should be considered a reconstructive procedure, often performed as an alternative to limb salvage
- An interdisciplinary team approach should be employed to help patient deal with psychologic implications and alteration of body self-image.

Metabolic Cost of Amputee Gait

- Metabolic cost of walking is increased with proximal-level amputations and inversely proportional to length of residual limb and number of functional joints preserved.
- With a proximal amputation, patient has a decreased self-selected maximum walking speed.
- The higher the level of amputation (or the shorter the residual limb), the higher the metabolic demand; thus the transfemoral amputee with peripheral vascular disease may have an obligate doubling of energy expenditure while walking (Table 10.3). (Commonly tested exception to this rule: a Syme amputation is more energy efficient than the more distal midfoot [Chopart] amputation.)
- Of note is that the required increase in energy expenditure for ambulation in bilateral transtibial amputation (40%–50%) is less than that of unilateral transfemoral amputation (65%–75%).

Load Transfer

- Soft tissue acts as an interface between the bone of the residual limb and the prosthetic socket.

Table 10.3

Energy Expenditure for Ambulation.

Amputation Level	Energy Above Baseline Required (%)	Speed (m/min)	O_2 Cost (mL/kg/m)
Long transtibial	10	70	0.17
Average transtibial	25	60	0.20
Short transtibial	40	50	0.20
Bilateral transtibial	41	50	0.20
Transfemoral	65	40	0.28
Wheelchair	0–8	70	0.16

  - ▫ The optimal soft tissue interface is composed of a well-attached mobile mass covering the bone end and full-thickness skin that tolerates the direct pressures within the prosthetic socket.
- ▪ Load transfer (i.e., weight bearing) occurs either directly or indirectly.
  - ▫ Direct load transfer (i.e., terminal weight bearing) occurs in knee (through-knee) or ankle disarticulation (Syme); intimacy of prosthetic socket fit is necessary only for suspension.
  - ▫ Indirect load transfer occurs in transosseous amputation through a long bone (i.e., transfemoral or transtibial). The end of the stump does not take all the weight, and the load is transferred indirectly by the total contact method. The process requires an intimate fit of the prosthetic socket.

Amputation Wound Healing

- ▪ Healing of amputation wounds depends on several factors, including nutrition, adequate immune status, and vascular supply. Transcutaneous partial pressure of oxygen ($TcPO_2$) is the factor most predictive of successful wound healing.
  - ▫ Nutrition and immune status:
    - • Patients with malnutrition or immune deficiency have a high rate of wound failure or infection. A serum albumin level of less than 3.5 g/dL indicates that a patient is malnourished. An absolute lymphocyte count of less than 1500 cells/mm^3 is a sign of immune deficiency.

- If possible, amputation surgery should be delayed in patients with stable gangrene until these values can be improved by nutritional support, usually in the form of oral hyperalimentation.
- In severely affected patients, nasogastric or percutaneous gastric feeding tubes are sometimes essential.
- When infection or severe ischemic pain necessitates urgent surgery, open amputation at the most distal viable level, followed by open-wound management, can be accomplished until wound healing can be optimized.

□ Vascular supply: oxygenated blood is a prerequisite for wound healing, and a hemoglobin concentration of more than 10 g/dL is necessary. Amputation wounds generally heal by collateral flow; thus, arteriography is rarely useful for predicting the success of wound healing.

- Standard Doppler ultrasonography helps measure arterial pressure and has been used as the measure of vascular inflow to predict the success of wound healing in the ischemic limb.
    - An absolute Doppler pressure of 70 mm Hg was originally described as the minimum inflow pressure to support wound healing.
    - The ischemic index is the ratio of the Doppler pressure at the level being tested to the brachial systolic pressure. It is generally accepted that patients require an ischemic index of 0.5 or greater at the surgical level to support wound healing. The ischemic index at the ankle (i.e., the ankle-brachial index) is the most accepted method for assessing adequate inflow to the ischemic limb.
    - In the normal limb, the area under the Doppler waveform tracing is a measure of flow. In at least 15% of patients with diabetes and peripheral vascular disease, those values are falsely elevated and not predictive because of the incompressibility and loss of compliance of calcified peripheral arteries. The ischemic index for toe pressure is more accurate in such patients and, if greater than 0.45, is usually predictive of adequate blood flow.
- $TcPO_2$ is the current gold standard for measurement of vascular inflow. It reflects the oxygen-delivering capacity of

the vascular system to the level of contemplated surgery.

- Values higher than 40 mm Hg (ideally 45 mm Hg) are correlated with acceptable rates of uneventful wound healing, without the false-positive values seen in noncompliant diseased peripheral vascular vessels.
- Values higher than 30 mm Hg are also associated with healing.
- Values lower than 20 mm Hg are predictive of poor healing potential.

Pediatric Amputation

- Pediatric amputations are usually undertaken because of congenital limb deficiencies, trauma, or tumors.
- Congenital limb deficiencies are the result of failure of formation. The most common congenital limb deficiency is left transverse transradial deficiency.
- The International Society for Prosthetics and Orthotics (ISPO) classified limb deficiencies as either longitudinal (with some remaining distal portions) or transverse (without remaining distal portions). The Frantz classification describes limb deficiencies as terminal (complete loss of distal extremity) or intercalary (partial loss of intermediate parts with remaining proximal and distal parts).
- Amputation is rarely indicated in congenital upper limb deficiency; even rudimentary appendages can be functionally useful. In the lower limb, amputation of an unstable segment may allow direct load transfer and enhanced walking (e.g., Syme amputation for fibular hemimelia).
- In a growing child, disarticulations should be performed only when it is possible to maintain maximum residual limb length and prevent terminal bony overgrowth.
    - Such overgrowth usually occurs in the humerus, fibula, tibia, and femur, in that order; it is typical in diaphyseal amputations.
    - Numerous surgical procedures have been described to resolve this problem, but the best method is surgical revision of the residual limb with adequate resection of bone or autogenous osteochondral stump capping (Fig. 10.5).

Amputation After Trauma

- The grading scales for evaluating mangled extremities are not absolute predictors but provide reasonable guidelines for determining whether salvage is appropriate. The extent of soft tissue injury has the greatest impact on the decision-making process. Outcomes following amputation are improved with psychologic counseling and coping mechanisms.

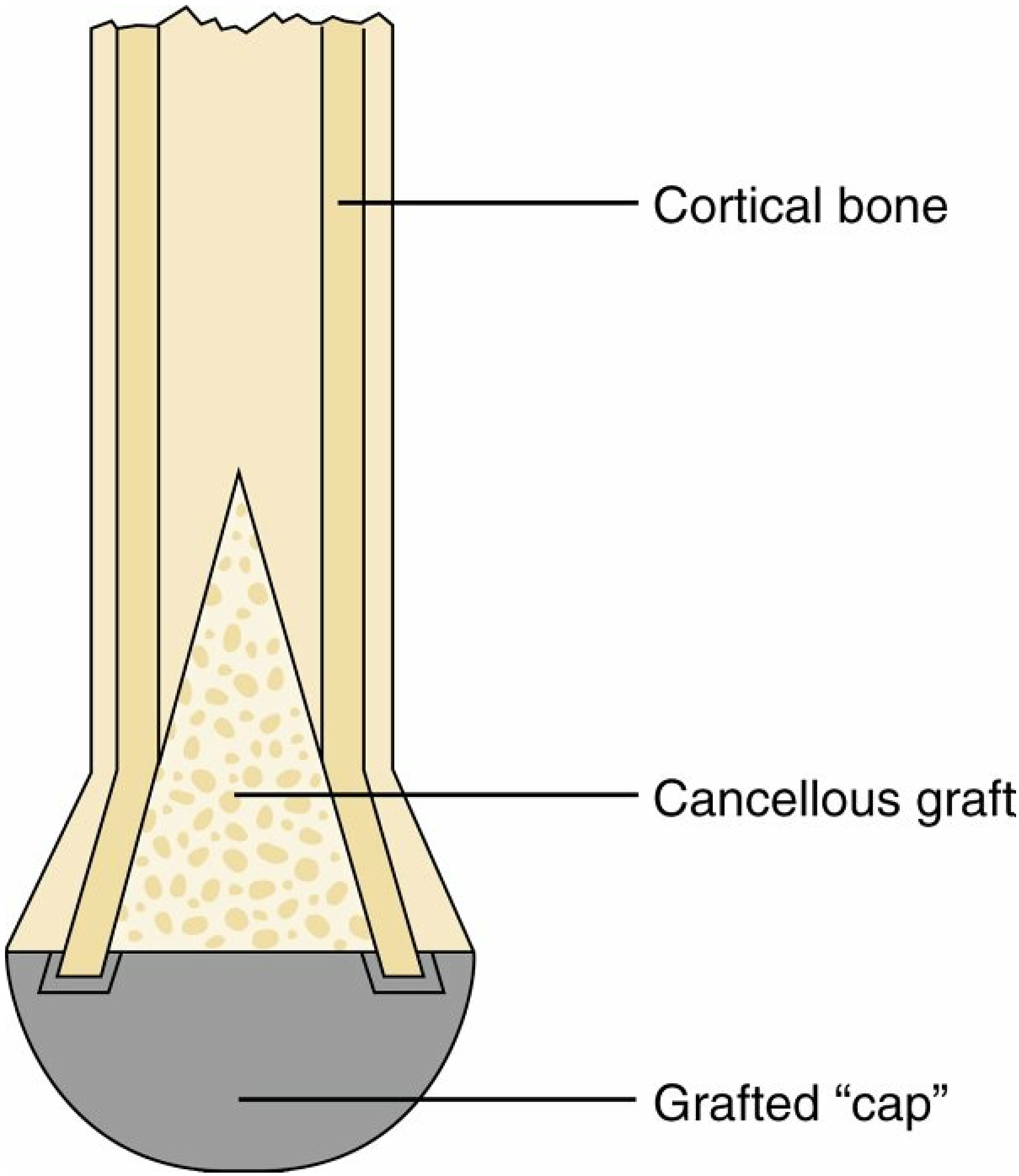


FIG. 10.5 Diagram of the stump-capping procedure. The bone end has been split longitudinally.
Adapted from Bernd L et al: The autologous stump plasty: treatment for bony overgrowth in juvenile amputees, *J Bone Joint Surg Br* 73:203–206, 1991.

□ Indications

- The absolute indication for amputation after trauma is an ischemic limb with a vascular injury that cannot be repaired.
- The guidelines for immediate or early amputation of mangled upper limbs differ from those for mangled lower limbs.
- Early amputation in appropriate scenarios may prevent

emotional, marital, financial, and addiction problems.

- Most grade IIIB and IIIC tibia fractures occur in young men who are laborers and may be more likely to return to gainful employment after amputation and prosthetic fitting.
- Sensation is not as crucial in the lower limb as in the upper limb, and current lower limb prostheses more closely approximate normal function.
- Disadvantages of limb salvage
    - Severe open tibia fractures that are managed by limb salvage rather than amputation are often associated with high rates of mortality and morbidity as a result of infection, increased energy expenditure for ambulation, and decreased potential to return to work.
    - Limb salvage for Gustilo-Anderson grades IIIB and IIIC open fractures of the tibia and fibula generally has poor functional outcomes and multiple complications, and many surgical procedures may be needed.
    - The salvaged lower extremity with an insensate plantar weight-bearing surface (loss of posterior tibial nerve), with associated major functional muscle and bone loss, is unlikely to provide a durable limb for stable walking and is a potential source of early or late sepsis.

□ Contraindications

- Upper limb
    - When a salvaged upper limb remains sensate and has prehensile function, it will often function better than an amputated limb with prosthetic replacement.
    - Maintaining as much length as possible is the key to subsequent prosthetic use.
- Lower limb
    - Lack of plantar sensation is not an absolute indication to amputate, because it may result from neurapraxia, which has been shown to resolve over long-term follow-up.
    - In the absence of other major factors, amputation should not be performed.

Risk Factors

- Cognitive deficits
    - Prosthetic device candidacy requires that patients have the ability to care for the limb residua and prostheses; they must be able to learn new tasks (relating to proper prosthesis use/maintenance, hygienic practices, troubleshooting dysfunctions and discomfort, and triaging changes to residuum appearance).
        - Patients with cognitive deficits may need to have other caretakers actively involved to ensure safe and meaningful prosthetic enablement.
- Diabetes
    - A majority of patients who undergo amputation are diabetic with relative immunodeficiency.
    - The most important risk factors in amputation in diabetic patients are the presence of peripheral neuropathy and development of deformity and infection.
- Peripheral vascular disease
    - Most of the other patients who undergo amputation are malnourished patients with peripheral vascular disease of sufficient magnitude to necessitate amputation, and their coronary and cerebral arteries are diseased.
    - Appropriate consultation with physiatry, physical therapy, social work, and psychiatry departments is important to determine rehabilitation potential.
    - Medical consultation helps determine cardiopulmonary reserve. The vascular surgeon should determine whether vascular reconstruction is feasible or appropriate.
    - The biologic amputation level is the most distal functional amputation level with a high probability of supporting wound healing.
        - This level is characterized by the presence of adequate viable local tissue to construct a residual limb capable of supporting weight bearing, an adequate vascular inflow, and serum albumin level and a total lymphocyte count sufficient to aid surgical wound healing.
        - Selection of an appropriate amputation level is determined by combination of the biologic amputation level with the rehabilitation potential in order to choose the level that maximizes ultimate functional independence.
        - Morbidity and mortality rates have remained unchanged for several decades; 30% of patients with peripheral vascular disease die in the first 3 months after amputation, and nearly 50% die within the first year.

Musculoskeletal Tumors

- Goal of surgery: to remove the tumor with clear surgical margins
- Amputation versus limb salvage
  - Advances in chemotherapy, radiotherapy, and allograft or prosthetic reconstruction have made limb salvage a viable option in extremity sarcomas.
  - If adequate margins can be achieved with limb salvage, the decision can then be based on expected functional outcome.
  - Limb salvage has superior cosmetic outcome but, in comparison to amputation, it has higher rates of postoperative complications, including infection, aseptic loosening, and graft or prosthetic failure.
  - The advantage of limb salvage over amputation—with regard to energy expenditure to ambulate, quality-of-life measures, and function with activities of daily living—is controversial in the literature.
  - Expected functional outcome should include the psychosocial and body image values associated with limb salvage.
    - These concerns should be balanced with improved task performance and lesser concern for late mechanical injury associated with amputation and fitting of prosthetic limbs.

Technical Considerations

- Skin flaps should be of full thickness, and dissection between tissue planes should be avoided. Wounds should not be sutured under tension.
- Periosteal stripping should be sufficient to allow for bone transection; this principle minimizes regenerative bony overgrowth.
- Two main approaches entail securing transected muscles either (1) directly to the distal end of a long transected bone at resting tension (myodesis) or (2) to antagonist muscles (myoplasty) across fascial layers. Myodesis may afford better control of a long residual transected bone, within a socket; however, it should be employed only in patients whose microcirculation is sufficient to sustain soft tissue viability at the anchoring points.
- All transected nerves variably form neuromas. These need not become symptomatic or distressing to the patient if nerve ends come to lie deep in a soft tissue envelope, away from externally transmitted pressures (i.e., with residuum manipulation or during socket wear and use). Crushing of peripheral nerves may contribute to postoperative phantom or limb pain.
- Surgical technique is related to development of heterotopic ossification in residual limbs.
- Rigid (postoperative) dressings help reduce swelling, decrease pain, and protect the residuum from trauma.

Complications

- Phantom limb sensation—the feeling that all or part of the amputated limb is present—may include formication, numbness, tingling, heaviness, and nondistressing sensations of coolness or slight burning. It occurs intermittently in almost all adults who have undergone amputation and it usually decreases with time following appropriate desensitization and regular prosthesis use.
- Pain
    - Phantom pain is a distressingly painful sensation in the limb segment that has been removed. Success in symptom relief has been reported with consistent prosthesis use, physical therapy, compression, mirror therapy, and transcutaneous nerve stimulation.
    - Common causes of neuropathic residual pain include neuroma, entrapment of nerve endings by scar tissue, and complex regional pain syndrome (CRPS) or causalgia. Amputation should not be performed for CRPS.
    - Localized somatic pain can be mechanical, occurring from poor trimming of bone or suturing of soft tissues; similarly, bony overgrowth in children can cause residual limb pain.
    - Other common sources of somatic pain are infection, inflammation, ischemia, heterotopic ossification (HO), and arthritis.
    - Pain referred to the limb occurs in a high number of cases.
- Edema
    - Postoperative edema occurs after amputation. It may impede wound healing and place significant tension on the tissues.
    - Rigid dressings and soft compression help reduce the edema.
    - Swelling occurring after stump maturation is usually caused by poor socket fit, medical problems, or trauma.
    - The ideal shape of upper limb and transtibial residua is cylindrical. Transfemoral residual limb is ideally conical.
    - Lack of distal (total) contact in a socket, due to proximal constriction, can result in negative pressure, impaired venous and lymphatic outflow, chronic lymphedema, and formation of verrucous plaque hyperplasia, with risk of secondary ulceration and infection. Verrucous plaques do not require harsh chemical, biochemical, or mechanical débridement and are reversible when total contact with the socket is restored; they may also be treated by a total-contact cast, which is changed regularly to accommodate the reduced edema.
- Joint contractures
    - These complications are usually noted as hip abduction and flexion contractures and knee flexion contractures, which can be produced at the time of surgery by anchoring of the respective muscles with the joints in a flexed position or, more importantly, postoperatively by

improper positioning and resultant mechanical imbalance.

- They can be avoided by correct positioning of the amputated limb. The transtibial amputee should have the knee fully extended (elevated leg rest on a wheelchair, avoidance of pillow under the knee, etc., should be considered). Similarly, the transfemoral amputee should avoid putting a pillow under the stump or between the legs; such a patient would benefit from a pillow applied laterally to control hip abduction and/or from a sandbag placed atop the residuum to keep a neutral position. Early education on contracture avoidance positioning and stretching exercises is important.

- Skin problems
  - Common skin issues after amputation are wound failure to heal, skin irritation, allergic contact dermatitis, ulcers, bursa, inclusion cyst, verrucous hyperplasia, and calluses.
  - Wound failure to heal occurs most often in patients with diabetes and those with vascular disease. If the wound is not amenable to local care, wedge excision of soft tissue and bone, with closure and without tension, is the preferred treatment.

Upper Limb Amputations (Fig. 10.6)

- Hand amputation
  - Transphalangeal, transmetacarpal, or transcarpal
  - Thumb opposition is the most important component of hand function.
    - Thumb reconstruction procedures include phalangization (deepening the web space to provide more mobile digits) and pollicization (moving a finger with its nerve and vessels to the site of an amputated thumb).

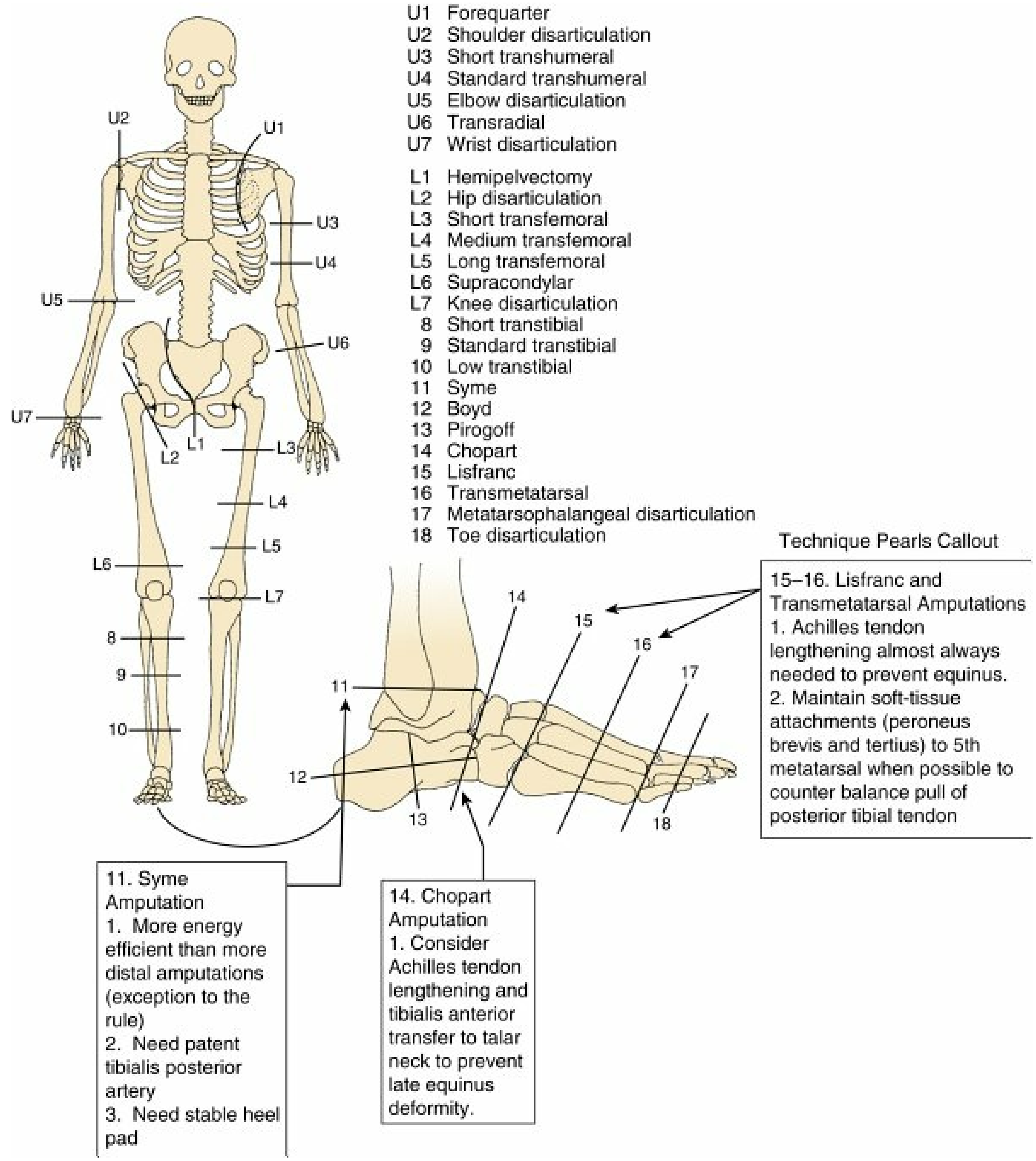


FIG. 10.6 Composite illustration of common amputation levels.

- Wrist disarticulation
  - Advantages
    - Wrist disarticulation has two advantages over transradial amputation.
      - Preservation of full elbow motion and forearm rotation because of preservation of the distal radioulnar joint
      - Improved prosthetic suspension because of the flare of the distal radius
    - Effective function can be obtained at this level of amputation. Forearm rotation and strength are directly related to the length of the transradial (below-elbow) residual limb.
  - Disadvantages

        - Wrist disarticulation provides challenges to the prosthetist that may outweigh its benefits.
        - Cosmetic disadvantage
            - Prosthetic limb is longer than contralateral limb.
            - If myoelectric components are used, the motor and battery cannot be hidden within the prosthetic shank.
- Transradial amputation or elbow disarticulation
    - Complete brachial plexus injury and a nonfunctioning hand and forearm may be best treated by a transradial amputation or elbow disarticulation, which can be fitted with a prosthesis.
    - The length of residual limb is a major determinant of the strength of elbow flexion, the preservation of forearm rotation, and the degree of elbow and humerus needed for suspension. The optimal length of the residual limb is at the junction of the middle and distal thirds of the forearm, where the soft tissue envelope can be repaired by myodesis and the components of a myoelectric prosthesis can be hidden within the prosthetic shank.
    - Because the patient can maintain prosthetic function at this level only by being able to open and close the terminal device, retention of the elbow joint is essential.
    - Krukenberg amputation converts the ulna and radius into digits to provide prehensile function.
    - The length and shape of elbow disarticulation provides better suspension and lever-arm capacity than transradial amputation. To enhance suspension and reduce the need for shoulder harnessing, a 45- to 60-degree distal humeral osteotomy is performed.
    - Elbow disarticulation is recommended for growing children to preserve the epiphyseal plate and avoid bony overgrowth.
    - Elbow disarticulation poses prosthetic fitting challenges that result in a limb that is bulkier and longer than the sound limb.
    - Gangrene of the upper limb, when it is not due to Raynaud or Buerger disease, represents end-stage disease, especially in diabetic patients. Such patients usually do not survive beyond 24 months.
        - Localized finger amputations in these patients are unlikely to heal. When surgery becomes necessary, amputation should be performed at the transradial level to achieve wound healing during the final months of the patient's life.

Lower Limb Amputations (see Fig. 10.6)

- Toe and ray amputations

  - Patients with ischemia generally ambulate with a propulsive gait pattern, so they suffer little disability from toe amputation.
  - Patients with traumatic amputations lose some stability after toe amputation in the late-stance phase.
  - The great toe should be amputated distal to the insertion of the flexor hallucis brevis.
  - Isolated second-toe amputation should be performed just distal to the proximal phalanx metaphyseal flare, leaving the stump to act as a buttress and prevent late hallux valgus.
  - Patients who undergo single outer (first or fifth) ray resections function well in standard shoes.
  - Resection of more than one ray leaves the forefoot narrow, which is difficult to fit in shoes and often results in a late equinus deformity.
  - Central ray resections are complicated by prolonged wound healing and rarely achieve better results than midfoot amputation.
- Transmetatarsal and Lisfranc tarsal-metatarsal amputations
  - There is little functional difference in outcome between these two procedures. The long plantar flap acts as a myocutaneous flap and is preferred to fish-mouth dorsal-plantar flaps.
  - Transmetatarsal amputation should be performed through the proximal metaphyses to prevent late plantar pressure ulcers under the residual bone ends.
  - Percutaneous Achilles tendon lengthening should be performed with transmetatarsal and Lisfranc amputations to prevent late development of equinus or equinovarus deformity.
  - Late varus deformity can be corrected with transfer of the tibialis anterior tendon to the neck of the talus.
    - The second tarsometarsal joint should be osteotomized to preserve midfoot stability.
    - The soft tissue at the fifth metatarsal base should be preserved because it represents the insertion site of the peroneus brevis and tertius muscles, which act as antagonists to the posterior tibial tendon.
      - Failure to preserve these tissues results in inversion during gait.
  - Some writers have reported reasonable functional outcomes with hindfoot amputation (i.e., Chopart or Boyd amputation), but most experts recommend avoiding amputation at these levels if possible in patients with diabetes or vascular disease.
  - Although children have been reported to function reasonably well with transmetatarsal amputation alone, adults retain an inadequate lever arm and are prone to experience fixed equinus deformity of the heel if Achilles tendon lengthening and tibialis anterior tendon transfer are

not also performed.

- Ankle disarticulation (Syme amputation)
    - Often performed for forefoot trauma, this amputation allows direct load transfer and possible short-distance ambulation without a prosthesis. It is rarely complicated by late residual limb ulcers or tissue breakdown.
    - It provides a stable gait pattern that rarely necessitates prosthetic gait training after surgery.
    - The outcome is more energy efficient than that of a midfoot amputation, despite the fact that it is a more proximal level **(commonly tested exception to the rule of energy efficiency and amputations).**
    - Surgery should be performed in one stage, even in ischemic limbs with insensate heel pads.
    - The posterior tibial artery must be patent to ensure healing.
    - The malleoli and metaphyseal flares should be removed from the tibia and fibula, but the remaining tibial articular surface should be retained to provide a resilient residual limb.
    - The heel pad should be secured to the tibia either anteriorly through drill holes or posteriorly by securing the Achilles tendon.
- Transtibial (below-knee) amputation
    - A long posterior myocutaneous flap is the preferred method of creating a soft tissue envelope, especially in patients with vascular disease, inasmuch as the direction of blood flow is from posterior to anterior.
    - The optimum bone length is at least 12 cm below the knee joint or longer if adequate amounts of the gastrocnemius or soleus muscle can be used to construct a durable soft tissue envelope.
    - The posterior muscle should be secured to the beveled anterior tibia by myodesis.
    - Rigid dressings are preferred during the early postoperative period, and early prosthetic fitting may be started, 5–21 days after surgery, if the residual limb is capable of transferring load and if the patient has a satisfactory physical reserve.
- Knee disarticulation (through-knee amputation)
    - The current technique involves the use of a long posterior flap, with the gastrocnemius muscle as end padding.
    - The alternative is to use sagittal skin flaps and cover the end of the femur with the gastrocnemius muscle to act as a soft tissue envelope end pad.
    - The Mazet technique involves partial removal of the femoral condyles, an effective myodesis for the adductors as well as anterior and posterior compartment muscles, and appropriation of a partial patella in the intercondylar groove. The resultant residuum shape does not

pose a challenge to fit, because it lacks the distal bulkiness/flaring otherwise present due to retained femoral condyles.

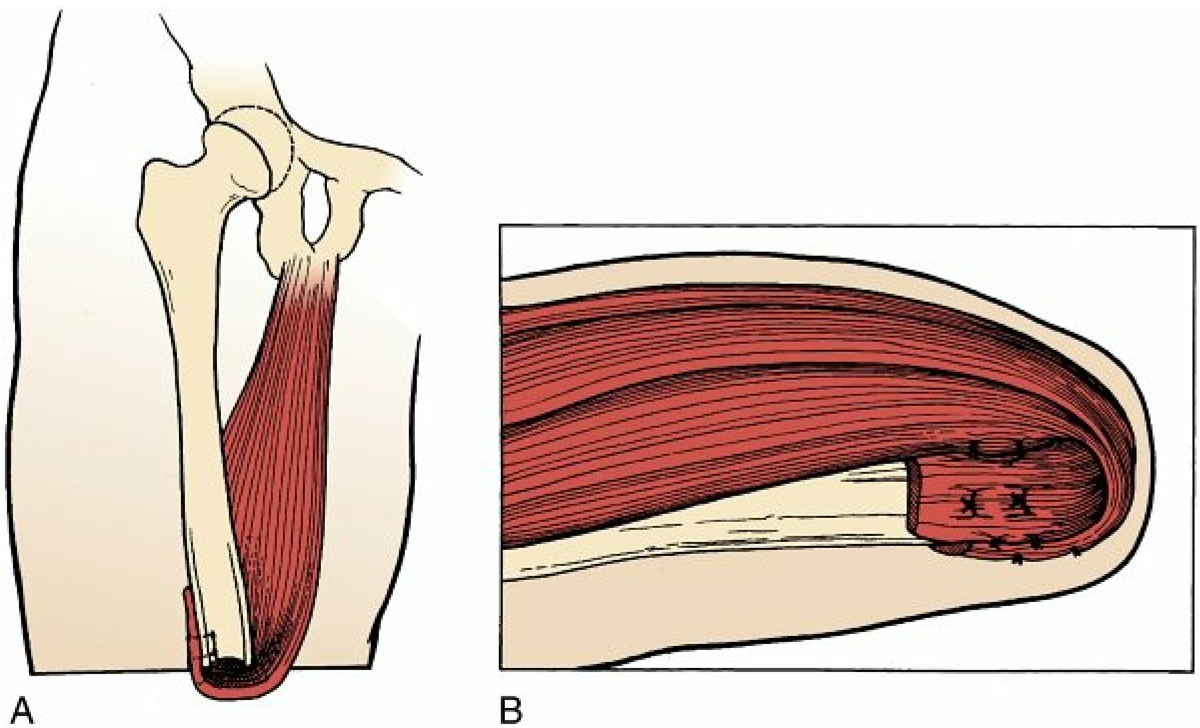


FIG. 10.7 (A) Diagram showing attachment of the adductor magnus to the lateral part of the femur. (B) Diagram depicting attachment of the quadriceps over the adductor magnus.
From Gottschalk F: Transfemoral amputation. In Bowker J, Michael J, editors: *Atlas of limb prosthetics*, St. Louis, 1992, Mosby–Year Book, pp 479–486.

- ▫ The patellar tendon is sutured to the cruciate ligaments in the notch, leaving the patella on the anterior femur.
    - This level is generally used in nonambulatory patients who can support wound healing at the transtibial or distal level.
    - Data from the Lower Extremity Assessment Project (LEAP) study have demonstrated that knee disarticulations result in the slowest walking speed and produce the least self-reported satisfaction.
- ▫ Knee disarticulation is muscle balanced and provides an excellent weight-bearing platform for sitting and a lever arm for bed-to-chair transfer. When this type of amputation is performed in a potential walker, it provides a residual limb for direct bed-to-chair transfer (end bearing).

▪ Transfemoral (above-knee) amputation

- ▫ This form of amputation increases the energy cost for walking.
- ▫ Patients with transfemoral amputations who have peripheral vascular disease are unlikely to become efficient walkers; thus salvaging the limb at the knee disarticulation (transtibial level) is crucial for maintaining functional walking independence.
- ▫ With greater femoral length, the lever arm, suspension, and limb

advancement are optimized. The optimum transfemoral bone length is 12 cm above the knee joint to accommodate the prosthetic knee.

- Adductor myodesis is important for maintaining femoral adduction during the stance phase to allow optimal prosthetic function (Fig. 10.7).
- The major deforming force is toward abduction and flexion. Adductor myodesis at normal muscle tension eliminates the problem of adductor roll in the groin. Transecting the adductor magnus results in a loss of 70% of the adductor pull (Fig. 10.8).
- Rigid dressings are difficult to apply and maintain at this level. Elastic compression dressings are used and may be suspended about the opposite iliac crest.

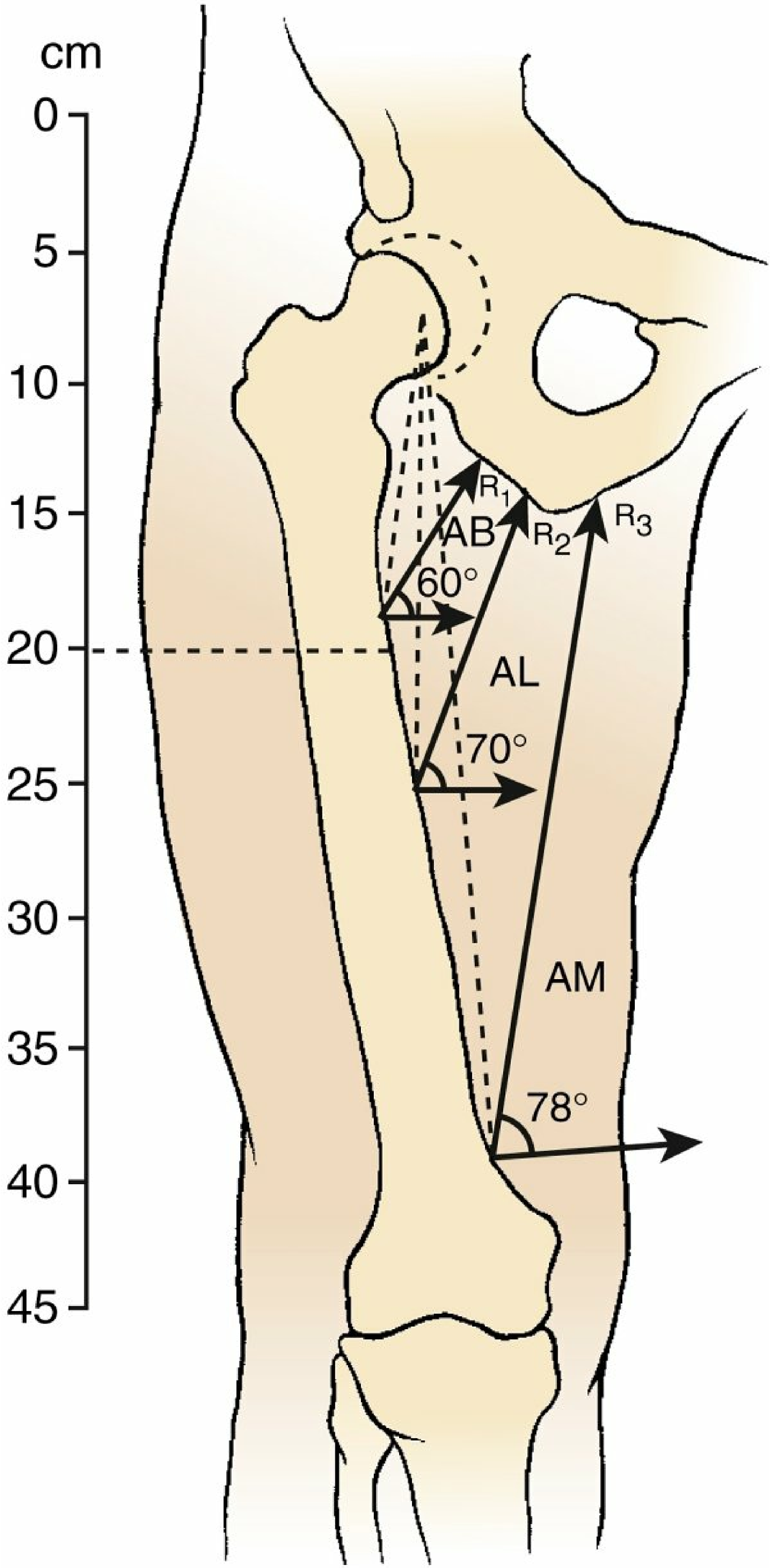

cm
0
5
10
15
20
25
30
35
40
45
R1
AB
R2
R3
60°
AL
70°
AM
78°

FIG. 10.8 Diagram of moment arms of the three adductor muscles *(R1, R2, and R3)*. Loss of the distal attachment of the adductor magnus *(AM)* will result in a loss of 70% of the adductor pull. *AB,* Adductor brevis; *AL,* adductor longus.
From Gottschalk FA et al: Does socket configuration influence the position of the femur in above-knee amputation? *J Prosthet Orthot* 2:94–102, 1989.

- Hip disarticulation
  - This procedure is infrequently performed, and of the patients who undergo this amputation, only a few make meaningful use of prostheses because of the high energy requirements of walking.
  - Patients who have suffered trauma or who have tumors occasionally use the prostheses for limited activity. These patients sit in their prostheses and must use the torso to achieve momentum for “throwing” the limb forward to advance it.

Section 3 Prostheses

Upper Limb

- Upper limb biomechanics
  - The shoulder provides the center of the radius of the functional sphere of the upper limb, and the range of motion of the shoulder dictates the functional placement and reach for the entire upper limb. The elbow acts as the caliper to position the hand for performing its tasks.
  - In a typical arm, tasks performed with the use of multiple joint segments usually occur simultaneously, whereas upper limb prostheses perform these same tasks sequentially; thus salvage of the joint and residual limb length are directly correlated with functional outcome.
  - Motion at the retained joints is essential for maximizing function.
  - Residual limb length is important for suspending the prosthetic socket and providing the lever arm necessary to “drive” the prosthesis through space.
- Benefit of limb salvage
  - Limb salvage is more important for the upper limb, where sensation is crucial for function.
- Timing of prosthetic fitting
  - Prosthetic fitting should be undertaken reasonably soon after amputation.
  - Prosthesis fitting for congenital limb deficiency should follow attainment of normal developmental milestones. The first fitting for transradial deficiency occurs at the age of 6–7 months, when the child achieves sitting balance; however, slightly delayed progression is recommended for transhumeral deficiency.
- Types of prostheses for different levels of amputation
  - Midlength transradial amputation
    - Myoelectric prostheses provide good cosmesis and are used for sedentary work. They can be used in any position, including overhead activity, and are the most successful for patients with midlength transradial amputations, for whom only the terminal devices need to be activated.
    - Body-powered prostheses are advantageous in providing sensory feedback and are used for heavy labor. The terminal devices are activated by shoulder flexion and abduction. For optimal mechanical efficiency of a figure-of-eight harness, the harness ring must be at the spinous process of C7 and slightly to the nonamputated side.
  - Elbow disarticulation and transhumeral (above-elbow) amputations

        - When the residual forearm is too short to function as an adequate lever arm for driving a prosthesis through space, supracondylar suspension (Munster socket) and step-up hinges can be used to augment function.
        - In elbow disarticulation and transhumeral (above-elbow) amputations, two control cables are needed to complete the process of prehension; thus these levels of amputation have significantly less efficient outcomes, and the prostheses are heavier than those for amputation at the transradial level.
            - One cable controls elbow flexion and terminal device by using shoulder flexion and abduction, whereas the other one locks and unlocks the elbow by using simultaneous shoulder depression, abduction, and extension.
        - The best function with the least weight at the lowest cost is provided by hybrid prosthetic systems, in which myoelectric, traditional body-powered, and body-driven switch components are combined; for example, a hybrid prosthesis consisting of a body-powered prosthetic elbow and an myoelectric terminal device.
    - Proximal transhumeral and shoulder disarticulation amputations
        - When the lever-arm capacity of the humerus is lost in proximal transhumeral (proximal to the deltoid insertion) or shoulder disarticulation amputations, limited function can be achieved with a manual universal shoulder joint positioned with the opposite hand and combined with lightweight hybrid prosthetic components.

Lower Limb

- Medicare functional classification level (MFCL) provides recommendations on prosthesis prescription (Table 10.4).
- The designs commonly used are nonarticulated, articulated, energy-storing/dynamic-resposne, and microprocessor-controlled prosthetic feet.
    - Articulated foot
        - Single-axis foot
            - Based on an ankle hinge that provides dorsiflexion and plantar flexion
            - Disadvantages include poor durability and cosmesis.
        - Multiaxial foot
            - Based on mechanical joints and flexible keel that

allow motion in all three planes

- □ Nonarticulated foot
  - Solid-ankle, cushioned-heel (SACH) foot
    - This has been the standard for decades and was appropriate for general use in patients with low levels of activity.
    - It may lead to overload problems on the nonamputated foot but is still used for the patients with K1 functional level in many developing countries because of cost-effectiveness and
  - Solid-ankle, flexible endoskeletal (SAFE) foot
    - Allows some inversion and eversion through the flexible keel with greater accommodation to uneven surface
  - Dynamic-response/energy-storing foot
    - Selection of the correct dynamic prosthetic foot depends on patient's height, weight, activity level, access for maintenance, cosmesis, and funding.
    - The dynamic-response foot prostheses, including the Seattle foot, Carbon Copy II/III, and Flex Foot, allow amputees to undertake most normal activities (Fig. 10.9).
    - Dynamic-response foot prostheses may be grouped into articulated and nonarticulated.

FIG. 10.9 (A) Flex Foot with carbon-fiber leaf and posterior projection of the keel for heel strike. (B) Flex Foot with split-toe configuration and leaf spring design.
Courtesy Flex Foot, Inc, Aliso Viejo, California.

Table 10.4

Medicare Functional Classification Levels.

Functional Level	Definition	Mobility with Prosthesis	Cadence	Prosthesis Recommendati
K0	This patient does not have the ability or potential to ambulate or transfer safely with or without assistance and a prosthesis does not enhance their quality of life	This patient does not have the ability or potential to ambulate or transfer safely with or without assistance and a prosthesis does not	NA	For cosmetic pu

	or mobility.	enhance their quality of life or mobility.		
K1	This patient has the ability or potential to use a prosthesis for transfers or ambulation on level surfaces at fixed cadence—a typical limited or unlimited household ambulator.	Household distance; level surfaces	Fixed	Feet: SACH, axis Knees: manu locking, activated control
K2	This patient has the ability or potential for ambulation with the ability to traverse low-level environmental barriers such as curbs, stairs, or uneven surfaces—a typical community ambulator.	Limited community distances; low-level barriers	Fixed	Feet: multia flexible k Knees: weig activated control
K3	The patient has the ability or potential for ambulation with variable cadence—a typical community ambulator with the ability to traverse most environmental barriers—and	Unlimited community distances; most barriers	Variable	Feet: multia energy-s Knees: hydr pneuma micropro controlle

	may have vocational, therapeutic, or exercise activity that demands prosthetic use beyond simple locomotion.			
K4	The patient has the ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels—typical of the prosthetic demands of the child, active adult, or athlete.	Unlimited community distances; most barriers; high-impact and high-endurance activities	Variable	Same as K3. Additional a specific compone may incl • Feet: energ storing r blades, climbing adapters, • Knees: spo specific c vocationa specific mechani

- Articulated dynamic-response foot
  - Allows inversion/eversion and rotation of the foot and is useful for activities on uneven surfaces
  - May absorb loads and decrease shear forces to the residual limb
  - Most dynamic-response feet have a flexible keel and are the standard for general use (Fig. 10.10). The keel deforms under load, becoming a spring and allowing dorsiflexion, thereby

        - decreasing load on the normal side and providing a springlike response for push-off.
        - Posterior projection of the keel provides a response at heel strike for smooth transition through the stance phase. A sagittal split allows for moderate inversion or eversion.
      - Nonarticulated dynamic-response foot
        - This prosthesis can have a short or long keel. Shortened keels are not as responsive and are indicated for the moderate-activity ambulator, whereas long keels are for very high-demand activities.
        - Separate prosthetic feet for running and lower-demand activities may be indicated.
    - Microprocessor-controlled foot
      - Internal power generation produces ankle dorsiflexion and plantar flexion to facilitate ambulation uphill.
      - These are heavy and require frequent charging as well as protection from wet environments.
- Prosthetic shanks
  - Prosthetic shanks provide the structural link between or among prosthetic components.
  - Two varieties exist: endoskeletal, with a soft exterior and load-bearing tubing inside (the most common), and exoskeletal, with a hard load-bearing exterior shell.
  - Rotator units are sometimes added for patients involved in twisting activities (e.g., golf) or for sitting.
- Prosthetic knees (Table 10.5)
  - Prosthetic knees provide controlled knee motion in the prosthesis.

- These components are used in transfemoral amputation and knee disarticulation and are chosen on the basis of the patient's needs.
- Alignment stability (position of the prosthetic knee in relation to the patient's line of weight bearing) is important in the design and fitting of prosthetic knees. Placing the knee center of rotation posterior to the line of GRF allows control in the stance phase but makes flexion difficult. Alternatively, with the knee center of rotation placed anterior to the line of GRF, flexion is made easier but at the expense of control. Only the polycentric knee component offers the possibility of both options by having a variable center of rotation.
- Several types of prosthetic knees are available:
    - Polycentric (four-bar linkage) knee (Fig. 10.11B): has a moving instant center of rotation that provides for different stability characteristics during the gait cycle and may allow increased flexion for sitting. It is recommended for patients with transfemoral amputations, those with knee disarticulations, and those with bilateral amputations.

FIG. 10.10 Ceterus prosthetic foot with leaf spring and shock absorber.
Courtesy Ossur Americas, Aliso Viejo, California.

    - Stance-phase control (weight-activated [safety]) knee (see Fig. 10.11A): functions like a constant-friction knee during the swing phase but "freezes" by application of high-friction housing when weight is applied to the limb. Its use is reserved primarily for older patients, those with very proximal amputations, and those walking on uneven terrain.

- Fluid-control (hydraulic and pneumatic) knee: allows adjustment of cadence response by changing resistance to knee flexion by means of a piston mechanism. The design prevents excessive flexion and is extended earlier in the gait cycle, allowing a more fluid gait. The knee is best used in active patients who prefer greater utility and variability at the expense of more weight.
- Constant-friction knee: essentially a hinge designed to dampen knee swing by means of a screw or rubber pad that applies friction to the knee bolt. It is designed for general utility and may be used on uneven terrain. It is the most common knee prosthesis for children. Its major disadvantages are that it allows only single-speed walking and that it relies solely on alignment for stance-phase stability; therefore it is not recommended for older, weaker patients.
- Variable-friction (cadence-control) knee: allows resistance to knee flexion to increase as the knee extends by employing a number of staggered friction pads. This knee allows walking at different speeds but is neither durable nor available in endoskeletal systems.
- Manual locking knee: consists of a constant-friction knee hinge with a positive lock in extension that can be unlocked to allow functioning similar to that of a constant-friction knee. The knee is often left locked in extension for more stability. It has limited indications and is used primarily in weak, unstable patients, those just learning to use prostheses, and blind amputees.
- Microprocessor (microprocessor-controlled) knee: A microprocessor adjusts the setting and behavior of a knee mechanism (which can be rheomagnetic, hydraulic, or pneumatic) based on real-time multisensor integration (e.g., pressure sensors and accelerometers) correlating to patient movement.

▪ Suspension systems: Suspension is provided in modern lower extremity prostheses primarily through socket design and suspension liners and sleeves. Straps and belts are usually used for supplementation.

□ Sockets are prosthetic components designed to provide comfortable functional control and even pressure distribution on the amputated residuum. Sockets can be single-walled and rigid or double-walled and typically composed of a more flexible inner thermoplastic socket surrounded by a rigid outer shell. In general, suction is the primary suspension modality used, and it is effected through achieving total contact between socket and residuum. The suction socket provides an airtight seal by means of a pressure differential between socket and atmosphere. An elevated vacuum system can be used to draw additional air out of the socket, and its usage is facilitated by the interface liners. Total-contact support of the residual limb surface prevents edema formation. In total-contact support, different areas have different loads.

Table 10.5

Characteristics of Various Prosthetic Knees.

	Characteristics		
Prposthetic Type	**Action**	**Advantages**	**Disadvantages**
Constant-friction	Limits flexion	Durable, long resistance	Decreased stability
Variable-friction	Varies with flexion	Variable cadence	Poor durability
Stance-control	Friction brake	Stability during stance	Poor durability, difficult to use on stairs
Polycentric	Instant center moves	Stable, increased flexion	Poor durability, heavy
Manual locking	Must be unlocked for sitting	Maximum stability	Abnormal gait
Fluid-control	Deceleration in swing	Variable cadence	Weight, cost
Microprocessor	Computer-programmed real-time adjustment of the knee's actuator	Variable cadence, stability during stance	Increased cost and maintenance, weight

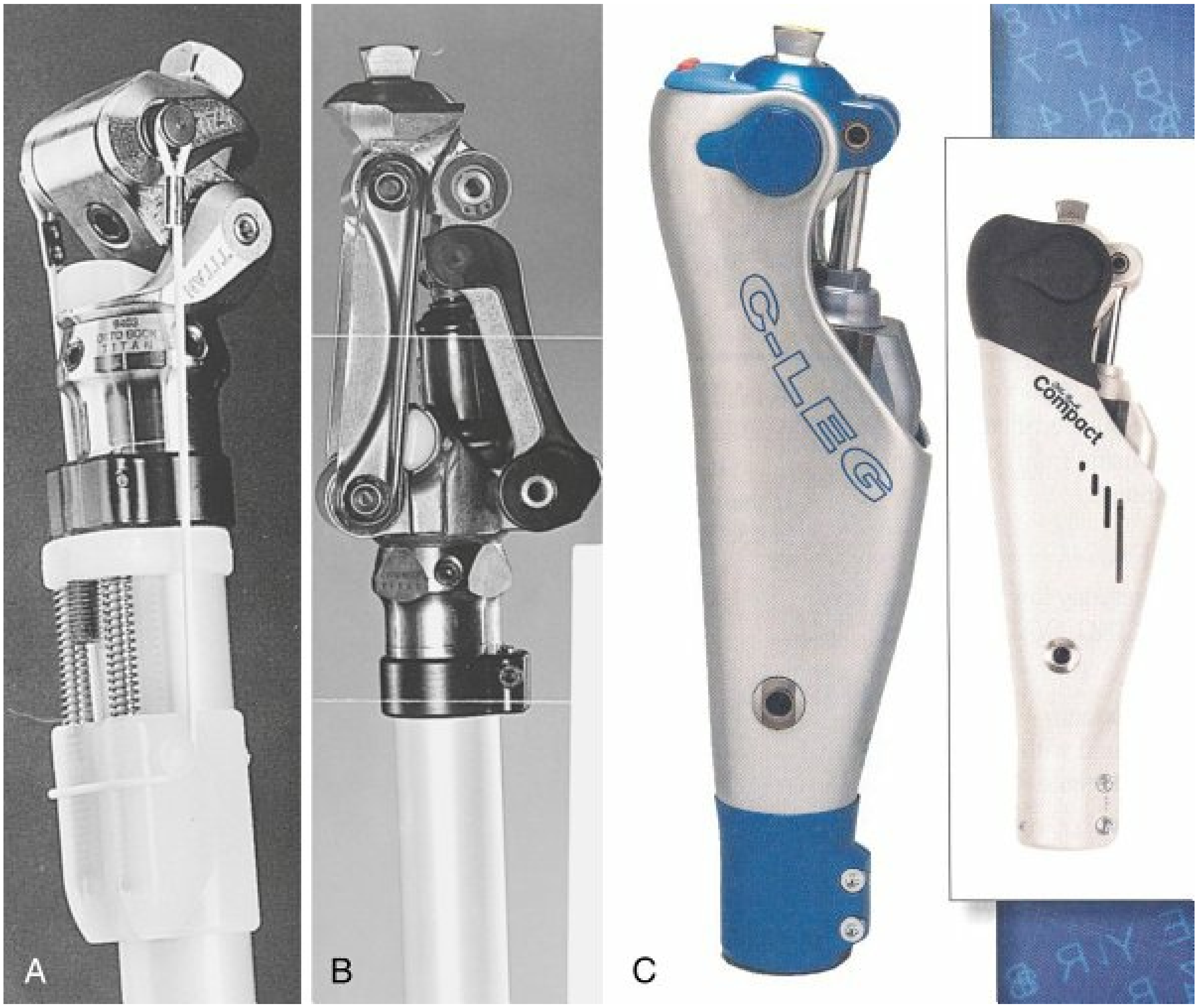


FIG. 10.11 (A) Stance-phase control unit for transfemoral prosthesis. (B) Modular endoskeletal four-bar knee with hydraulic swing-phase control unit. (C) Microprocessor knee unit.
Courtesy Otto Bock Orthopaedic Industries, Minneapolis, Minnesota.

- Transfemoral socket
    - Quadrilateral socket, in which the posterior brim provides a shelf for the ischial tuberosity, has been the classic suspension system. However, the design made it difficult to keep the femur in adduction.
    - Narrow mediolateral (ischial containment) transfemoral socket distributes the proximal and medial concentrations of forces more evenly and also enhances rotational control of the socket.
- Transtibial socket
    - Weight bearing by the patellar ligament (or tendon) loads all areas of the residual limb that tolerate weight (i.e., patellar tendon, medial tibial flare, anterior compartment, gastrocnemius muscle, and fibular shaft). Weight-intolerant areas include the tibial crest and tubercle, distal fibula and fibular head, peroneal nerve, and

hamstring tendons.

- The patellar tendon–bearing supracondylar/suprapatellar socket has proximal extensions over the distal femoral condyles and patella.
- Total-surface weight bearing is different from total-contact weight bearing. With total-surface weight bearing, pressure is distributed more equally across the entire surface of the transtibial residual limb, and the interface liner material in the socket is important.
    - Thermoplastic elastomer (TPE), silicone, and urethane are available materials for liner; also, some manufactures offer hybrid gels—combinations of TPE and silicone.
    - Each gel type has benefits and certain indications for clinical use based on the gel properties (durometer, compressive resistance, adherence, etc.); however, more research is needed to guide gel selection.

□ A supracondylar suspension system is recommended when the residual limb is less than 5 cm long. The socket is designed to increase the surface area for pressure distribution by raising the medial and lateral socket brim. A wedge may be used in the soft liner.

- A supracondylar-suprapatellar suspension system encloses the patella in the socket and has a bar proximal to the patella. This design also provides mediolateral stability, and no additional cuffs or straps are required. Corset-type prostheses can lead to verrucous hyperplasia and thigh atrophy, but they reduce socket loads, control the direction of swing, and provide some additional weight support.

□ In prosthetic sleeves, friction and negative pressure are used for suspension. The sleeves fit snugly to the upper third of the tibial prosthesis and are made from neoprene, latex, silicone, or TPE.

- Transtibial suspension
    - Gel liner suspension systems with a locking pin constitute the preferred method of suspension.
    - Liners are made from silicone, urethane, or TPE.

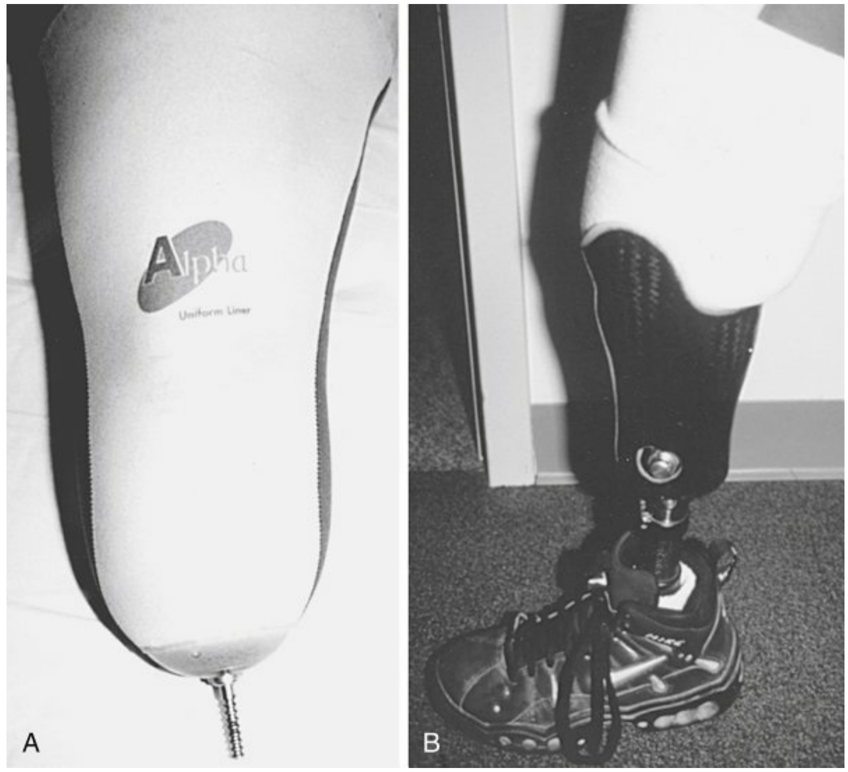


FIG. 10.12 (A) Gel liner suspension with locking pin. (B) Transtibial prosthesis with liner locked in place.

- The sleeve rolls onto the stump, and the locking pin is then locked into the socket (Fig. 10.12).
- The liner provides suspension through suction and friction and acts as the socket interface.
- Prosthetic socks worn over the liner accommodate volume fluctuation.
- This suspension allows unrestricted knee flexion and minimal piston action.

- Transfemoral suspension
    - Vacuum (suction) suspension is frequently used.
    - It relies on surface tension, negative pressure, and muscle contraction.
    - A one-way expulsion valve helps maintain negative pressure, and no belts or straps are required. Stable body weight is required for this intimate fit.
    - Roll-on silicone or TPE liners may be used with or without locking pins.
    - The Silesian belt and total-elastic suspension (TES) belt are commonly used auxiliary suspension. The TES belt is made of neoprene, fastens around the waist, and spreads over a larger surface area (Fig. 10.13).

▪ Common prosthetic problems
  □ Transtibial prostheses (Table 10.6)

- Pistoning during the swing phase of gait is usually caused by an ineffective suspension system.
- Pistoning in the stance phase results from a poor socket fit or volume changes in the stump (a change in thickness of the stump sock may be needed).
- Alignment problems are common.
- Factors leading to pressure-related pain or redness should be identified and corrected.
- Other problems may be related to the foot: too soft a heel results in excessive knee extension, whereas too hard a heel causes knee flexion and lateral rotation of the toes.

FIG. 10.13 Total-elastic suspension belt for suspending a transfemoral socket.
Courtesy Syncor Manufacturers, Green Bay, Wisconsin.

□ Transfemoral prostheses (Table 10.7)

- A long prosthesis (height) and weak hip abductors can lead to circumduction, vaulting, and lateral trunk bending.
- Hip flexion contractures and insufficient anterior socket support can cause excessive lumbar lordosis (compensatory).
- Inadequate prosthetic knee flexion can result in a terminal knee snap for some types of knees.
- A medial whip (heel-in, heel-out) can be caused by a varus knee, external rotation of the knee axis, or uncontrolled rotation of the socket due to improper fitting or donning.
- A lateral whip (heel-out, heel-in) is caused by the opposite problem: valgus knee, internal rotation at knee, or

uncontrolled rotation of socket due to improper fitting or donning.

- □ Stair climbing
  - In general, amputees ascend stairs by leading with the normal limb and descend by leading with the prosthetic limb (“up with the good, down with the bad”).

Section 4 Orthoses

Introduction

- The primary function of an orthosis is control of the motion of certain body segments.
- Orthoses are used to protect long bones or unstable joints, support flexible deformities, and occasionally substitute for a functional task. They may be static, static progressive, or dynamic.
- With few exceptions, orthoses are not indicated for correction of fixed deformities or for spastic deformities that cannot be easily controlled manually.
- Orthoses are named according to the joints they control, the function they provide, and the method used to obtain or maintain that control (e.g., a short-leg, below-knee brace is an ankle-foot orthosis [AFO]).

Shoes

- Specific shoes can be used by themselves or in conjunction with foot orthoses. The Blucher (open throat) and the Bal (closed throat) are the two types of shoes commonly worn. The Blucher type is better in terms of accommodating foot orthoses.
- Extra-depth shoes with a high toe box designed to dissipate local pressures over bony prominences (such as claw deformities) and are recommended for diabetic patients.
- The plantar surface of an insensate foot is protected by use of a pressure-dissipating material. A paralytic or flexible foot deformity can be controlled with more rigid orthoses.
- SACH heels absorb the shock of initial loading and lessen the transmission of force to the midfoot as the foot passes through the stance phase.
- A rocker sole can lessen the bending forces on an arthritic or stiff midfoot during midstance as the foot changes from accepting the weight-bearing load to pushing off. It is useful in treating metatarsalgia, hallux rigidus, and other forefoot problems. For the rocker sole to be effective, it must be rigid.
- Medial heel out-flaring is used to treat severe flatfoot of most causes. A foot orthosis is also necessary.

Foot Orthoses

- Most foot orthoses are used to align and support the foot; prevent, correct, or accommodate foot deformities; and improve foot function.
- Three main types of foot orthosis are used: rigid, semirigid, and soft.
    - Rigid foot orthoses limit joint motion and stabilize flexible deformities.

- ◻ Semirigid orthoses aim to provide some support as well as absorb shock.
- ◻ Soft orthoses have the best shock-absorbing ability and are used to accommodate fixed deformities of the feet, especially neuropathic, dysvascular, and ulcerative disorders.

Ankle-Foot Orthoses

- The most commonly prescribed lower limb orthosis (AFO) is used to control the ankle joint. It may be fabricated with metal bars attached to the shoe or with TPE. The orthosis may be rigid, preventing ankle motion, or it can allow free or spring-assisted motion in either plane.
- After hindfoot fusions, the primary orthotic goals are absorption of GRF, protection of the fusion sites, and protection of the midfoot. In addition, AFOs are commonly prescribed for footdrop, plantar spasticity, and spinal cord injury.
- The TPE foot section achieves mediolateral control of various degrees with different trimlines. Choice of full/anterior, intermediate, and posterior trimlines takes into consideration the intended function, level of control, as well as medical comorbidities, such as limb sensation and recurrent swelling.
- When ankle motion is present, an articulating AFO permits motion through a mechanical ankle joint design.
- Primary factors in selection of an orthotic joint include range of motion, durability, adjustability, and the biomechanical effect on the knee joint.

Knee-Ankle-Foot Orthosis

- The knee-ankle-foot orthosis (KAFO) extends from the upper thigh to the foot. It is generally used to control an unstable knee joint. It provides mediolateral stability with the prescribed amounts of flexion or extension control.
- The stability of knee joints in KAFOs can be provided by various designs and use of knee locks of different types.
- A subset of KAFOs are knee orthoses, which can be used to relieve pain of knee osteoarthritis, stabilize the patella or ACL deficient knee, or facilitate postoperative rehabilitation.

Hip-Knee-Ankle-Foot Orthosis

- The hip-knee-ankle-foot orthosis (HKAFO) provides hip and pelvic stability but is rarely used by paraplegic adults because of the cumbersome nature of the orthosis and the magnitude of effort in achieving minimal gains.
- In experimental studies, it is being used in conjunction with implanted electrodes

and the computerized functional stimulation of paraplegic patients.

Table 10.6

Gait Abnormalities With Transtibial Prostheses.

Gait Phase	Abnormality	Prosthetic Causes (Alignment Factors)				
		Foot				Ankle
		Anterior Displacement to Socket	Posterior Displacement to Socket	Inset	Outset	Plantar flexion
Early stance	Knee excessive flexion (high pressure at anterior and distal tibia) at initial contact/loading response		✓			
	Knee excessive extension (or limited flexion) at initial contact/loading response	✓				✓
	Toe off floor after initial contact	✓				
Throughout stance	Knee extended too much (recurvatum)	✓				✓
	Knee flexed too much (instability)		✓			
	Knee valgus (pain/pressure on the distal medial and proximal lateral sides)				✓	

	Knee varus (pain/pressure on the distal lateral and proximal medial sides)			✓		
	High pressure against patella	✓				✓
	Prosthesis seemingly short (hip level)		✓			
	Pistoning					
	Lateral bending (truncal lean)					
	Broad-based gait				✓	
	Short step length					
Late stance						
	Early heel rise		✓			
	Late heel rise ("hill-climbing")	✓				✓
	Drop-off on the sound side		✓			
Swing	Circumduction			✓		

	Vaulting of sound side					
	Pistoning					
Standing	Toe off					
	Heel off					✓

Table 10.7

Gait Abnormalities With Transfemoral Prostheses.

	Prosthesis Factors				
	Total Length	**Suspension**	**Socket Design**	**Socket Alignment**	**Knee**
STANCE					
Foot slap at initial contact					
Foot rotation at initial contact		Loose		Flexion excessive	
Instability of prosthetic knee during loading response				Flexion excessive	Displaced anteriorly Mechanical failure of knee unit
Drop-off at the end of stance				Socket too anterior in relation to foot	

Lateral bending (truncal lean)	Short		Medial wall too high Lateral wall support insufficient	Abduction	
Exaggerated lordosis			Anterior brim insufficient; higher posterior brim	Flexion insufficient	Displaced anteriorly
Abducted (wide-based) gait	Long		Medial wall too high Lateral wall support insufficient	Adduction built-in	
Asymmetric step length				Flexion insufficient	Friction or flexion dampening insufficient Extension aid inadequate
Short stance duration					Friction or flexion dampening insufficient

	Prosthesis Factors					
	Total Length	**Suspension**	**Socket Design**	**Socket Alignment**	**Knee**	**Foot**
SWING						
Medio/lateral whip at the beginning of swing		Too tight		Socket rotated on limb due to	Rotation excessive (lateral whip:	Toe breal aligne poorl

				improper donning or fitting	internal rotation; medial whip: external rotation) Valgus (lateral whip) or varus (medial whip)	
Rapid heel rise at the beginning of swing					Friction or flexion dampening insufficient Extension aid inadequate	
Circumducted gait	Long	Inadequate			Friction or flexion dampening excessive Extension aid excessive Displaced posteriorly	
Vaulting (on sound side)	Long	Inadequate			Flexion limited (lock, extension aid excessive)	
Terminal swing impact					Friction or flexion dampening insufficient Extension aid excessive	

- In children with upper-level lumbar myelomeningocele, the reciprocating gait orthoses are modified HKAFOs that can be used for therapeutic upright activities and simulated walking as a complement to wheelchair use.

Elbow Orthosis

- Hinged-elbow orthoses provide minimum stability in the treatment of ligament instability.
- Dynamic spring-loaded orthoses have been successfully used in the treatment of flexion and extension contractures.
- An elbow strap is used to treat lateral epicondylitis. In addition, a long arm splint with the elbow flexed at 45 degrees can be tried to treat cubital tunnel syndrome.

Wrist-Hand Orthosis

- The most common use of wrist and hand orthoses (WHOs) today is for postoperative care after injury or reconstructive surgery. These devices can be static, static-progressive, or dynamic.
- The opponens splint is successful in prepositioning the thumb but impairs tactile sensation.
- Wrist-driven hand orthoses are used in patients with lower cervical quadriplegia. The devices may be body powered by tenodesis action or motor driven. Weight and cumbersomeness are the major limiting factors.

Fracture Braces

- Fracture bracing remains a valuable treatment option for isolated fractures of the tibia and fibula.
- Prefabricated fracture orthoses can be used in simple foot and ankle fractures, ankle sprains, and simple hand injuries.

Pediatric Orthoses

- Many dynamic orthoses are used by children to control motion without total immobilization.
- The Pavlik harness has become the mainstay for early treatment of developmental dislocation of the hip.
- Several dynamic orthoses have been used for containment in Perthes disease.

Spine Orthoses

- Cervical spine
  - Numerous orthoses are used to immobilize the cervical spine.
  - Effective immobilization options range from the various types of collars, to posted orthoses that gain purchase about the shoulders and under the chin, to the halo vest, which achieves the most stability by the nature of its fixation into the skull.

- Thoracolumbar spine
    - Orthoses used to mechanically stabilize the back, thus reducing back pain, rely on three-point pressure mechanism and increasing body cavity pressure.
    - Three-point orthoses achieve their control through the length of their lever arm and the subsequent limitation of motion.

Section 5 Surgery for Stroke and Closed-Head Injury

Introduction

- The orthopaedic surgeon can play a role in early management of adult-acquired spasticity secondary to stroke or closed-head brain injury when spasticity interferes with the rehabilitation program.
  - Nonsurgical treatment
    - When functional joint ranging is insufficient to control the deformity, intervention is often indicated.
    - Interventional modalities may include orthotic prescription, serial casting, and motor point nerve blocks with short-acting (bupivacaine HCl) or long-acting (phenol 6% in glycerol or botulinum toxin type A [Botox]) agents.
    - Splinting a joint (e.g., the ankle) in the neutral position is not sufficient to prevent development of a contracture (e.g., equinus contracture).
    - Local anesthetic injection to the posterior tibial nerve or sciatic nerve before casting relieves pain and allows for maximum correction of the deformity.
    - Open nerve blocks may be warranted to avoid injecting mixed nerves with large sensory contributions.
    - Pre-procedure botulinum toxin injection, nerve block, or dynamic EMG is also beneficial for surgery planning.
  - Prerequisites for surgical treatment
    - Surgical intervention in adult-acquired spasticity should be delayed until the patient achieves maximal spontaneous motor recovery (6 months for stroke and 12 to 18 months for traumatic brain injury).
    - When patients reach a plateau in functional progress or the deformity impedes further progress, intervention may be considered.
    - Invasive procedures in this population should be adjuncts, not alternatives, to a standard functional rehabilitation program. Realistic goal setting for surgical outcomes is important and should be discussed among patient, family, and healthcare providers.
    - When surgery is considered as a method of improving function, patients should be screened for cognitive deficits, motivation, and body image awareness.
      - Patients should not be confused and must have adequate short-term memory and the capacity for new learning.

- In addition to specific cognitive strengths, motivation is necessary for patients to use functional gains and participate in their rehabilitation programs.
- Body image awareness is essential for surgical intervention to become meaningful and potentially beneficial. Patients who lack awareness of a limb or its position in space should undergo therapy directed toward ameliorating these deficits before undergoing surgical intervention.

Lower Limb

- Balance is the best predictor of a patient's ability to ambulate after acquired brain injury. The mainstay of treatment for the dynamic ankle equinus component of this gait deviation is to achieve ankle stability in the neutral position during initial floor contact (i.e., initial contact and stance) as well as floor clearance during the swing phase.
- An adjustable AFO with ankle dorsiflexion and a plantar-flexion stop at the neutral position are often used during the recovery period, followed by a rigid AFO once the patient has reached a plateau in recovery.
- When the dynamic equinus overcomes the holding power of the orthosis and the patient is unable to keep the brace in place, motor-balancing surgery is indicated.
- The equinus deformity is treated by percutaneous lengthening of the Achilles tendon. Tendon lengthening procedures are also frequently used for hamstrings, iliopsoas, and hip adductor.
- The dynamic varus-producing force in adults is the result of out-of-phase tibialis anterior muscle activity during the stance phase. This dynamic varus deformity is corrected by either split or complete lateral transfer of the tibialis anterior muscle.

Upper Limb

- There is a paucity of literature dealing with acquired spasticity in the upper limb. Invasive intervention can be considered for nonfunctional and functional goals.
  - Nonfunctional goals: surgical release of static contracture; generally performed to complement nursing care or hygiene when the fixed contracture or spastic component results in skin maceration or breakdown.
  - Functional goals: one functional use of static contracture release is to improve upper extremity "tracking" (i.e., arm swing) during walking.

Most upper extremity surgery performed in this patient population has the goal of increasing prehensile hand function. The goal may be simply to improve placement, enabling use of the hand as a "paperweight," or to achieve improved fine motor control. In patients with prehensile potential, surgery may allow the "one-handed" patient to be "two-handed" by increasing involved hand function from no function to assistive or from assistive to independent.

- Screening: When the goal of surgery is to improve function, patients must first be screened for cognitive capacity, motivation, and body image awareness.
    - Patients must have the cognitive skills and learning capability to participate in their therapy after surgery and to functionally make use of their newly acquired skills at completion of the rehabilitation program.
    - If they are not motivated, they will not participate in the prolonged effort necessary to achieve meaningful functional improvement.
    - Patients with poor stereognosis or neglect (i.e., poor body image awareness) find that the involved hand "drifts" in space and is not "available" for use if they have not been carefully trained in visual compensation techniques.
- Grading: Once it has been determined that the patient has the potential to make functional upper extremity gains with surgery, he or she is graded on the basis of hand placement, proprioception and sensibility, and voluntary motor control. Dynamic EMG is used when delineation of phasic motor activity is essential.
- Methods: By means of fractional musculotendinous or step-cut (Z-plasty) methods, muscle unit lengthening of the agonist-deforming muscle units is combined with motor-balancing tendon transfers of the antagonists to achieve muscle balance and improve prehensile hand function. Brachioradialis transfer can be performed to reconstruct lateral pinch function of the thumb.

Section 6 Postpolio Syndrome

Cause

- Polio is a viral disease affecting the anterior horn cells of the spinal cord. Postpolio syndrome, manifested as a new wave of progressive weakness below the functional baseline, is *not* a reactivation of the poliovirus but rather a "burnout" of the motor unit of the alpha motor neuron that has expanded in size.
- The syndrome occurs after middle age, usually 30 to 40 years following the original polio illness.
- Symptoms include progressive muscle and joint weakness and pain, general fatigue and exhaustion with minimal activity, muscle atrophy, breathing or swallowing problems, sleep-related breathing disorders (e.g., obstructive sleep apnea), and decreased tolerance of cold temperatures.
- In most patients the syndrome progresses slowly, with symptomatic periods followed by periods of stability.
- Affected patients use a high proportion of their capacity for normal activities of daily living. With aging and the drop-off of muscle units, they no longer have the reserves to perform their daily activities.
- Risk factors for development of postpolio syndrome include severity of the initial polio illness, initial diagnosis as an adolescent or adult, longer recovery from initial illness, and engaging in physical activity to the point of exhaustion or fatigue.

Treatment

- Treatment comprises prescribed limited exercise combined with periods of rest so that muscles are maintained but not overtaxed.
- Standard polio surgical procedures, combining contracture release, arthrodesis, and tendon transfer, are indicated when the deformity overcomes functional capacity.
- The use of lightweight orthoses is important in helping patients remain functionally independent.

Testable Concepts

- Gait cycle is divided into stance and swing phases with 20%–30% of the gait cycle spent in double-limb support. Energy expenditure of walking decreases as the vertical and horizontal displacement of the body's center of gravity is minimized.
- Muscle action across the joints is associated with the relationship of the joints of interest with ground reaction force, the mean loading-bearing vector throughout the gait cycle.

- The soft tissue in the residual limb serves as the interface through which load transfer or weight bearing takes place. Transected muscles can be sutured to antagonist muscles (myoplasty) or anchored directly to the distal end of a bone (myodesis), the latter providing better residual limb control.
- Common complications of amputation include phantom limb sensation, pain (somatic and neuropathic), edema, joint contracture, and skin problems. The prosthetic systems for upper limb amputation can be myoelectric, traditional body-powered, or hybrid.
- Medicare functional classification level (MFCL) provides recommendations on prosthesis proscription for lower limb amputations.
- Orthoses are used to control the motion of certain body parts, which can be indicated for the protection of long bones and unstable joints, support of flexible deformities, or substitution for functional deficits.
- Orthopedic surgery can be considered for spasticity if maximal spontaneous motor recovery is achieved and the patient retains adequate cognitive capacity, motivation, and body image awareness.

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CHAPTER 11

Trauma

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Section 1 Care of the Multiply Injured Patient

Principles of Trauma Care

- **Primary assessment—begins with the primary survey, which seeks to identify any life-threatening injuries. A rapid assessment of airway, breathing, and circulation (the ABCs) is performed.**
- **Fluid resuscitation**
    - Aggressive fluid resuscitation should begin immediately with the placement of two large-bore intravenous cannulas.
    - Two liters of lactated Ringer solution or normal saline should be administered.
    - If the patient remains hemodynamically unstable after initial crystalloid infusion, begin infusion of blood products.
        - Typically requires more than 30% blood loss
- **Blood products**
    - Universal donor
        - Group O negative
        - Used in severe shock when specific blood products are not yet available
    - Type-specific blood
        - Crossmatched for ABO and Rh type
        - Typically available within 10 minutes
    - Fully typed and crossmatched
        - Minor antibodies are crossmatched.
        - Typically available within 60 minutes
    - Fresh frozen plasma
        - Contains coagulation factor proteins, immunoglobulins, and complement
    - Platelets
        - Typically prepared from whole blood and should be stored at 20°–24°C with continuous gentle agitation
        - Platelets stored in the cold become activated and lose their normal discoid shape.
- **Transfusion**
    - If a patient does not respond to 2 L of crystalloid, 2 units of packed red blood cells should be administered.
    - Patients become coagulopathic and thus require both fresh frozen plasma and platelets.
        - Newer literature supports administration of packed red blood cells, fresh frozen plasma, and platelets in a 1:1:1 ratio.
            - May prevent early coagulopathy
    - The most common complication of massive transfusion is a dilutional

thrombocytopenia, followed by hypothermia and metabolic alkalosis.

Table 11.1

Classification and Treatment of Hemorrhagic Shock

Class	Parameters				Treatment
	Blood Volume Loss (%)	Heart Rate (beats/min)	Blood Pressure	Urine Output (mL/h)	
I	Up to 15	<100	Normal	>30	Fluid replacement
II	15–30	>100	Decreased	20–30	Fluid replacement
III	30–40	>120	Decreased	5–15	Fluid and blood replacement
IV	>40 (emergently life threatening)	>140	Decreased	Negligible	Fluid and blood replacement

From Browner BD, on behalf of the American College of Surgeons Committee on Trauma: *Advanced trauma life support: skeletal trauma: basic science, management, and reconstruction*, ed 8, Chicago, 2008, American College of Surgeons.

- □ Increased citrate from packed red blood cells binds calcium directly and can cause hypocalcemia.
- □ Hemodynamic instability may result from internal injury or fractures.
  - Rapid application of splints and reduction of fractures when possible can decrease bleeding and relieve pain.
- □ End points of adequate resuscitation: use of hemodynamic parameters is inadequate.
  - Base deficit, as measured by lactate level, is a proxy for the amount of anaerobic metabolism by the body and is the best measure of patient's resuscitation.
    - In general, lactate levels less than 2.5 mg/dL indicate adequate resuscitation.

▪ **Shock**

- □ Hemorrhagic shock is divided into four classes (Table 11.1)
- □ Class III/IV requires administration of blood products.
  - Manifests as:
    - Increases in heart rate and systemic vascular resistance
    - Decreases in cardiac output, pulmonary capillary wedge pressure, central venous pressure, and mixed venous oxygen saturation
  - Neurogenic shock
    - Due to a loss of sympathetic tone in setting of a spinal cord injury
    - Manifests as low heart rate, low blood pressure,

and warm skin
        - Treat with dobutamine and dopamine.
    - Septic shock
        - Typically a hyperdynamic state with a massive loss of systemic vascular resistance
        - Cardiac index is increased and central venous pressure is decreased.
        - Treat with antibiotics and norepinephrine (causes vasoconstriction without increasing cardiac output).
    - Hemodynamic shock
        - Tension pneumothorax; pericardial tamponade that prevents diastolic filling; pulmonary embolism
  - □ The systemic inflammatory response syndrome (SIRS) is a generalized response to trauma characterized by an increase in cytokines, complement, and many hormones.
    - SIRS is present when two or more of the following criteria are met:
        - Heart rate higher than 90 beats per minute
        - White blood cell (WBC) count less than 4000/μL^3 or greater than 12,000/μL
        - Respiration higher than 20 breaths per minute, with Pa_{CO_2} less than 32 mm Hg
        - Temperature less than 36°C or greater than 38°C
    - SIRS is associated with disseminated intravascular coagulopathy, acute respiratory distress syndrome (ARDS), renal failure, shock, and multisystem organ failure.
- ▪ **Tranexamic acid** is a synthetic analogue of lysine that can be used to prevent excessive bleeding. Its **mechanism of action is competitive inhibition of plasminogen activation.**
- ▪ **Radiologic workup**
  - □ A rapid radiologic workup that includes at a minimum anteroposterior (AP) chest, AP pelvis, and lateral cervical spine views is standard.
  - □ With the availability and increased processing speed of CT scanners, CT of cervical spine is replacing lateral cervical spine radiography for trauma evaluation.
  - □ Pelvic fractures can be life threatening. The orthopaedic surgeon may be called on to stabilize pelvic fractures in the emergency department (ED) and should be prepared to immediately place a pelvic binder or sheet.
  - □ Pelvic bleeding that does not respond rapidly to pelvic compression with a sheet or binder should be evaluated by angiography and

embolization, if indicated.

- **Trauma scoring systems—numerous systems seek to quantify the injury a patient has sustained.**
  - Although some may yield prognostic value, none is perfect; a thorough workup is needed to identify all injuries and prioritize their management.
  - Although it may be desirable to repair all fractures on the day of admission, it may be inherently dangerous to do so because of hemodynamic instability and the added trauma surgery creates.
- **Damage control orthopaedic principles involve staging the definitive care of the patient to avoid adding to the early overall physiologic insult.**
  - Trauma is associated with a surge in inflammatory mediators, which peaks 2–5 days after trauma.
  - After the initial burst of cytokines and other mediators, leukocytes are "primed" and can be activated easily with further trauma such as surgery. This may lead to multisystem organ failure or ARDS.
  - To minimize the additional trauma from surgery, traumatologists often treat only potentially life-threatening injuries during this acute inflammatory window.
  - In the *severely injured* polytrauma patient or the patient with significant chest trauma, only emergent and urgent conditions should be treated.
    - Compartment syndrome, fractures associated with vascular injury, unreduced dislocations, long bone fractures, open fractures, and unstable spine fractures should be stabilized acutely.
  - Acute stabilization is achieved primarily via external fixation.
    - Femur fractures may be converted from external fixator to intramedullary (IM) nail within 3 weeks.
    - Tibia fractures should be converted within 7 to 10 days. If longer periods are necessary, a staged removal of the external fixator with nailing several days later is recommended.
- **Care of the pregnant patient**
  - Trauma is the most common cause of death in pregnancy.
  - Place any pregnant patient at more than 20 weeks' gestation in the left lateral decubitus position.
    - The vena cava may be compressed by the uterus, reducing maternal cardiac output 30%.
  - The radiation associated with most diagnostic radiographs is below the threshold of risk to the fetus.
    - The first-trimester fetus is most at risk.
- **Psychologic sequelae**
  - Polytrauma has a major impact on quality of life.
  - Women are more affected than men, and at 10 or more years after

severe polytrauma, women show higher rates of posttraumatic stress disorder and take more sick leave time.

Care of Injuries to Specific Tissues

- **Soft tissue injuries**
  - Vascular injury—may be due to penetrating or blunt trauma
    - Vascular injury can be present when pulses are palpable; a change in pulse or a difference from the contralateral side may be the only harbinger of a serious vascular injury.
    - If pulses are not equal to the uninjured side, a workup is indicated.
    - Vascular compromise may develop over the course of hours in the case of knee dislocations and must be recognized promptly.
    - Hard signs of arterial injury mandate immediate operative treatment: observed pulsatile bleeding, rapidly expanding hematoma, palpable thrill, audible bruit, obvious arterial occlusion after reduction/realignment of fracture (6 *P*s: pulselessness, pallor, paresthesia, pain, paralysis, poikilothermia).
    - Soft signs of arterial injury prompt consideration of arteriogram, serial examination, or duplex examination: history of arterial bleed at scene, penetrating wound or blunt trauma in proximity to major artery, diminished unilateral pulse, small nonpulsatile hematoma, evolving neurologic deficit, ankle-brachial index (ABI) less than 0.9, abnormal flow velocity waveform on Doppler ultrasound.
    - Treatment: reduction of fracture often restores vascularity in the case of a long bone fracture.
  - Compartment syndrome
    - Diagnosis: intracompartmental pressure exceeds capillary pressure, thus preventing exchange of waste and nutrients across vessel walls. One of the most frequently missed complications of trauma.
    - Unless treated within 4–6 hours, permanent injury will ensue; diagnosis is clinical or made using a pressure monitor.
    - Clinical hallmarks are pain out of proportion to the injury and pain with passive stretching of the muscle.
    - Paresthesias and motor weakness are late findings.
    - Pulselessness and pallor are not commonly seen in

compartment syndrome and suggest arterial compromise.

- Intracompartmental pressure measurement is abnormal if pressure is within 30 mm Hg of the diastolic pressure (ΔP)
- Intraoperative diastolic blood pressure during anesthesia is approximately 18 mm Hg lower than "baseline," potentially giving spurious ΔP values.
- Treatment: emergent decompression via fasciotomy
    - In the medial approach of a two-incision fasciotomy, the soleus must be released to allow access to the deep posterior compartment.
    - Sequelae of untreated compartment syndrome are common and include claw toes and contractures in the hand.

□ Rhabdomyolysis

- May occur from crush injury, untreated compartment syndrome, and even strenuous endurance exercise
- Myoglobin released into the bloodstream from damaged muscle can lead to renal failure. Initially urine is dark owing to presence of myoglobin.
- Elevated serum creatine kinase—levels five times normal upper limit indicate rhabdomyolysis.
- Treatment includes supportive care; intravenous sodium bicarbonate, glucose, and insulin for treatment of hyperkalemia; sodium bicarbonate to alkalinize urine and reduce risk of acute tubular necrosis; diuretics (mannitol and furosemide) may be used to maintain urine output.
- Complications include hyperkalemia with associated ECG abnormalities and disseminated intravascular coagulation (DIC)

□ Nerve injury

- Cause
    - Blunt trauma—direct impact, crush injury, or shock wave from missile injury
    - Laceration—sharp edge of bone or penetrating trauma
- Most common form is nerve palsy (neurapraxia), caused by stretching of the nerve, which will recover over time (1 mm/day)
    - Following gunshot wounds, ulnar nerve injuries exhibit the worst functional recovery.
- Treatment
    - Nerve laceration (neurotmesis—may be treated by repair or grafting. Results vary according to

the specific nerve injured and the degree of injury to the nerve.

        - Radial nerve injuries in high-energy open humeral shaft fractures have been shown to be more frequently due to neurotmesis than neurapraxia in some studies.
    - Disruption of the nerve axon with an intact epineurium (axonotmesis) may be treated initially by observation
- Motor recovery potential after repair
    - Excellent
        - Radial, musculocutaneous, femoral nerves
    - Moderate
        - Median, ulnar, tibial nerves
    - Poor
        - Peroneal nerve

□ Human and animal bites

- Pathogens—despite association of certain bites with specific bacteria, *Staphylococcus* and *Streptococcus* remain most prevalent pathogens. Others include:
    - Cat bites—*Pasteurella*
    - Dog bites—*Eikenella*
    - Human bites—variable, including *Eikenella*
- Treatment—broad-spectrum antibiotic is commonly given, although regional variations are also common.

□ Thermal injury

- Hypothermia
    - Cause: injury due to formation of ice crystals outside cell(s)
    - Treatment: rapid rewarming and attention to arrhythmias are the current treatments. Amputation may be necessary.
- Burns—extremity burns may be treated by orthopaedic surgeons. Débridement of deep dermal burns and skin grafting are hallmarks of treatment after early aggressive fluid resuscitation. Antibiotic prophylaxis and tetanus are routine.
- Electrical injury—may cause bone necrosis and massive soft tissue necrosis. Extent of tissue injury may not be apparent for days after injury because skin may not be broken despite significant injury underneath.

            - Treatment is similar to that of burns; débridement followed by reconstruction with amputation, a flap, or a skin graft as required.
        - Chemical burns—first rule: avoid contamination from other people and further damage to the victim.
            - Initial treatment: dilution with copious irrigation. After initial irrigation, the degree of necrosis is assessed, with débridement of necrotic tissue. Hydrofluoric acid is extremely toxic, causing profound hypocalcemia and cardiac death with little exposure; calcium gluconate may be used to treat skin exposure.
    - High-pressure injury (water, paint, grease)—hand injuries most common. There may be extensive damage to underlying soft tissues despite a small entrance wound. Wide débridement of necrotic tissue and foreign material is required.
        - Hyperbaric oxygen—can be used to provide enhanced oxygen delivery to peripheral tissues damaged by trauma
            - Pressure-sensitive implanted medical devices (e.g., insulin pump) are contraindications to use of hyperbaric therapy.
    - Joint injuries—may be caused by penetrating or blunt trauma
        - Dislocations—orthopaedic emergencies that should be reduced as soon as possible to avoid injury to the nerves, vessels, and articular cartilage; general anesthesia may be needed. Neurovascular status should be assessed and documented both before and after reduction.
        - Open joint injuries
            - Antibiotics—penetrating trauma such as gunshot wounds may be treated with oral antibiotics if there is no debris in the joint; however, foreign matter is often carried into the joint as it is penetrated, even in “clean” gunshot wounds.
            - Saline load test
                - Performed by injecting saline into the joint and observing the injured area for signs of extravasation
                - At least 175 mL must be injected into the knee.
                - This test may miss a small puncture wound.
    - Fractures
        - Open fractures

- Classification
  - Gustilo and Anderson grading system is widely used. There is considerable interobserver variability, and the type may change over time with further débridement. Absolute wound length is less important than energy of injury.
    - Type I—no periosteal stripping, minimum soft tissue damage, small skin wound (1 cm)
    - Type II—little periosteal stripping, moderate muscle damage, skin wound (1–10 cm)
    - Type IIIA—contaminated wound (high-energy gunshot wound, farm injury, shotgun injury) or extensive periosteal stripping with large skin wound (>10 cm)
    - Type IIIB—same as IIIA but requires flap coverage
    - Type IIIC—same as IIIA but with vascular injury that requires repair
  - Orthopaedic Trauma Association (OTA) Open Fracture Classification
    - Developed to address shortcomings of Gustilo and Anderson classification, which was designed only for open tibia fractures and uses treatment (i.e., type of wound closure) to determine classification. Ideal

classification should guide treatment rather than treatment guiding classification.
            - Assesses five factors associated with open fractures using specific identifiable subcategories:
            - Skin
            - Muscle
            - Arterial
            - Contamination
            - Bone loss
- Treatment
    - Antibiotics—usually started immediately. Antibiotic bead pouch with methylmethacrylate, tobramycin, and/or vancomycin may be used to initially manage highly contaminated wounds.
        - Types I and II—first-generation cephalosporin (cefazolin) for 24 hours
        - Type III—cephalosporin and aminoglycoside for 72 hours after injury or not more than 24 hours after each débridement or soft tissue coverage
        - Heavily contaminated wounds and farm injuries—cephalosporin, aminoglycosides, and high-dose penicillin
        - Freshwater wounds—fluoroquinolones (ciprofloxacin, levofloxacin) or third- or fourth-generation cephalosporin

(ceftazidime)
    - Saltwater wounds—doxycycline and ceftazidime *or* a fluoroquinolone
- Tetanus prophylaxis
    - Tetanus is caused by the exotoxin of *Clostridium tetani,* which produces convulsion and severe muscle spasms with a 30%–40% mortality rate.
    - Required tetanus prophylaxis treatment is based on the characteristics of the wound and the patient's immunization status.
    - Tetanus-prone wounds are more than 6 hours old, are more than 1 cm deep, have devitalized tissue, and are grossly contaminated.
    - Patient with an unknown tetanus immunization status or who has received fewer than three tetanus immunizations and who has a tetanus-prone wound should receive tetanus and diphtheroid toxoid and human tetanus immunoglobulins (intramuscular injection of toxoid and immunoglobulin should occur at different sites).
    - Patient with unknown tetanus immunization

status or who has received fewer than three tetanus immunizations and who has a non–tetanus-prone wound should receive only tetanus toxoid.

- Fully immunized patient should receive tetanus toxoid if the wound is severe or is more than 24 hours old, or if the patient has not had a booster in the past 5 years.

- Débridement—initial treatment should consist of local wound débridement that is adequate to clean the wound and remove all necrotic tissue.
- Stabilization of bony injuries—will decrease further damage to soft tissue
- Early coverage (goal: <5 days). However, zone of injury must be well defined before coverage
    - Gastrocnemius flap—for proximal-third tibial fractures
    - Soleus flap—for middle-third tibial fractures
    - Fasciocutaneous flap or free-tissue transfer—for distal-third fractures
- Negative-pressure therapy is commonly used to treat wounds but is not a substitute for definitive coverage.

- Stabilization with external fixation
    - Immediate treatment: most fractures should be reduced and splinted promptly to avoid further soft tissue damage. External fixation may be used

to treat grossly contaminated wounds and fractures that will require time for soft tissues to heal before definitive fixation.

- Definitive treatment: external fixation may be used definitively for periarticular fractures, articular fractures that cannot be reconstructed, and segmental fractures, but internal fixation is far more common.
- Perioperative complications
    - Thromboembolic disease—incidence very high in pelvic, spine, hip, and lower extremity fractures. Pulmonary embolus develops in as many as 5% of patients who have deep venous thrombosis (DVT).
        - Diagnosis of DVT is by Doppler ultrasound, magnetic resonance venography, or D-dimer titers.
        - Treatment: all patients with these injuries should receive some form of thromboembolic disease prophylaxis (mechanical or pharmacologic). Risks of pharmacologic prophylaxis include prolonged bleeding from surgical or traumatic wounds and cerebral bleed.
    - Fat embolus syndrome—associated with reaming of long bones but can occur with any long bone fracture. Hypoxia, a petechial rash on the chest, and tachycardia are the hallmarks. Treatment is supportive.
    - ARDS—patients with chest trauma and multiple fractures at high risk. It is unclear whether reamed nailing of

long bone fractures causes it directly, but this procedure may be implicated in the “second hit” phenomenon. Treatment is supportive (O_2, ventilator).

- Fracture complications
  - Cast treatment complications
    - Pressure sore—care must be taken to pad bony prominences and perform more frequent skin inspections in patients with diminished sensory capacity
    - **Cast burn**; can be **minimized by not dipping plaster in hot water (use water temperature 20°–24°C [68°–75.2°F]),** not resting cast on a pillow while setting, not using excessive layers, and not overwrapping with fiberglass while plaster cast is curing
  - Delayed union—defined as no progression of healing over serial radiographs. Treatment may include bone grafting and external bone stimulation.
  - Nonunion
    - Classification
      - Weber-Cech: hypertrophic, oligotrophic, atrophic.
    - Biologic treatments—many new treatments, but scant literature to support any one over the others
      - Bone morphogenetic protein—expensive, indicated in some acute tibia fractures, and possibly useful in nonunions
    - Traditional treatment
      - Identify infection and treat appropriately.
      - Address patient factors including vitamin D deficiency and

nutrition.
            - Correct any deformity.
            - Provide stability for hypertrophic nonunions.
            - Provide improved biology (autogenous bone graft, muscle flap) for atrophic nonunions.
            - Preserve native biology.
        - Bone stimulator—no strong evidence for effectiveness of one method over another
            - Ultrasound—delivers small cumulative doses of ultrasound energy; thought to induce microfracture and healing response; **30 mW/cm^2 pulsed wave ultrasound has been shown effective for healing acute fractures.**
            - Electromagnetic—attempts to promote healing by directing integral ion flow at cellular level of bone
- Segmental bone loss—treatment includes bone graft, induced membrane technique followed by bone graft, interposition free tissue transfer (free-fibula transfer), bone transport (ring fixation), and amputation.
- Heterotopic ossification (HO)
    - Diagnosis: common in head-injured patients and in hip, elbow, and shoulder fractures. Any fracture associated with extensive muscle damage is at risk.
    - Prophylaxis: indomethacin 25 mg orally three times a day, or indomethacin sustained-release 75 mg orally daily for 6 weeks has been

recommended. Efficacy of indomethacin is debatable and may increase nonunion rate.

- Radiation therapy (600–700 cGy) given 24 hours before or up to 72 hours after surgery; equal to indomethacin in effectiveness (but no issues with compliance with medication regimen)

- Treatment: early active range of motion (ROM) for elbow and shoulder. Excision of problematic heterotopic ossification can be considered when no further growth (controversial how to assess—“quiet” bone scan, stable disease shown on radiographs, time >1 year).

- Osteomyelitis
  - Diagnosis
    - Definitive diagnosis—by bone biopsy. Bone culture and microscopic pathology. Bone culture may have high false-negative rate. Microscopic pathology to evaluate for inflammatory changes consistent with infection.
    - Other tests—may be used in combination with physical examination (draining wound, pain) to confirm diagnosis
      - Chronic draining wounds can differentiate into squamous cell

carcinoma and should undergo histologic analysis when excised.
    - MRI—95% sensitive and 90% specific
    - Technetium (Tc) 99m (^{99m}Tc) study —85% sensitive and 80% specific
    - Indium (In) 111 study—95% sensitive and 85%–90% specific
- Treatment—based on grade and host type (Cierny/Mader classification)
    - Grade
        - Grade I—intramedullary; débridement by intramedullary reaming
        - Grade II—superficial, involves cortex, often seen in diabetic wounds; curettage
        - Grade III—localized, involves cortical lesion with extension into medullary canal; requires wide excision, bone grafting, and perhaps stabilization

        - Grade IV—diffuse, indicates spread through cortex and along medullary canal; wide sequestrectomy, muscle flap, bone graft, and stabilization
    - Host
        - A—normal healthy patient
        - B—locally compromis (vasculopat
        - C—not considered a medical candidate for surgery; may require suppressiv antibiotics
- Fractures caused by gunshot wounds
    - Velocity is the most important determinant of the energy imparted to soft tissues.
    - High-energy gunshot and shotgun wounds—considered grade III open fractures because they are often associated with considerable soft tissue injury. They require extensive surgical débridement of necrotic tissue as well as surgical stabilization of the fracture.
    - Low-energy gunshot wounds—can be treated as closed fractures but single-dose, first-generation cephalosporin and local wound care should be given
    - Bullets that pass through colon—may

contaminate any fracture caused by the bullet after perforation (pelvis, spine). Bony fractures may be managed with antibiotics alone if extraarticular and the fracture pattern is stable.

- Osteoporotic fractures
  - World Health Organization Fracture Risk Assessment Tool (FRAX) calculates the 10-year risk of hip fracture
  - Low-energy stress fractures associated with bisphosphonate use in patients treated for osteoporosis; fracture characterized by cortical thickening, mostly transverse pattern, minimal comminution.
  - Fracture of the proximal humerus consistently predicts patient's risk for a subsequent low-energy hip fracture.

□ Principles of lower extremity amputation
- Maintain knee joint and stump length when soft tissues permit, even if free flap is required for coverage
- Lower Extremity Assessment Project (LEAP)
  - Multicenter prospective study of severe lower extremity trauma in the U.S. civilian population. Key findings and recommendations include:
    - Injury severity scoring systems do not provide valid predictive value to guide amputation decision.
    - Absence of plantar sensation on presentation is not predictive of extremity function or return of plantar sensation at 2-year follow-up.
    - At 2- and 7-year follow-up, no difference in functional outcome between patients who underwent limb salvage surgery and those who underwent amputation
    - Outcomes found to be affected more by patient's economic, social, and personal resources than by the injury treatment method
    - Patients with mangled extremity injuries have poor outcomes at 2 years. Outcomes continue to worsen between 2 and 7 years' follow-up.

Factors associated with poor outcome include older age, female gender, nonwhite race, lower level of education, current or prior smoking history, poor economic status, low self-efficacy, poor health status prior to injury, and involvement in legal system to obtain disability.
- Patients presenting with mangled lower extremity injuries are less agreeable and more likely to drink alcohol, to smoke, to be poor and uninsured, and to be neurotic and extroverted in comparison with population norms.
- Patients who undergo below-knee amputation function better than those who undergo above-knee amputation. Patients undergoing through-knee amputation have the poorest function.

Biomechanics of Fracture Healing

- **Stability and fracture healing**
  - Stability determines strain
    - Absolute stability
    - Relative stability
  - Strain determines type of healing
    - *Strain* is defined as change in fracture gap divided by the fracture gap ($\Delta L/L$).
      - Highest fracture site strain is seen in a simple fracture that is fixed with a gap (incompletely reduced).
    - Strain less than 2% results in primary bone healing (endosteal healing).
    - Strain 2%–10% results in secondary bone healing (enchondral ossification).
    - Strain greater than 10% does not permit bone formation.
  - Relative stability
    - Micromotion at fracture site under physiologic load leads to callus formation.

- Strain decreases as callus matures, leading to increased stability.
- If there is too much motion, callus becomes hypertrophic as it tries to spread out force, and hypertrophic nonunion can result.
- Examples: casts, external fixators, IM nails, bridge plates

- □ Absolute stability
  - No motion at fracture site under physiologic load
  - Bone heals through direct healing (no callus).
  - Strain is low or zero.
  - Healing times are longer and more difficult to confirm by radiography.
  - Implants must have longer fatigue life.
  - Examples: oblique fractures fixed with lag screws and transverse fractures fixed with compression plating technique

- **Healing in different bone types**
  - □ Diaphyseal (cortical)
    - Decreased blood supply leads to longer healing times.
    - Bone is more amenable to compression techniques (in short oblique/transverse fractures).
    - Strain is concentrated over a smaller surface area.
  - □ Cancellous (metaphyseal)
    - Larger surface area and better blood supply
    - Strain is lower as forces spread out over larger area.
    - Healing is more rapid.
    - However, joint surfaces tolerate very little malreduction (<2 mm), so there is often increased time to bear weight versus diaphyseal fractures.

Biomechanics of Open Reduction and Internal Fixation (Orif)

- **Lag screws**
  - □ Provide rigid interfragmentary compression (absolute stability)
  - □ Force is concentrated over a small area (around screw), so typically a plate is needed to protect/neutralize the deforming forces.
- **Position screws**
  - □ Compress plate to bone but do not provide interfragmentary compression
  - □ Friction between screw, plate, and bone resists pullout or bending.
- **Plating**

- □ Plate length matters more for bending stability than number of screws in plate.
- □ Torsional stability is more affected by position of screws (end hole must be filled).
- □ Longer plates spread the strain over more area (working length).
- □ To increase bending stiffness of a plate, decrease the working length by placing screws closer to the fracture site (a 10-hole plate centered at a fracture with screws in holes 1, 5, 6, and 10 has a higher bending stiffness than one with screws in holes 1, 3, 8, and 10).
- □ Plates are load bearing—will stress shield area they cover; important to protect area temporarily if plate removed after healing
- □ Compression plate function
  - Plate design (oval holes) or use of compression device allows plate to apply compressive forces across fracture.
  - Provides absolute stability when properly applied
  - Relies on friction between plate and bone (needs at least some nonlocking screws)
  - May need to be prebent to achieve compression of both near and far cortex
  - Insertion order is neutral position, then compression on opposite side of fracture, then lag screw (if being placed through plate).
  - Tight contact of plate to bone when initially applied causes decreased periosteal blood flow and temporary osteopenia.
- □ Bridge plate function
  - Primarily for comminuted fracture patterns
  - Plate "bridges" area of comminution with fixation above and below fracture.
  - Allows some elastic deformation (relative stability)
  - Use of screws very close to fracture should be avoided.
  - Number and types of screws to insert are fracture dependent —no clear, widely accepted guidelines.
  - Nonlocking screws compress plate to bone and can be used to lag in fragments; locking screws provide angular stability in short metaphyseal segments or in osteoporotic bone.
- □ Buttress plate function
  - Plate provides support at 90-degree angle to fracture—typically in depressed metaphyseal/articular fractures that have been reduced.
  - Can provide absolute stability to metaphyseal fragments
- □ Submuscular/percutaneous plating
  - To preserve biology at fracture site, plate may be placed in submuscular plane by sliding through small incisions

proximal or distal to fracture and avoiding exposure of fracture site.
        - Typically used in bridge mode, although not exclusively
        - Advantage: decreased soft tissue and biologic compromise
            - Perfusion of both medulla and periosteum is better retained.
        - Disadvantage: more prone to malreduction/malrotation
    - Locked plating
        - Screws have threads in head that lock into corresponding holes in plate
            - Fail simultaneously rather than sequentially
        - Stability does not depend on friction between plate and bone.
        - Provides fixed-angle construct—similar to blade plate
        - Most useful in unstable short-segment metaphyseal fractures and osteoporotic bone
        - Fractures in which locking plate use is supported by data include
            - Periprosthetic fractures
            - Proximal humerus fracture
            - Intraarticular distal femur and proximal tibia
            - Humeral shaft nonunion in the elderly
- **Unicortical locked screws**
    - Typically for metaphyseal bone
    - Similar in pullout strength to bicortical locked screws in good-quality diaphyseal bone (but rare indications for use there)
    - Weaker in torsion than bicortical screws
- **Bicortical locked screws: biggest advantage is in osteoporotic diaphyseal bone**
- **Multiaxial screws**
    - May increase options for fixation in working around periprosthetic fractures
    - No advantage in strength or pullout
- **"Hybridization" describes the use of both locking and nonlocking screws in combination. This allows for both compression and fixed-angle support.**
- **IM nails**
    - Load-sharing devices—relative stability
    - Stiffness depends on:
        - Material
            - Stainless is stiffer than titanium.
        - Size
            - Increased diameter leads to increased stiffness at a ratio of radius to the power of:
                - 3 in bending

- 4 in torsion
- Wall thickness
  - Larger = stiffer nail
- Radius of curvature of femoral nails is typically less than anatomic, improving frictional fixation.
  - A large mismatch of curvature, however, results in difficult insertion, increased risk of intraoperative fracture, and malreduction in extension.
- Nails resist bending very well and require interlocks to resist torsion or compression loads.
- *Working length* is the portion of the nail that is unsupported by bone when loaded.
  - Increased working length produces increased interfragmentary motion and may delay union.
- Advantage of intramedullary position is decreased lever arm for bending forces (especially useful in peritrochanteric fractures vs. plate-and-screw construct).

Section 2 Upper Extremity

Shoulder Injuries

- **Sternoclavicular dislocation—"serendipity" view or CT scan reveals dislocation of sternoclavicular joint**
  - ▫ Anterior dislocation—more common, treated by closed reduction. The majority will remain unstable regardless of initial treatment modality, but these are typically asymptomatic.
  - ▫ Posterior dislocation—more serious—30% associated with significant compression of posterior structures. May cause dysphagia or difficulty breathing and sensation of fullness in the throat. Treated by closed reduction with a towel clip in the operating room. A thoracic surgeon should be on standby.
  - ▫ Chronic dislocation—treated by resection of the medial clavicle, with preservation and reconstruction of costoclavicular ligaments
  - ▫ Pseudodislocation—medial clavicular epiphysis is the last to close, at a mean age of 25 years. In younger patients, sternoclavicular dislocation is often a Salter-Harris type I or II fracture.
- **Clavicle fracture (** Fig. 11.1)
  - ▫ Classification—classified by thirds
    - Middle—80%
    - Distal—15%
    - Medial—5%
  - ▫ Associated injuries—open clavicle fractures associated with high rates of pulmonary and closed-head injuries
  - ▫ Treatment
    - Nonoperative treatment: midthird fracture has traditionally been treated nonoperatively, in a sling.
      - No difference in outcome between regular sling and figure-eight bandage
      - Risk of nonunion after midshaft fracture is higher in female and elderly patients and with fractures that are displaced, shortened more than 2 cm, or comminuted.
      - Lateral fractures have higher rates of nonunion compared with midshaft fractures.

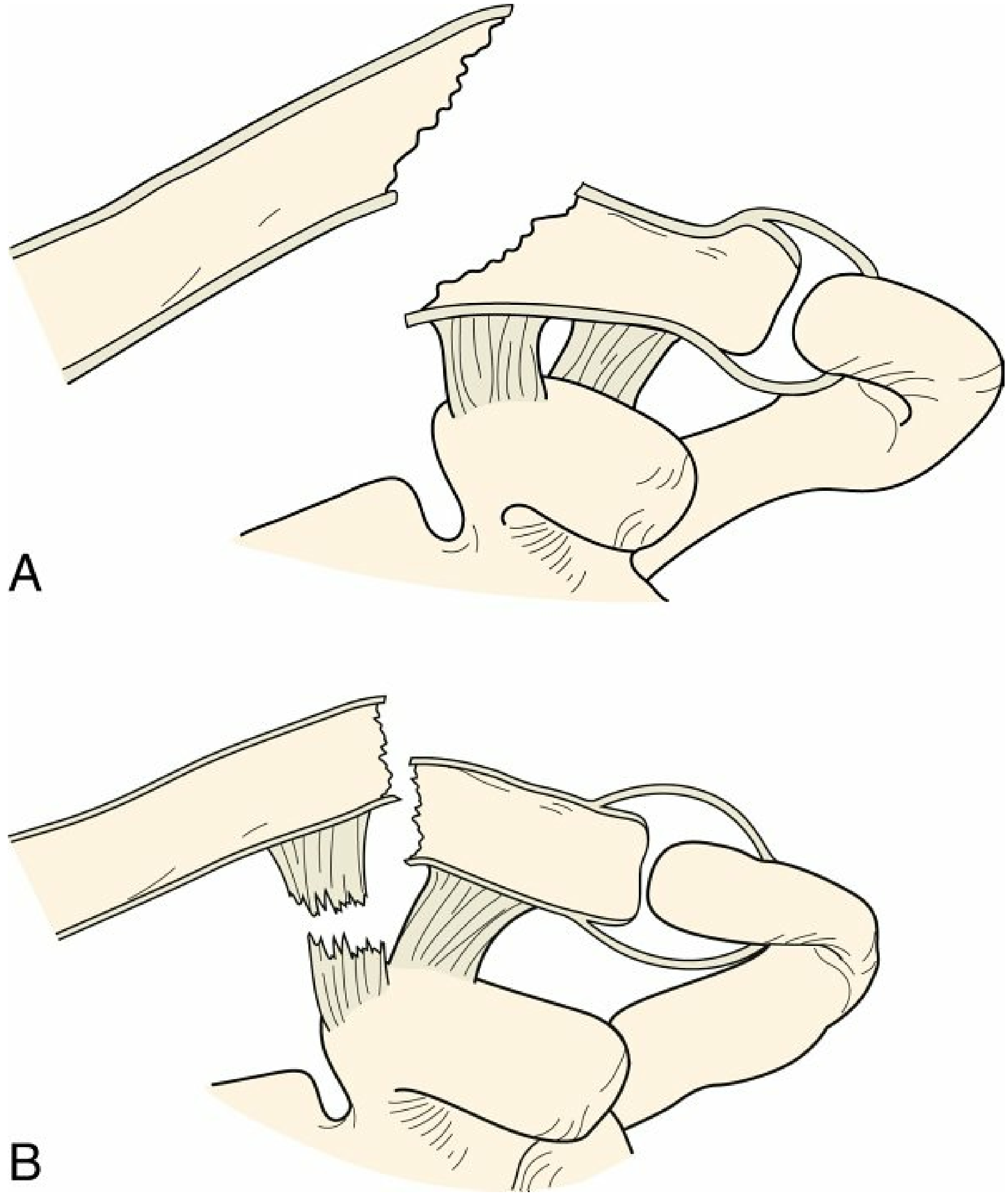


FIG. 11.1 When the distal end of the clavicle is fractured, the ligaments may either (A) remain intact and maintain apposition of the fracture fragments (type I) or (B) rupture, allowing wide displacement of the fragments (type II).
Redrawn from Rockwood CA, Green DP, editors: *Fractures,* ed 4, vol 1, Philadelphia, 1996, JB Lippincott.

- Operative treatment
  - Middle third
    - Have higher rates of nonunion and decreased shoulder strength and endurance (≈15%)
    - Absolute surgical indications: open fracture, displaced fractures with skin compromise, associated neurovascular injury
    - Relative surgical indications: floating shoulder (associated scapular neck fracture), shortening greater than 15–20 mm, complete displacement,

comminution

- Prospective randomized study comparing operative with nonoperative treatment of displaced midthird clavicle fractures: operative treatment group had a 10-point improvement in Constant and DASH (Disabilities of the Arm, Shoulder, and Hand) scores at all time points, earlier time to union, and statistically fewer nonunions, symptomatic malunions, and complications than the nonoperative treatment group.

- Distal third
  - Some recommend operative treatment of distal fractures that extend into the acromioclavicular joint, whereas others recommend a late Mumford procedure.
  - Type II distal clavicle fractures, which involve displacement, have the highest nonunion incidence, but many nonunions are asymptomatic. Nonoperative and operative management approaches provide similar results. Operative decision based on amount of displacement and individual patient demands. For example, **sling and early ROM are the best treatments for middle-aged woman with 100% displacement of a distal clavicle fracture.**
- Fixation options
  - Plate—typically dynamic compression plate; applied to superior aspect (better biomechanical strength but more prominent → hardware removal) or to anterior-inferior aspect (less hardware removal).
  - IM rod and screw—may be inserted percutaneously; higher rates of hardware irritation and complication
  - Avoid Steinmann pins, especially

nonthreaded—can migrate.

- **Acromioclavicular dislocation**
  - Classification—classified by extent of involvement of the ligamentous support and direction and magnitude of displacement. Coracoclavicular (CC) and acromioclavicular (AC) ligaments may be ruptured.
    - Type I—sprain of AC joint
    - Type II—rupture of AC ligaments and sprain of CC ligaments
    - Type III—rupture of both AC and CC ligaments
    - Type IV—clavicle is buttonholed through trapezius posteriorly
    - Type V—trapezius and deltoid detached
    - Type VI—Clavicle is dislocated inferior to coracoid
  - Treatment
    - Types I and II—always treated with brief immobilization in a sling
    - Type III—may be treated nonoperatively, but many advocate early operative treatment in patients who are heavy laborers and throwers. Weaver-Dunn procedure is the treatment of choice.
    - Types IV to VI—usually treated operatively
- **Scapula fracture**
  - Associated with pulmonary contusion, pneumothorax, clavicle fracture (i.e., floating shoulder), rib fracture, head injury, brachial plexus injury, upper extremity vascular injury, pelvic or acetabular fracture and spine fracture.
  - Scapula body fractures are generally treated in a sling for 7–10 days and then with early ROM.
- **Glenoid fracture**
  - Nonoperative treatment—used for nondisplaced fractures
    - Operative treatment—indicated for intraarticular fractures that are displaced more than 2 mm and for extraarticular fractures that are widely displaced. Approach is usually through a posterior portal, although the Neviaser portal may be used to place a superoinferior screw in the glenoid.
- **Glenoid neck fracture**
  - Nonoperative treatment—advocated by many in almost all cases
  - Operative treatment—indicated when glenoid neck and humeral head are translocated anterior to the proximal fragment or are medially displaced.
    - Reduction and plating are through a posterior approach between infraspinatus (suprascapular nerve) and teres

minor (axillary nerve).
        - The suprascapular nerve and artery are at risk from excessive superior retraction, whereas the circumflex scapular artery is at risk during the approach.

- **Scapulothoracic dissociation—result of significant trauma to chest wall, lung, and heart. Severe cases are treated essentially with a closed forequarter amputation.**
    - □ Associated with:
        - Brachial plexus avulsion
        - Subclavian or axillary artery injury
        - AC dislocation, clavicle fracture, and sternoclavicular dislocation
        - Mortality rate of 10%
    - □ Diagnosis should be suspected when there is a neurologic and/or vascular deficit. More than 1 cm of lateral displacement of the scapula on a chest radiograph is also suggestive.
    - □ Management
        - Hemodynamically stable: angiography before surgery. Vascular injury may potentially be treated nonoperatively owing to the extensive collateral network around the shoulder.
        - Hemodynamically unstable: high lateral thoracotomy or median sternotomy to control bleeding
        - Musculoskeletal injury treatment is controversial but is often nonoperative if vascular repair is not undertaken.
    - □ Functional outcome is based on severity of associated neurologic injury.
- **Floating shoulder—fracture of the glenoid neck and clavicle**
    - □ Some recommend fixation when a clavicle fracture is associated with a displaced glenoid neck fracture, whereas others do not consider it necessary (depends on stability of superior shoulder suspensory complex [SSSC]).
- **Proximal humerus fracture (** Fig. 11.2)
    - □ Neer classification (Neer defines "part" as displacement of >1 cm or angulation of >45 degrees); parts are articular surface, greater tuberosity, lesser tuberosity, and shaft

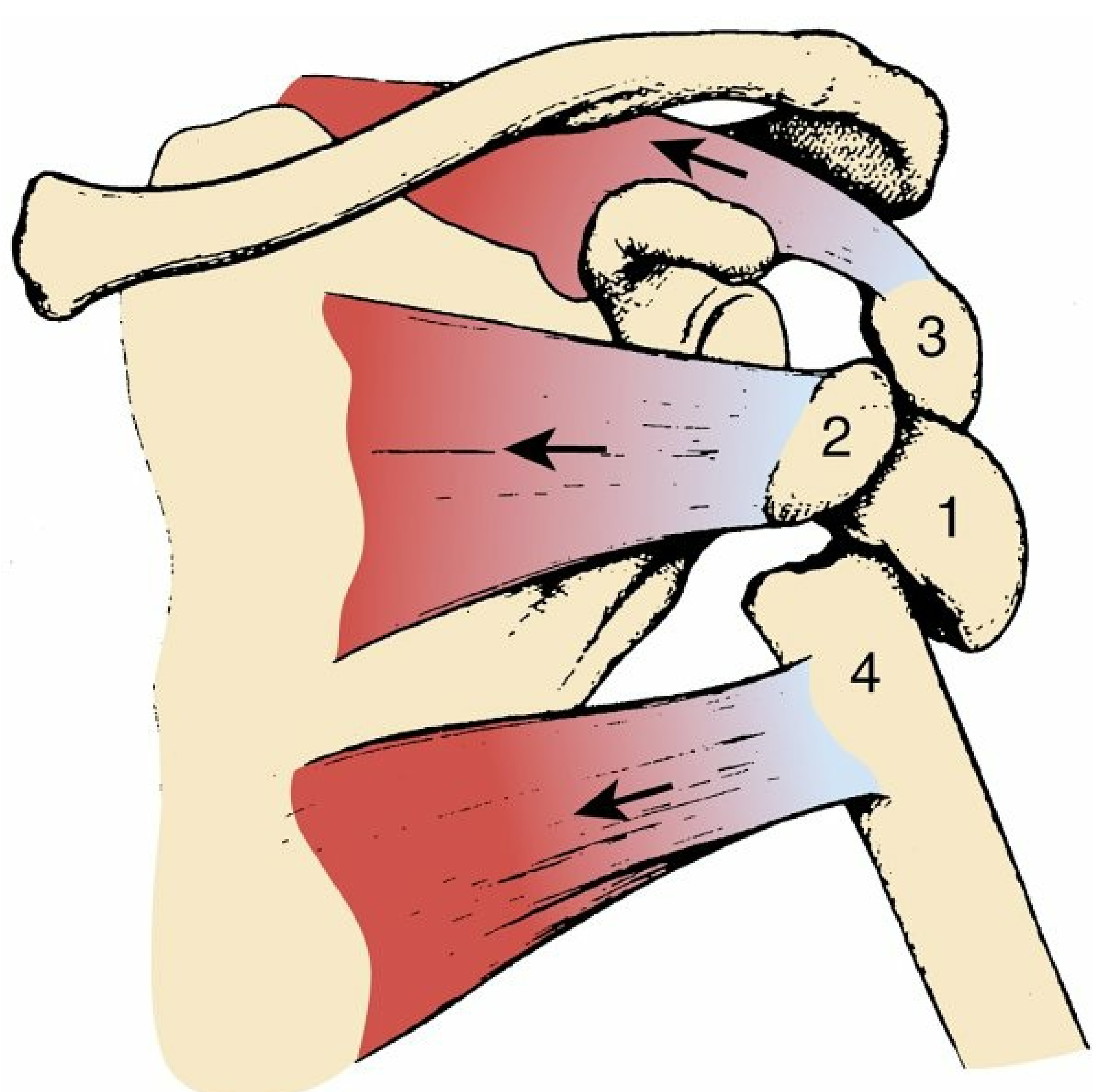


FIG. 11.2 Proximal humeral fracture. There are four parts: *1,* head; *2,* lesser tuberosity; *3,* greater tuberosity; and *4,* humeral shaft. *Arrows* indicate muscle contraction vector.
From Neer CS, Rockwood CA: Fractures and dislocations of the shoulder. In Rockwood CA, Green DP, editors: *Fractures in adults,* ed 2, Philadelphia, 1984, JB Lippincott, p 696.

- One-part—nondisplaced or minimally displaced fracture (often of the humeral neck)
- Two-part—displacement of tuberosity of more than 1 cm; or surgical neck with head/shaft angled or displaced
- Three-part—displacement of the greater or lesser tuberosities and articular surface
- Four-part—displacement of shaft, articular surface, and both tuberosities.
    - "Head splitting" is a variant, with split through the articular surface (usually requires replacement for treatment).

□ Treatment

- One-part—sling for comfort and early mobilization
- Two-part—repair of the displaced tuberosity with sutures or

tension band wiring; surgical neck fractures can normally be managed nonoperatively.

- Unstable, nonimpacted fractures may be treated with closed reduction with percutaneous pinning (CRPP), ORIF with locking plate fixation, or IM nailing
  - Varying humeral nail designs. Straight nails are placed through a more central entry point (through superior articular cartilage) that can provide additional point of fixation. Nails with proximal bend are placed through an entry point just medial to the rotator cuff insertion.
- Immediate physical therapy during nonoperative management results in faster recovery.
- Greater tuberosity fractures are displaced superiorly and posteriorly owing to deforming pull of supraspinatus, infraspinatus, and teres minor. Healing in a displaced position would block abduction and external rotation.
  - Surgery is indicated for displacement greater than 5 mm. In young patients with good bone, screws alone can be used, but nonabsorbable suture technique should be used in older patients.

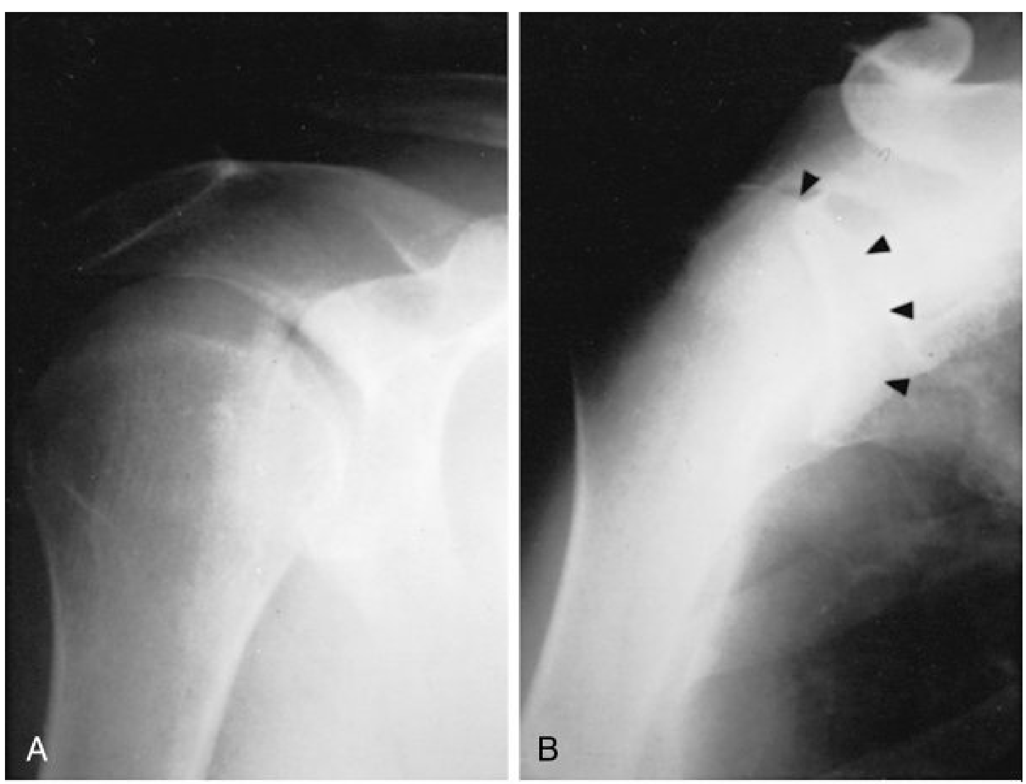
- Three-part
  - ORIF for young patients, with repair of the tuberosities or rotator cuff
    - Screw cutout is the most common complication following ORIF with a periarticular locking plate.
  - Hemiarthroplasty for older patients, with repair of the rotator cuff/tuberosities
- Four-part—same as for three-part
  - Humeral height can be judged most reliably using the superior border of the pectoralis major insertion.
  - Nonanatomic placement of the tuberosities leads to significant impairment in external rotation kinematics and an eightfold increase in torque requirements.

- Complications
  - Avascular necrosis (AVN)
    - Factors associated with humeral head ischemia (Hertel criteria):
      - Disruption of the medial periosteal hinge
      - Medial metadiaphyseal extension less than 8 mm
      - Increasing fracture complexity
      - Displacement greater than 10 mm
      - Angulation greater than 45 degrees
  - Neurovascular injury
    - Axillary nerve injury
      - Lateral pins placed during CRPP place the nerve most at risk.
    - Anterior pins placed during CRPP risk the biceps tendon, cephalic vein, and musculocutaneous nerve.
  - Hardware failure
    - The most common complication after locking plate fixation is screw cutout.
  - Nonunion
    - Most common after two-part fracture of surgical neck
    - Nonunion of greater tuberosity following arthroplasty—loss of active shoulder elevation

- **Shoulder dislocation**
  - Helpful mnemonics:
    - TUBS: *t*raumatic, *u*nidirectional, *B*ankart lesion, requires *s*urgical treatment.
    - AMBRI: *a*traumatic, *m*ultidirectional, often *b*ilateral, *r*ehabilitation is primary initial treatment, *i*nferior capsular shift indicated for failure of conservative therapy.
  - Anterior—most common shoulder dislocation
    - Most commonly caused by fall on an abducted, externally rotated shoulder
    - Diagnosis
      - Apprehension sign
      - Axillary view is diagnostic.
      - Usually traumatic and unilateral
      - Usually painful
    - Treatment: reduction (multiple maneuvers available)
      - Sling for 2 weeks in the elderly and 4 weeks in the

young, followed by rotator cuff strengthening
- Operative treatment should be considered in cases of recurrence or rotator cuff tear.
  - The most common associated injury at arthroscopy after acute dislocation is anterior labral tear, followed by anterior capsular insufficiency and Hill-Sachs lesion.
- High recurrence rate (≈50%) in young patients (owing to unstable labral tear)
- High incidence of rotator cuff injury in older patients (>45 years)

□ Multidirectional
- Diagnosis
  - Often bilateral
  - Often atraumatic, not painful
  - Examination of the shoulder reveals subluxation posteriorly as well as anteriorly and inferiorly.
  - Generalized ligamentous laxity



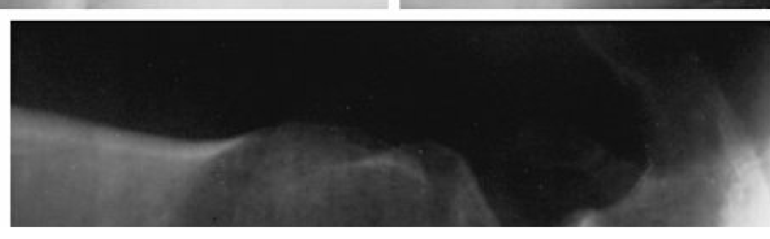


FIG. 11.3 Anteroposterior radiographs. (A) In the sagittal plane of the body (missed posterior dislocation). (B) In the sagittal plane of the scapula, overlap of the head and glenoid *(arrowheads)* indicates a dislocation. (C) Axillary or computed tomography scans are the best views for diagnosing posterior dislocation or fracture-dislocation.
From Browner BD et al, editors: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier.

- Treatment
  - Rotator cuff strengthening
  - Inferior capsular shift is indicated if instability is refractory to nonoperative treatment.

□ Posterior (Fig. 11.3)
- Diagnosis
  - Associated with seizures and electric shock
  - Often missed but easily seen on axillary view
  - **Lack of external rotation is key physical examination finding in fixed posterior dislocations.**
  - Fracture of lesser tuberosity or reverse Hill-Sachs lesion may also be present.
- Treatment
  - Immobilization for 3–6 weeks
  - Rotator cuff strengthening
  - Possible open bone grafting of humeral head defect and repair of posterior labral tear
  - Allograft, coracoid transfer, or resurfacing for large defects

□ Inferior (luxatio erecta)
- Diagnosis
  - Associated with motor vehicle collision or sporting injury
  - **Arm is typically abducted between 100 and 160 degrees.**
  - Diminished or absent pulses
- Treatment
  - Closed reduction successful in 50%
  - Capsular reconstruction if unstable

Humeral Injuries

- **Shaft fracture**
  - Classification by location and fracture pattern
  - Treatment
    - Nonoperative treatment: functional brace if there is less than 20 degrees of anterior angulation, less than 30 degrees of valgus/varus angulation, or less than 3 cm of shortening; **contraindicated in patients with associated brachial plexus palsy**
    - Operative treatment: open fracture, floating elbow, polytrauma, pathologic fracture, associated brachial plexus injury
      - ORIF
        - Probably the gold standard
          - Proximal two-thirds—anterolateral approach
          - Distal half—posterior approach
          - Need for radial nerve exploration—lateral approach
        - Higher union rates and decreased secondary operations
        - **Weight bearing to tolerance is safe after plate fixation**.
      - IM nail
        - Possibly better for segmental or shaft/proximal humerus combination as well as pathologic fracture
        - Complication rate may be higher and may be associated with higher rates of reoperation than plate fixation.
      - Distal locking screw risks
        - Radial nerve with lateral-to-medial screw
        - Musculocutaneous nerve with anteroposterior screw
  - Complications
  - Radial nerve palsy (5%–10%)
    - When to observe:
      - The vast majority (up to 92%) resolve with observation for 3 to 4 months.

- Brachioradialis followed by extensor carpi radialis longus **(wrist extension in radial deviation) are the first to return**, whereas extensor pollicis longus and extensor indicis proprius are last to return.
- When to explore
  - Open fracture
    - A higher likelihood of transection
    - Perform ORIF of fracture at time of exploration.
- Controversial whether to observe or explore
  - Secondary nerve palsy (i.e., after fracture manipulation)
  - Spiral or oblique fracture of distal-third (Holstein-Lewis) fracture
- Management of palsy that does not recover is also controversial as to timing of electromyography, nerve exploration, and tendon transfers.

□ Nonunion—treated with compression plate with bone graft if atrophic.

□ Shoulder pain; some papers report a high incidence of shoulder pain, whereas others do not. Overall incidence is higher with IM nails.

▪ **Distal humerus single-column (condyle) fracture**

□ Classification
- Classified as Milch types I and II lateral condyle fractures (more common) and types I and II medial condyle fractures.
- In type I lateral condyle fractures the lateral trochlear ridge is intact, and in type II lateral condyle fractures there is a fracture through lateral trochlear ridge (Fig. 11.4).

□ Treatment—type I nondisplaced: immobilize in supination (lateral condyle fracture) or pronation (medial condyle fracture); otherwise, CRPP or ORIF

□ Complications: cubitus valgus (lateral) or cubitus varus (medial), ulnar nerve injury, and degenerative joint disease (DJD)

▪ **Distal humerus both-column fracture**

□ Presentation: five major fragments identified
- Capitellum/lateral trochlea
- Lateral epicondyle
- Posterolateral epicondyle

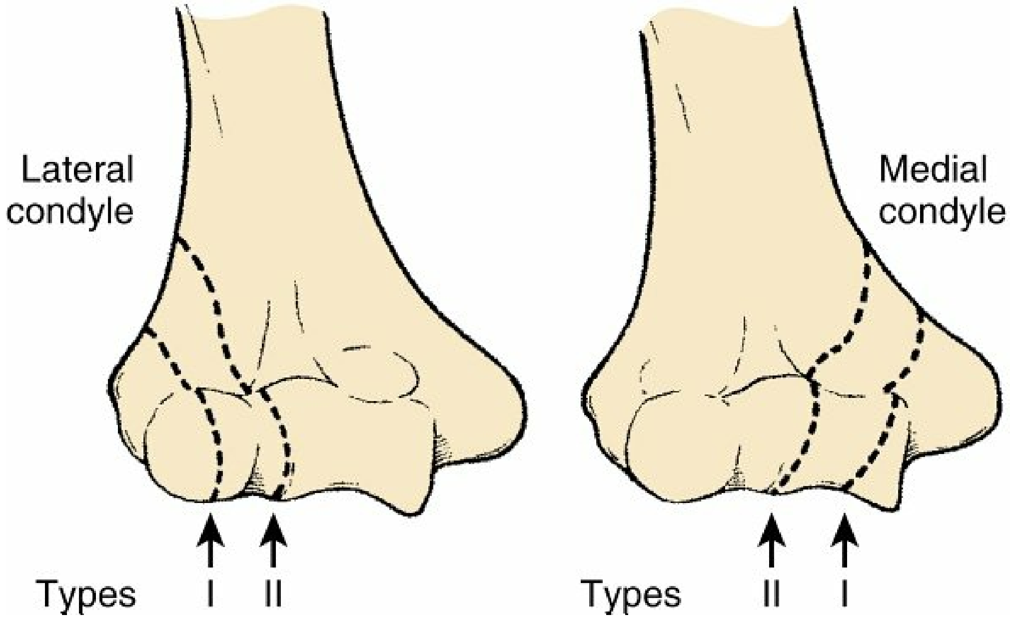


FIG. 11.4 Humeral condyle fractures.
From Gelman MI: *Radiology of orthopedic procedures: problems and complications,* ed 24, Philadelphia, 1984, WB Saunders, p 56, reprinted by permission.

- Posterior trochlea
- Medial trochlea/epicondyle

□ Treatment (goal is early ROM with <3 weeks of immobilization)

- ORIF using a posterior approach with two plates applied to either column
  - Biomechanical studies support both parallel placement (one plate medial, one plate lateral) and perpendicular placement (one plate medial, one plate posterolateral) configurations
  - Used with olecranon osteotomy or triceps split/peel (final muscle strength similar with both)
  - In an open fracture, ORIF by means of a triceps split through the defect should be used, producing better results than osteotomy.
  - Very distal fractures are more difficult and frequently require reoperation (almost 50%) for stiffness
- **No benefit from ulnar nerve transposition during ORIF**
- "Bag-of-bones" technique—reasonable in patients with dementia and those who have severe medical comorbidities that prevent surgical treatment
- Total elbow arthroplasty—useful for comminuted fractures in patients with low functional demands older than 65 years, particularly those with osteoporosis or rheumatoid arthritis

□ Complications

- Stiffness

        - Most common complication
        - Initially treated with static-progressive splinting
    - Loss of elbow muscle strength of 25%
    - Ulnar nerve injury
        - Treated with anterior transposition
    - Heterotopic ossification (4%)
        - Infection

- **Capitellum fracture**
    - Treatment
        - Type I (complete fracture)—if nondisplaced, splinted for 2 to 3 weeks and then allowed motion; if displaced more than 2 mm, ORIF.
        - Type II (shear fracture of articular cartilage)—if nondisplaced, splinted for 2 to 3 weeks and then allowed motion; if displaced, fragment excision.
        - Type III (comminuted fractures)—if displaced, fragment excision.
        - Type IV (fracture involving capitellum and trochlea)—ORIF; lateral approach recommended
    - Complications: nonunion (1%–11% with ORIF), olecranon osteotomy nonunion, ulnar nerve injury, heterotopic ossification (4% with ORIF), and AVN of capitellum

Elbow Injuries

- **Olecranon fracture**
    - Treatment
        - Less than 1–2 mm displaced—splinted at 60–90 degrees for 7–10 days, followed by gentle active ROM exercises.
        - Tension band—stainless steel wire or braided cable, not braided suture material
            - The wire loop should be dorsal to the midaxis of the ulna, thus transforming tensile forces at the fracture site into compressive forces at the articular surface.
            - Kirschner wires are (K-wires) buried in anterior cortex for increased stability. Protrusion through the anterior cortex, however, is associated with reduced forearm rotation.
            - Migration of K-wires and prominent or painful hardware occurs in 71%.
            - **Compared with K-wires that are positioned into**

the intramedullary canal, wires that penetrate the volar ulna cortex are associated with a higher potential risk of diminished forearm rotation.

- IM screw fixation—inadequate by itself, but a properly placed 7.3-mm partially threaded screw with tension band wiring works well.
- Plate fixation (dorsal or tension side)—preferred technique for oblique fractures that extend distal to the coronoid process; more stable than tension band wiring
- Excision with triceps advancement—used for nonreconstructible proximal olecranon fractures in elderly patients with low functional demands. Reattached close to the articular surface. Resection of more than 50% of the olecranon should be avoided.

□ Complications: decreased ROM, DJD, nonunion, ulnar nerve neurapraxia, and instability

▪ **Coronoid fracture**

□ Classification

- Regan and Morrey classification
- Type I—fracture of the tip of the coronoid process
- Type II—fracture of 50% or less of coronoid
- Type III—of greater than 50% of coronoid
- O’Driscoll classification
    - Tip
        - Anteromedial process—caused by a varus posteromedial rotatory force and may be associated with posteromedial instability. Injury is at the attachment site of the anterior bundle of the medial collateral ligament.
    - Basal

□ Treatment

- Type I—associated with episodes of elbow instability. If instability persists, cerclage wire or No. 5 suture is applied through drill holes; if instability does not persist, no operation.
- Types II and III—ORIF helps restore elbow stability; stability must be confirmed before nonoperative treatment begins.

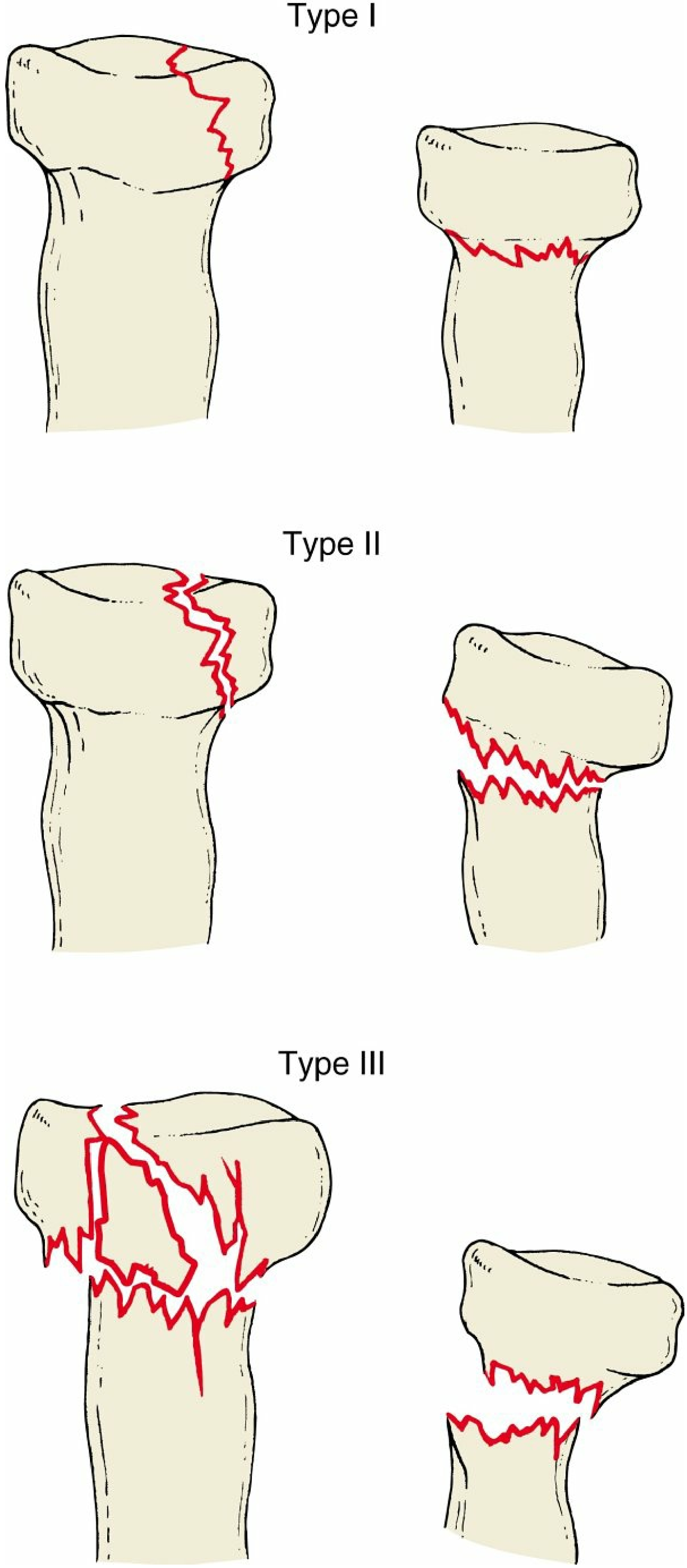

Type I
Type II
Type III

FIG. 11.5 Modified Mason classification system for radial head fractures.
From Browner BD et al, editors: *Skeletal trauma*, ed 4, Philadelphia, 2008, Elsevier.

- Complications: instability (particularly medial) and DJD

- **Radial head fracture**
  - Classification (Fig. 11.5)
    - Type I—nondisplaced
    - Type II—partial articulation with displacement
    - Type III—comminuted fractures involving the entire head of the radius
    - Type IV—fractures associated with ligamentous injury or other associated fractures
  - Treatment
    - Type I—Splinted for no more than 7 days, and then allowed motion.
    - Type II—nonsurgical treatment with analgesics and active ROM as symptoms resolve if elbow is stable and there is no block to motion with good reduction. Otherwise, ORIF. Surgery provides better results (90%–100% good or excellent).
    - Type III—replacement of the radial head, usually with a metal implant. ORIF if fewer than three pieces. Excision only in elderly patients with low functional demands.
    - Type IV—requires surgical repair: either ORIF or metallic radial head replacement must be used. Excision must not be done without addition of radial head implant.
    - Safe zone for ORIF of radial head/neck is 110-degree arc (i.e., 25%) along lateral side, defined by radial styloid and Lister tubercle.
  - Complications
    - Loss of motion
    - Posterior interosseous nerve (PIN) injury
      - Arm is pronated to avoid injury.
    - Radial shortening if Essex-Lopresti injury
    - Synovitis if a silicone elastomer (e.g., Silastic) radial head implant is used
- **Dislocation**
  - Classification
    - 80% are posterolateral; the rest are posterior, anterior, medial, lateral, or divergent
    - Simple (no associated fracture) or complex (fracture)
    - Associated injuries
      - Avulsion fracture of medial or lateral epicondyle
      - Radial head and neck fractures

        - Coronoid fractures
        - Osteochondral injury
- **Mechanism of injury in elbow dislocation: disruption of circle of Horii; begins laterally and progresses medially in three stages:**
    - Stage 1 (posterolateral rotational instability)—lateral collateral ligament partially or completely disrupted
    - Stage 2 (perched ulna)—additional anterior and posterior disruption. Incomplete posterolateral dislocation with subluxation/dislocation of radial head, medial edge of ulna resting on the trochlear, and coronoid perched on the trochlear.
    - Stage 3 (complete dislocation)—elbow dislocated and coronoid lying posterior to trochlear.
    - Stage 3A—all soft tissue sleeve including posterior part of medial collateral ligament (MCL) disrupted (anterior medial collateral ligament intact)
    - Stage 3B—entire MCL (including anterior bundle) disrupted. Varus, valgus, and rotatory instability all manifest after reduction. Immobilized in cast in 90-degree flexion.
    - Stage 3C—soft tissues stripped off entire distal humerus (including flexor-pronator and common extensor origins). Grossly unstable even in flexion.
- **Treatment**
    - Simple—brief immobilization (1 week) for most and then allowed motion. Long-term results are good.
    - Complex—surgical treatment is indicated. Anterior or divergent dislocations are usually high-energy injuries with a much higher incidence of open wounds, neurovascular injury, fracture, and recurrent instability.
- **Complications**
    - Stiffness and flexion contracture
        - Directly correlated with period of immobilization longer than 3 weeks
    - Heterotopic ossification (collateral ligaments)
    - Ulnar or median nerve injury
    - Brachial artery injury
- **Terrible triad of the elbow**
    - Elbow dislocation with lateral collateral ligament injury, radial head fracture, and coronoid fracture
        - The lateral collateral ligament injury is typically a ligamentous avulsion from the origin on the distal humerus.
    - Always unstable and requires treatment
    - Treatment
        - Coronoid ORIF

- Radial head ORIF or replacement
- Lateral collateral ligament repair (typically to distal humerus)
- Possible MCL repair depending on stability

Forearm Fractures

- **Monteggia fractures**
  - Diagnosis/classification
    - Bado classification
      - Type 1 (60%)—anterior radial head dislocation and apex anterior proximal-third ulna fracture
      - Type 2 (15%)—posterior radial head dislocation and apex posterior proximal-third ulna fracture. Annular ligament is disrupted in posterior Monteggia fracture dislocations.
      - Type 3—lateral radial head dislocation and proximal ulnar metaphyseal fracture
      - Type 4—anterior radial head dislocation and proximal-third radius and ulna fractures
      - Monteggia-equivalent or variant—radial head fracture instead of dislocation
        - Interosseous membrane evaluation is important with Monteggia and Monteggia-equivalent injuries.
    - Physical examination—findings considered abnormal if more than 3 mm of instability is noted when the radius is pulled proximally, indicating injury. If injury is greater than 6 mm, both the interosseous membrane and the triangular fibrocartilage complex (TFCC) are injured.
    - Diagnosis confirmed with findings on MRI or ultrasonography
    - Middle third is strongest and most important for stability.
  - Treatment—all Monteggia fractures in adults should be treated with ORIF.
    - The radial head normally reduces and is stable. If not, the most common cause is a nonanatomic reduction of the ulna.
    - If the ulna is anatomically placed and the radial head does not reduce, an open reduction with a separate approach is required to address the annular ligament.
  - Complications
    - The complication rate is higher for Monteggia-equivalent and

Bado type II injuries.

- PIN injury
  - Usually resolves spontaneously and should be observed for 3 months
- Redislocation/subluxation, synostosis, and loss of motion

▪ **Both-bone forearm fractures**

- □ Classification—displaced versus nondisplaced
- □ Treatment
  - ORIF in adults
  - ORIF with cancellous bone graft
    - Significant segmental bone loss
    - Bone loss associated with open injury
    - Routine use of bone graft for closed, comminuted fractures is no longer indicated.
- □ Complications
  - Malunion (stiffness/deformity)
    - Restoration of the radial bow is directly related to functional outcome.
  - Nonunion
    - Typically due to technical error or use of IM fixation
    - Treated with ORIF and bone grafting.
  - Refracture after plate removal
    - Associated with premature plate removal (<12–18 months)
    - After plate removal, a functional forearm brace should be worn for 6 weeks, and activity protected for 3 months.
  - Synostosis
    - Associated with single-incision approach to ORIF
    - Treated with early excision, irradiation, and indomethacin
  - PIN injury
    - Henry (volar) approach to the middle and upper thirds of radial diaphysis
  - Vascular injury

▪ **Ulna "nightstick" fractures**

- □ Classification: stable (traditional definition is <50% displacement) versus unstable (newer literature suggests that 25%–50% displacement or 10–15 degrees of angulation is unstable)
- □ Treatment
  - Distal two-thirds, less than 50% displaced, and less than 10 degrees of angulation—short-arm cast or functional fracture

brace with good interosseous mold
    - Proximal third, very distal shaft/head, more than 50% displaced, or more than 10 degrees angulation—ORIF
    - For nondisplaced fractures, there is no difference in outcome between surgical and nonsurgical treatments.
  - Complications: malunion/nonunion
- **Distal-third radius fracture with radioulnar dislocation (Galeazzi)**
  - Diagnosis/classification: fracture of the radius (usually at junction of middle and distal thirds), with distal radioulnar joint (DRUJ) instability
    - DRUJ instability
      - DRUJ is unstable in 55% of patients in whom the radial fracture is less than 7.5 cm from the articular surface.
      - DRUJ is unstable in 6% of patients in whom the radial fracture is more than 7.5 cm away from the articular surface.
      - Signs of DRUJ instability include ulnar styloid fracture, widened DRUJ on posteroanterior view, dislocation on lateral view, and 5 mm or more of radial shortening.
  - Treatment
    - ORIF of the radius followed by supination of the forearm and assessment of the DRUJ.
      - Reduced and stable: protective splint and early motion
      - Reduced and unstable
        - Large ulnar styloid fragment: ORIF of styloid and immobilization in supination.
        - No fragment: ulna pinned to radius and immobilized in supination.
      - Irreducible
        - Most commonly due to interposition of extensor carpi ulnaris tendon
        - DRUJ approached via dorsal incision for removal of block.
  - Complications: malunion/nonunion and DRUJ subluxation

Wrist Fractures (Table 11.2)

- **Distal radius fractures**

- Lafontaine predictors of instability—patients with three or more factors have high chance of loss of reduction. Among these variables, radial shortening is the most predictive of instability, followed by dorsal comminution.
  - Dorsal angulation greater than 20 degrees
  - Dorsal comminution greater than 50%, palmar comminution, intraarticular comminution
  - Initial displacement greater than 1 cm
  - Initial radial shortening greater than 5 mm
  - Associated ulnar fracture
  - Severe osteoporosis
- Treatment—based on Fernandez classification
  - Type I—usually an extraarticular metaphyseal fracture. Comminution determines stability. The volarly displaced radial fracture is much more unstable. Conservative treatment with reduction and casting if stable, and CRPP versus internal or external fixation if unstable. **American Academy of Orthopaedic Surgeons Clinical Practice Guidelines gives a moderate-strength recommendation for surgical fixation of distal radius fractures.**
  - Type II—shearing injury of the joint surface (volar or dorsal lip or radial styloid). This type is usually unstable, and carpal subluxation frequently occurs. Treatment is with ORIF.
  - Type III—articular compression (die-punch) injuries follow patterns described by Melone.
    - Conservative treatment if nondisplaced
    - ORIF with disimpaction of the articular surface if displaced. Arthroscopy may be adjunct.
  - Type IV—rare and follows high-energy trauma
    - These are avulsion fractures with radiocarpal fracture dislocations.
    - Surgical repair of the avulsed styloid usually restores stability. Treated with closed or (more frequently) open reduction, pin or screw fixation, or tension wiring.
  - Type V—combination fractures of types I to IV after high-energy trauma. These are very severe and unstable fractures. There are always associated injuries. Treatment is open, with combined methods.
- Outcomes—restoration of anatomic alignment best predictor of a good outcome
  - Loss of radial length and volar tilt is the most important; radial inclination is less important.

- Articular step-offs of more than 1–2 mm also predict poor outcome.

- Complications—loss of reduction, malunion or nonunion, median nerve neuropathy, weakness, tendon adhesion, instability, extensor pollicis longus rupture, dorsal intercalated segment instability (DISI), Volkmann ischemic contracture, and complex regional pain syndrome (CRPS). Some studies have shown that vitamin C can reduce the likelihood of CRPS following distal radius fracture.

- **Other variants and eponyms**
  - Dorsal rim radius fractures—dorsal Barton
    - Classification—Fernandez type II
    - Treatment—ORIF with dorsal approach in the vast majority
    - Complications—same as for distal radius fracture

Table 11.2

Adult Wrist Fractures

Injury	Eponym/Other Name	Classification	Treatment	Complications
Distal radius fracture	Colles (dorsal displacement)	Frykman (I–VIII; even numbers = ulnar styloid fractures) I—extraarticular III—intraarticular radiocarpal joint fracture V—intraarticular radioulnar joint fracture VII—displaced intraarticular radiocarpal and radioulnar joint fractures	Distraction, manipulation, splint in 15 degrees palmar flexion and ulnar deviation, external fixation, and/or ORIF if comminuted/unstable; external fixation for severe comminution; ORIF for large fragments with >15-degree dorsal tilt, >1–2-mm articular displacement; bone grafting for comminuted fractures	Loss of reductio nonunion, malunion, n neuropathy/ tunnel synd weakness, te adhesion/ru instability, extensor pol longus ruptu DISI >15 de (extension), side pain (shortening) CRPS, Volk ischemic contracture
	Smith (volar displacement)	Intraarticular vs. extraarticular	Distraction, manipulation, splint in supination, flexion; CRPP vs. ORIF (volar approach)	Missed diagnos others simila Colles fractu complicatio
Dorsal rim of radius	Dorsal Barton	Fernandez type II	Majority: ORIF with dorsal approach	Similar to Colle fracture

fracture				complicatio
Radial styloid fracture	Chauffeur's	Fernandez type II	Reduction, CRPP, cannulated screw or plate; immobilization in ulnar deviation	Similar to Colle fracture complicatio associated perilunate ir must be rul (ORIF)
Volar rim of radius fracture	Volar Barton	Fernandez type II	Majority: ORIF with volar buttress plate	Similar to Colle fracture complicatio
Distal radioulnar joint dissociation		Based on ulna displacement; fracture of base of ulnar styloid associated with TFCC tear	Dorsal—reduction, full supination, long-arm cast for 6 wk Volar—reduction (may require open reduction), long-arm cast for 6 wk in pronation	Osteochondral fracture, TF injury, ulnar compressio instability, arthrosis, w grip, decrea forearm rota

- □ Radial styloid fractures—chauffeur's fracture
  - Diagnosis/classification—frequently high-energy trauma in young adults. Fernandez type II is associated with perilunate injuries.
  - Treatment—CRPP or ORIF with screws; immobilize in ulnar deviation.
  - Complications—same as for distal radius fracture
- □ Volar rim radius fractures—volar Barton fracture (Fig. 11.6)
  - Classification—Fernandez type II
  - Treatment—usually with ORIF by means of the volar approach; closed reduction (rare)
  - Complications—same as for distal radius fracture
- □ DRUJ injuries
  - Diagnosis/classification—fracture of the base of the ulnar styloid, associated with TFCC tear
  - Treatment—closed or open reduction to achieve anatomic ulnar styloid reduction; immobilized in supination
  - Complications—osteochondral fracture, ulnar nerve compression, instability, arthrosis, weak grip, decreased forearm rotation

Carpal Injuries

- **See** Chapter 7, Hand, Upper Extremity, and Microvascular Surgery.

Hand Injuries

- **See** Chapter 7, Hand, Upper Extremity, and Microvascular Surgery.

Section 3 Lower Extremity and Pelvis

Pelvic and Acetabular Injuries

- **Pelvic ring injuries**
  - Diagnosis
    - Mechanism of injury—often high-energy
    - Associated injuries common (chest, head, other orthopaedic)
    - Nonpelvic sources of bleeding must be ruled out.

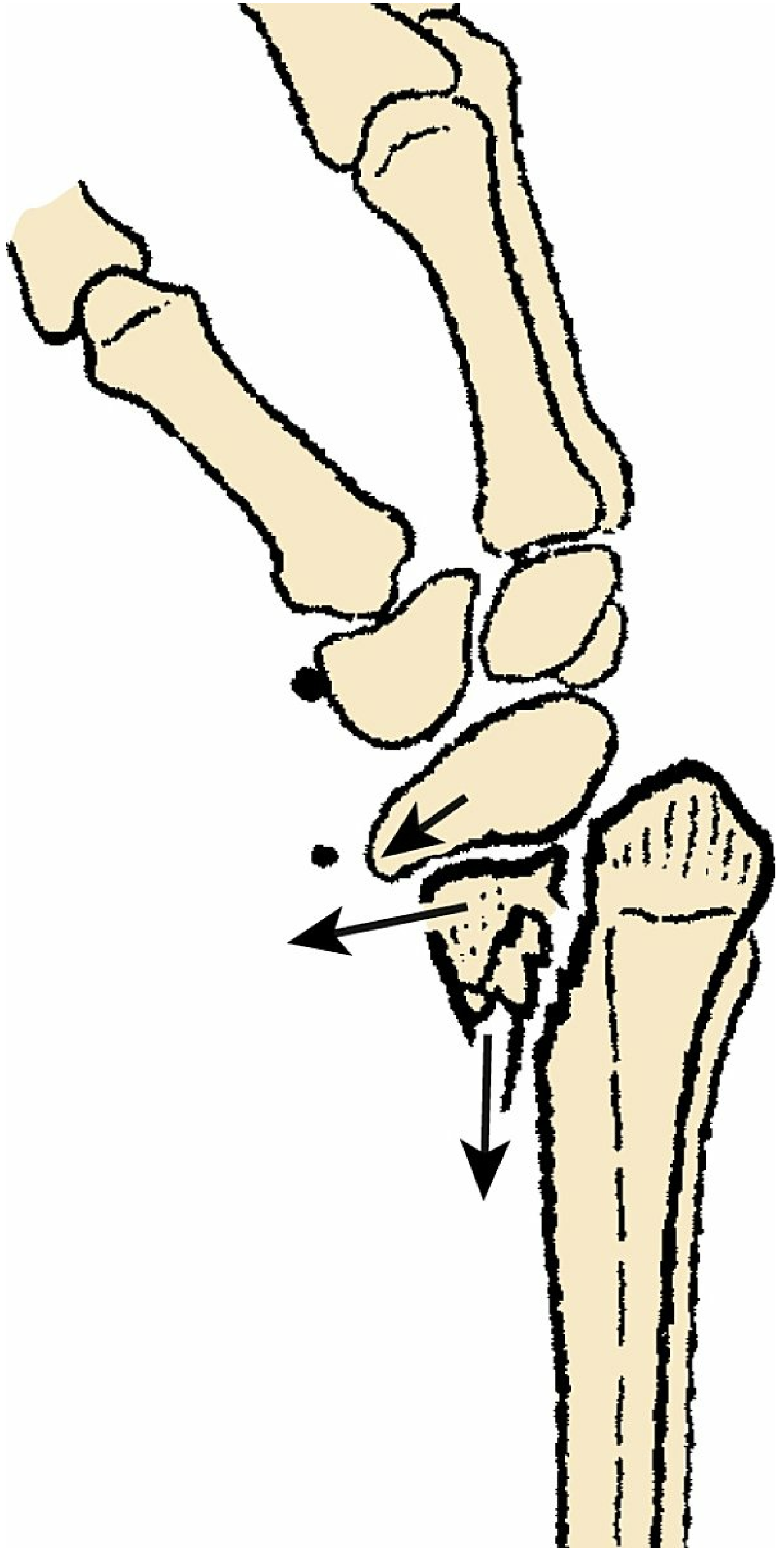


FIG. 11.6 The Barton fracture (volar). *Arrows* indicate displacement force vectors.
From Connolly JF, editor: *DePalma's the management of fractures and dislocations: an atlas,* ed 3, Philadelphia, 1981, WB Saunders, p 1028, reprinted by permission.

- Mortality usually related to nonpelvic injuries.

- **Radiographs**
  - AP pelvis
  - Inlet—evaluation of AP displacement of sacroiliac (SI) joint and internal/external rotational deformity
  - Outlet—evaluation of vertical displacement of SI joint and flexion of hemipelvis

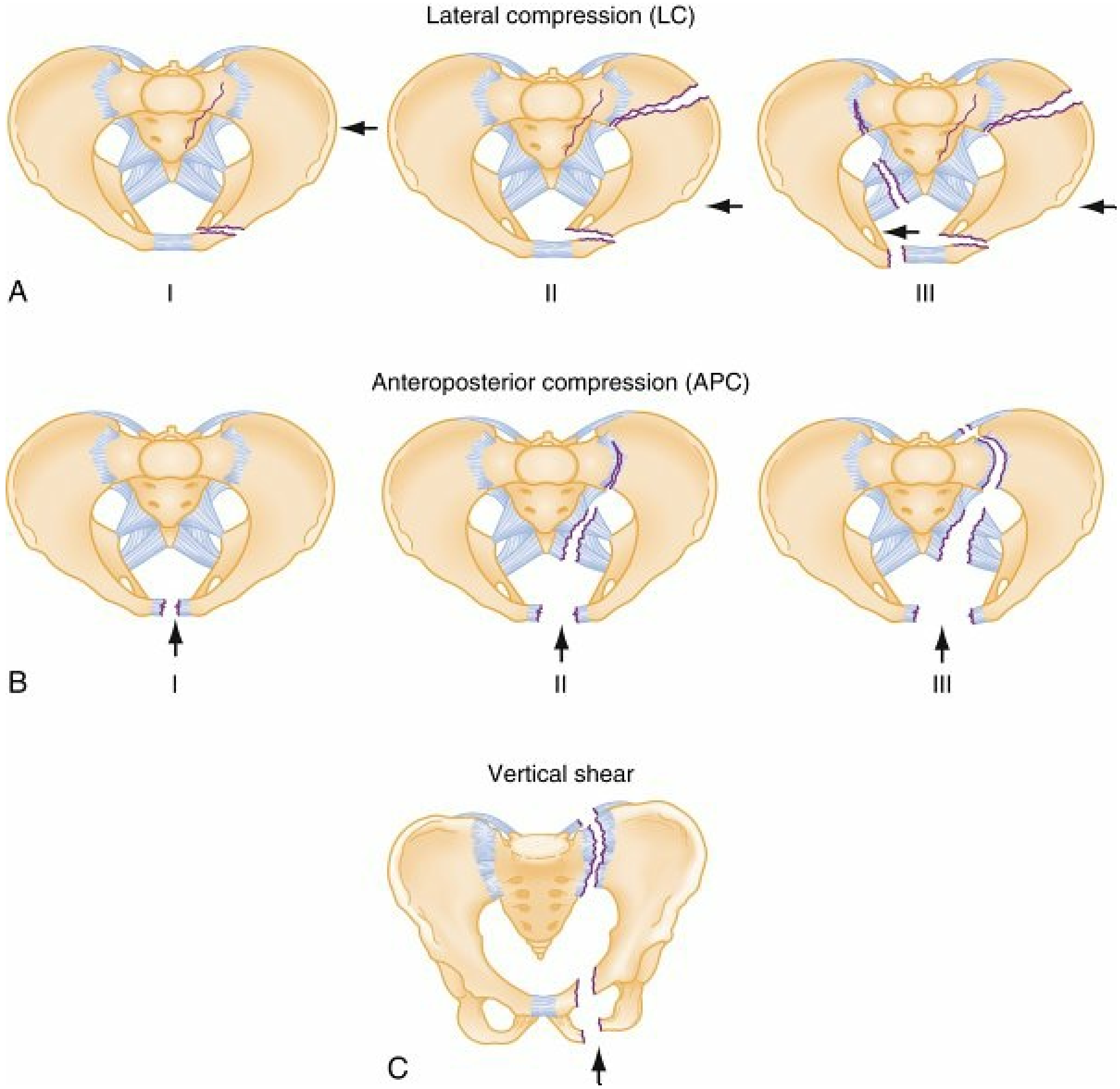


FIG. 11.7 Young-Burgess classification. (A) Lateral compression. Type I: a posteriorly directed force causing a sacral crushing injury and horizontal pubic ramus fractures ipsilaterally. Type II: a more anteriorly directed force causing horizontal pubic ramus fractures with an anterior sacral crushing injury and either disruption of the posterior sacroiliac joints or fractures through the iliac wing. Type III: an anteriorly directed force that is continued, causing external rotation of the contralateral side; the sacroiliac joint is opened posteriorly and the sacrotuberous and spinous ligaments are disrupted. (B) Anteroposterior compression. Type I: symphysis disrupted but with intact posterior ligamentous structures. Type II: continuation of a type I fracture with disruption of the sacrospinous and potentially the sacrotuberous ligaments and an anterior sacroiliac joint opening. Type III: continuation force disrupts the sacroiliac ligaments. (C) Vertical shear: vertical fractures in the rami and disruption of all posterior ligaments. This injury is equivalent to an anteroposterior type III or a completely unstable and rotationally unstable fracture. *Arrows* indicates the direction of force.
Redrawn from Young JWR, Burgess AR: *Radiologic management of pelvic ring fractures,* Baltimore, 1987, Urban & Schwarzenberg.

□ CT—particularly useful for evaluation of posterior pelvic injury patterns

□ Classification

- Young-Burgess (Fig. 11.7)—based on injury mechanism. Theorized to predict mortality, transfusion requirements, and associated nonorthopaedic injuries. Newer studies question its predictive value. One large series found it did predict transfusion requirements but did not predict mortality or associated nonorthopaedic injuries well.

- Lateral compression (LC)—all have anterior transverse pubic ramus fracture.
  - LC I—sacral compression fracture
  - LC II—posterior iliac wing fracture
  - LC III—contralateral anteroposterior compression injury (windswept pelvis)
    - Thought to be due to a rollover mechanism
- Anteroposterior compression (APC)—all have symphyseal diastasis.
  - APC I—symphyseal diastasis less than 2.5 cm
    - Stretching of anterior SI ligaments
  - APC II—symphyseal diastasis greater than 2.5 cm with widening of SI joint anteriorly
    - Rupture of sacrotuberous, sacrospinous, and anterior SI ligaments
  - APC III—symphyseal diastasis greater than 2.5 cm with complete disruption of SI joint, both anteriorly and posteriorly. Highest transfusion requirements.
    - Rupture of sacrotuberous, sacrospinous, and anterior and posterior SI ligaments
    - Complete separation of hemipelvis from pelvic ring
- Vertical shear (VS)
  - Usually due to a fall. Vertical displacement of hemipelvis commonly with complete disruption

of the SI joint.

- Combined mechanism
  - Stable types are lateral compression type I and anteroposterior compression type I
  - APC II, APC III, LC III, and VS may involve stretching and tearing of veins and arteries causing hemorrhagic shock
- Associated injuries
  - APC pattern has associated urethral and bladder injuries. Incidence of spleen, liver, bowel, and pelvic vascular injury increases from APC I to APC III categories.
  - LC I and LC II patterns have associated brain, lung, and abdominal injuries.
  - LC III pattern usually due to a crush injury to pelvis, sparing other organs from injury
  - Vertical shear mechanism fracture injury pattern and mortality similar to those for APC II and APC III patterns.
  - Combined mechanism pattern has organ injury pattern similar to lower-grade APC and LC patterns
  - Cause of death in LC pattern is primarily brain injury, whereas in APC pattern, causes are primarily shock, sepsis, and ARDS.

□ Tile—based on fracture stability
- Stable (posterior arch intact)
  - Avulsion fractures
  - Iliac wing fractures
  - Transverse sacral fractures
- Partially stable—rotationally unstable and vertically stable
  - External rotation
    - Anterior pelvic disruption alone
    - Anterior sacroiliac ligaments too
    - Anterior and posterior sacroiliac ligaments

- Lateral compression
  - Ipsilateral
  - Contralateral (bucket-handle)
  - Bilateral
- Unstable (complete disruption of posterior arch)
  - Unilateral
  - Bilateral but one side B type and one side C type
  - Bilateral C type

□ Treatment

- General principles
  - Emergent treatment: control hemorrhage and provisionally stabilize pelvic ring
  - Important to establish and follow a treatment protocol to avoid variation in treatment decision making
    - 85% of bleeding due to venous injury, only 15% have arterial source
    - Volume resuscitation and early blood transfusion
    - Pelvic binder or wrapped sheet. External rotational deformity may be reduced by taping feet together.
    - Angiographic embolization
    - Pelvic packing, initially popularized in Europe, provides tamponade of venous bleeding.
    - External fixation
      - Placed before emergent laparotomy
    - Skeletal traction—for vertically unstable patterns
    - Pelvic C clamp (rarely used)
- Nonoperative treatment
  - Indicated for stable fracture patterns
  - Weight bearing as tolerated for isolated anterior injuries
  - Protected weight bearing for ipsilateral anterior and posterior ring injuries
- Operative treatment
  - Indications
    - Symphysis diastasis greater than 2.5 cm. Extent of actual diastasis may not be apparent if patient is put in a

pelvic binder before initial AP pelvic x-ray. Intraoperative stress view exam may be required.

- Anterior and posterior sacroiliac ligament disruption
- Vertical instability of posterior hemipelvis
- Sacral fracture with displacement greater than 1 cm

- Anterior injuries
  - ORIF with plate fixation
  - External fixation via pins through anterior-inferior iliac spine (biomechanically stronger than iliac wing but less well tolerated clinically) or iliac wing
    - The lateral femoral cutaneous nerve is most at risk.
  - **Anterior subcutaneous internal fixator** offers the benefits of decreased open surgical dissection while limiting problems associated with standard external fixation.
    - Can cause femoral nerve injury (impairs quad function)
    - Injury to lateral femoral cutaneous nerve in third of patients
    - Heterotopic ossification (usually asymptomatic) is most common complication
- Posterior injuries
  - Percutaneous iliosacral screw fixation
    - Vertical sacral fractures are at higher risk for loss of fixation.
  - Anterior plate fixation across the sacroiliac joint

        - Posterior transiliac sacral bars or sacral plating
        - Spinal-pelvic fixation considered for bilateral sacral fractures
    - Vertically unstable patterns with anterior and posterior dislocations
        - Anterior ring internal fixation and percutaneous sacroiliac screw has been shown to be most stable fixation construct.
        - Spinal-pelvic fixation may also be considered.

□ Complications

- Severe life-threatening hemorrhage
    - Highest risk with APC II, APC III, and LC III patterns
- Neurologic injury
- Urogenital injury or dysfunction
    - Urethral stricture most common in men
    - Dyspareunia and need for cesarean section childbirth common in women
- Malunion
- Nonunion
- DVT and/or pulmonary embolus
    - DVT is the most common complication if thromboprophylaxis is not used.
- Infection—open fracture and associated contaminated laparotomy
- Death
    - Risk factors for death identified during initial treatment:
        - Blood transfusion requirement in first 24 hours
        - Unstable fracture type (APC II, APC III, LC II, LC III, vertical shear, combined mechanism)
        - Open fracture
        - Chronic instability following pelvic fracture can be best assessed with single-leg stance views (Flamingo views)

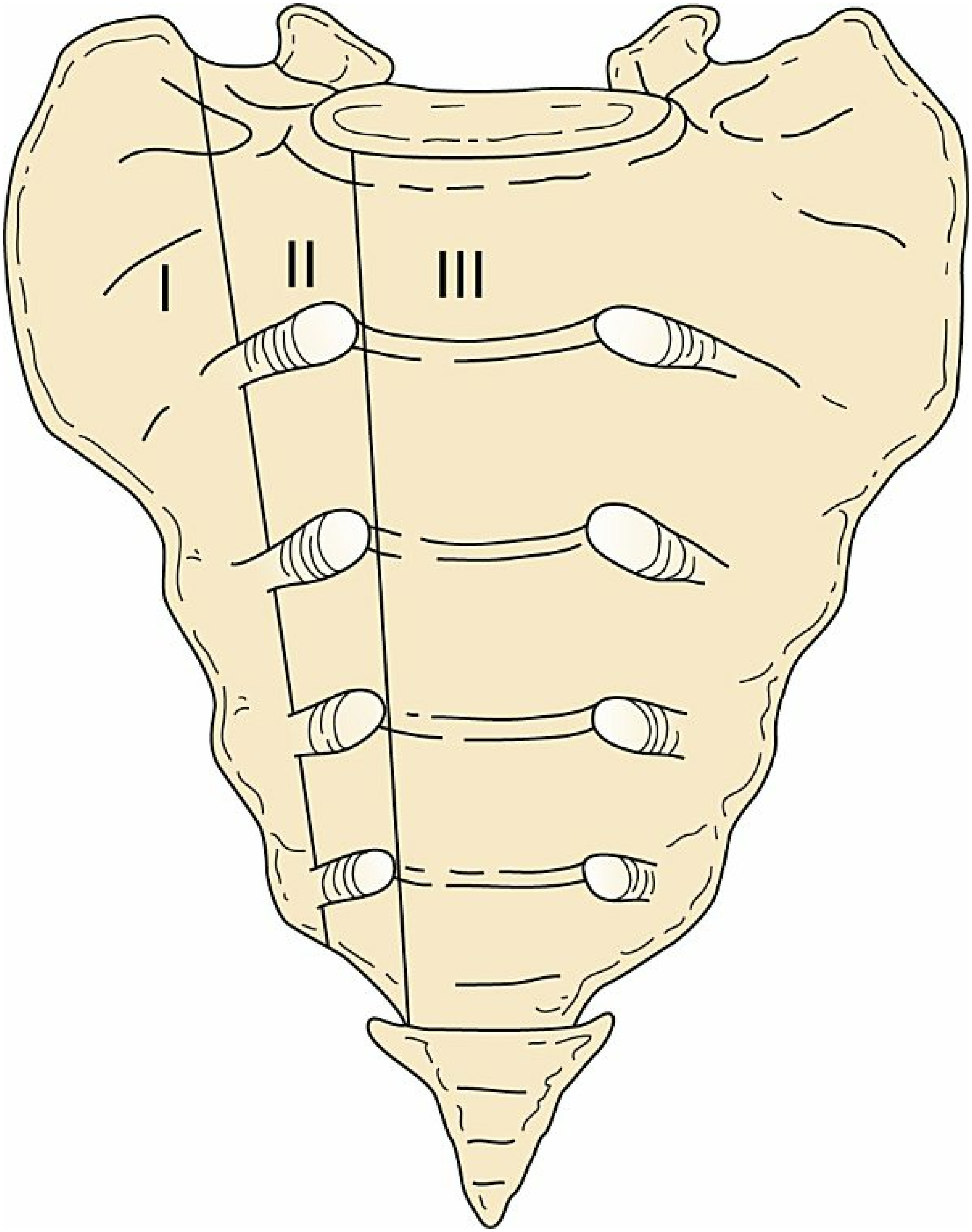


FIG. 11.8 The Denis classification of sacral fractures, showing the three zones.
From Browner BD et al, editors: *Skeletal trauma,* Philadelphia, 1992, WB Saunders, p 820.

- **Sacral fractures**
  - □ Diagnosis
    - Mechanism of injury—high energy
    - Radiographs—AP pelvis, inlet, outlet, and lateral views
    - CT (usually required)
  - □ Classification—Denis classification (Fig. 11.8) based on fracture location relative to foramen (zones I, II, and III)
  - □ Treatment
    - Nonoperative

        - Indicated for stable and minimally displaced fractures
        - Weight bearing as tolerated for incomplete fractures in which the ilium is contiguous with the intact sacrum (e.g., anterior impaction fractures from lateral compression mechanism or isolated sacral alar fractures)
        - Touch-toe weight bearing for complete fractures
    - Operative treatment
        - Indicated for displaced fractures (>1 cm)
        - Percutaneous iliosacral screws
            - Appropriate fluoroscopic visualization of anatomic landmarks is mandatory before surgery.
            - The pelvic outlet radiograph allows optimal visualization of the S1 neural foramina to avoid injury.
            - The lateral sacral view identifies the sacral alar slope and minimizes risk to the L5 nerve root.
            - High incidence of sacral dysmorphism (20%–44%). Sacralization of L5 or lumbarization of S1. Risk of anterior screw penetration causing neurologic injury is much higher with anterosuperior sacral concavity (Fig. 11.9).
                - Radiographic signs of sacral dysmorphism best seen on outlet view: prominent mammillary processes, laterally downsloping sacral ala, residual vestigial disc space between S1 and S2, top of iliac wing at level of L5–S1 instead of at L4–5, noncircular S1 anterior neural tunnel
                - Radiographic signs of sacral dysmorphism best seen on axial CT

scan: peaked or prow-shaped sacral promontory, tongue-in-groove sacroiliac articulation, oblique and narrow S1 sacral ala, wider S2 alar channel

- Posterior plating
  - Transiliac sacral bars
  - Open foraminal decompression considered for neurologic injury associated with zone II fracture

- □ Complications
  - Neurologic injury
    - Highest incidence with displaced zone II fractures
    - L5 nerve root usually involved with zone II fractures
    - Cauda equina syndrome can be associated with zone III injuries.
  - Chronic low back pain
  - Malunion

▪ **Acetabular fractures (** Fig. 11.10)

- □ Diagnosis
  - Mechanism of injury
    - Pattern of injury dependent on position of hip and direction of impact
    - Flexed hip with axial load (dashboard injury mechanism) most common
  - Plain radiographs
    - AP pelvis—six cardinal lines (Fig. 11.11)
    - **Obturator oblique—profiles anterior column and posterior wall. Best view to ensure that screw placed in anterior column does not penetrate into hip joint (** Fig. 11.12 **).**
    - **Iliac oblique—profiles posterior column and anterior wall (** Fig. 11.13 **)**
  - CT
    - Thin-cut (1–2 mm) axial
    - Three-dimensional reconstruction with femur subtracted
- □ Classification—Letournel classification (Fig. 11.14) based on involvement of acetabular columns and walls

- Simple types
    - Posterior wall (PW)—most common simple type
    - Posterior column (PC)
    - Anterior wall (AW)
    - Anterior column (AC)
    - Transverse
        - Involves both the anterior and posterior columns
- Associated types
    - Posterior column/posterior wall (PC/PW)
    - Transverse/posterior wall (TPW)
    - T-type
        - Transverse with vertical limbs through ischium
    - Anterior column/posterior hemitransverse (AC/PHT)
        - Least common type
    - **Associated both-column (ABC)**
        - Most common associated type
        - Dissociation of acetabular dome from intact ilium
            - Spur sign seen on obturator oblique view represents the posterior ilium that is undisplaced (Fig. 11.15).

□ Radiographs

- A systematic evaluation can be used to classify most acetabular fractures using plain radiographs (see Fig. 11.10):
- Examine the iliopectineal and ilioischial lines.
    - If both lines are intact:
        - PW fracture
    - If only one line disrupted:
        - Iliopectineal line
            - AW fracture
            - AC fracture
        - Ilioischial line
            - PC fracture
            - PC and PW fracture
    - If both lines disrupted:
        - Look at the obturator ring and determine whether it is intact.
            - Obturator ring intact

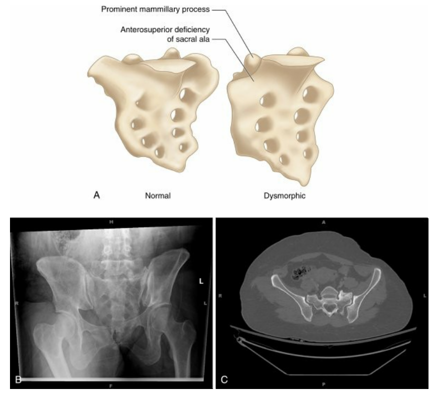


FIG. 11.9 (A) Schematic representation of the normal *(left)* and dysmorphic *(right)* sacrum. Characteristics of sacral dysmorphism include the presence of prominent mammillary processes and anterosuperior deficiency of the sacral ala. (B) Outlet view showing classic features of sacral dysmorphism. Iliac crest is at the same level as the upper sacral border; there are prominent mammillary processes, down-sloping sacral ala, and a vestigial disc remnant. (C) CT scan showing irregular tongue-and-groove contour of the sacroiliac joint, a characteristic feature of sacral dysmorphism.

  - Transverse fracture
  - Transverse/PW
- Obturator ring disrupted
  - Look at iliac wing.
    - Iliac wing intact
      - T-type
    - Iliac wing

disrupted
- AC/PHT
- ABC fracture

□

- Typically used to evaluate posterior injuries, articular fragments, marginal impaction, and congruency of the hip joint
- Axial CT may be useful to aid in fracture classification.
    - Vertical fracture line
        - Transverse or T-shaped fracture
        - If the wall can clearly be visualized, then AW or PW fracture
    - Horizontal fracture line
        - Column fracture
- Sequential axial CT cuts that demonstrate no intact support between the acetabular articular surface and axial skeleton through the sacroiliac joint indicate ABC fracture.

□ Treatment

- General principles
    - Restore articular congruity and hip stability.
    - Avoid injury to blood supply to femoral head.
    - DVT screening and prophylaxis
    - **During surgery, hip extended and knee flexed to minimize tension on sciatic nerve**
    - Patients are generally on touch-down weight-bearing status postoperatively. **Getting up from chair using the affected leg produces the greatest risk of fixation failure by creating the highest acetabular contact pressures.**
- Nonoperative treatment
    - Indications
        - Nondisplaced or minimally displaced fracture (<1-mm step and <2-mm gap)
        - Roof arc angle 45 degrees on AP, iliac oblique, and obturator oblique—CT correlate is a fracture less than 10 mm from the dome apex.
        - PW fracture without instability (<20%–30% of posterior wall—exact number controversial)
        - Operative dynamic stress examination may be considered to

assess stability of posterior wall fracture.

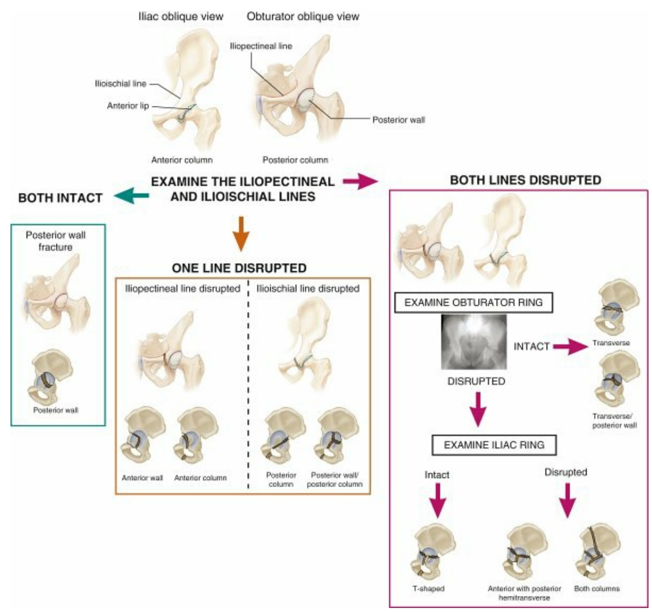


FIG. 11.10 Systematic evaluation for determining acetabular fracture type using plain radiographs.

- Fracture of both columns, with secondary congruence
- Severe comminution in the elderly patient in whom total hip replacement is planned after fracture healing

- Protected weight bearing for approximately 6 weeks
- For unstable injuries that cannot be operated on——femoral traction for 2–3 weeks, followed by toe-touch weight bearing for 3–4 weeks

- Operative treatment
  - Early surgery (<5 days from injury) is associated with better fracture reduction than late surgery (10–14 days).
  - Indications
    - Displacement with a greater than 1-mm step or greater than 2-mm gap associated with the roof arc angle less than 45 degrees on any view or documented instability with stress examination.
    - PW fracture of more than 20%–30% or hip instability

- Intraarticular bone fragments
- Irreducible fracture-dislocation

- Relative contraindications to surgery
  - Morbid obesity
  - Physiologically elderly and nonambulatory patient
  - Presence of DVT, with contraindication to inferior vena cava filter
  - Contaminated wound compromising surgical approach
  - Delay to operation longer than 3 weeks
- Surgical approaches
  - Kocher-Langenbeck
    - Posterior approach
    - **Indicated for PW, PC, transverse, transverse/PW (when PW requires fixation), PC/PW, and some T-type**
  - Ilioinguinal
    - Anterior approach procedure
    - Indicated for AW, AC, AC/PHT, ABC, and some T types (if limited posterior wall involved)
    - Can be divided into three “windows”: lateral (iliac), middle (vascular), and medial (Stoppa)
    - **Ilioinguinal nerve travels with round ligament or spermatic cord through superficial inguinal ring.**

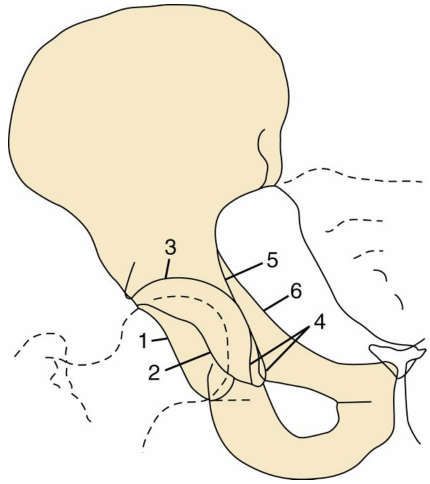


FIG. 11.11 The six cardinal radiographic lines of the acetabulum. *1,* Posterior wall; *2,* anterior wall; *3,* roof; *4,* teardrop; *5,* ilioischial line; *6,* iliopectineal line.
From Tornetta P III, Baumgaertner M: *Orthopaedic knowledge update: trauma 3,* Rosemont, IL, 2005, American Academy of Orthopaedic Surgeons, p 264.

- **Injury to obturator nerve will cause hypesthesia of inner thigh.**
- Injury to lateral femoral cutaneous nerve will cause hypesthesia of lateral thigh.
- The modified Stoppa procedure exposes the internal pelvis and provides the best access to the quadrilateral surface.
- Corona mortis: common (10%–30%) vascular communication between external iliac and the obturator arteries, typically seen about 5 cm medially

from pubic symphysis. Needs to be ligated to prevent retraction of inadvertently injured vessel.

- Extensile approaches considered for fractures more than 3 weeks old, complex associated fractures, and need for posterior column reduction
  - Combined anterior and posterior approaches
  - Extended iliofemoral approach
  - Triradiate approach
  - Posterior approach with trochanteric osteotomy
- Treatment with ORIF and acute total hip arthroplasty
  - Relative indications
    - Age older than 60 years with presence of superomedial dome impaction on radiograph (gull sign)
    - Associated displaced femoral neck fracture
    - Significant preexisting arthrosis

□ Complications

- Soft tissue degloving (Morel-Lavallée lesion) associated with higher infection rates
- DVT
  - Preoperative screening and inferior vena cava filter when DVT present. Postoperative screening and anticoagulation if DVT present.
- Pulmonary embolism—treatment similar to that for DVT
- Heterotopic ossification
  - **Highest in extended iliofemoral approach.** Higher in extended approaches (20%–50%) than in Kocher-Langenbeck approach (8%–25%) than in

anterior approach (2%–10%).

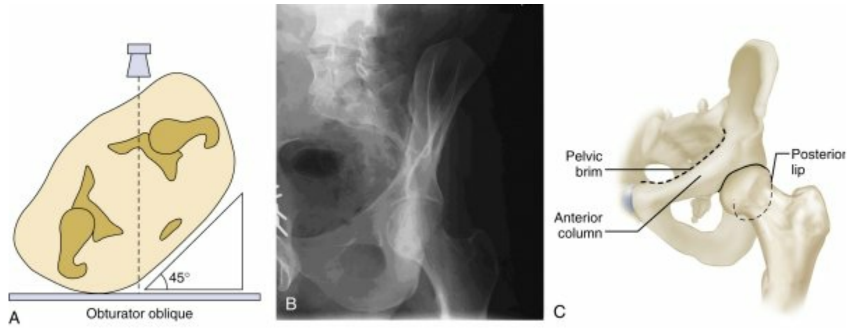


FIG. 11.12 (A) Obturator oblique view of pelvis obtained with the patient tilted 45 degrees, with the unaffected hip down and adjacent to the x-ray cassette. The x-ray beam was centered over the affected hip. (B) Obturator oblique radiograph profiles the anterior column and the posterior wall of the acetabulum. (C) Obturator oblique–related landmarks.

A and B from Tornetta P III, Baumgaertner M: *Orthopaedic knowledge update: trauma 3,* Rosemont, IL, 2005, American Academy of Orthopaedic Surgeons, p 263; C from Schemitsch E: *Operative techniques: orthopaedic trauma surgery,* Philadelphia, 2010, Saunders.

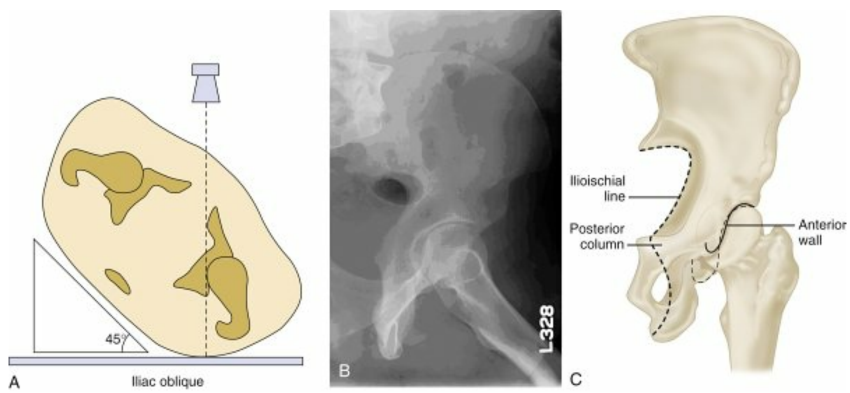


FIG. 11.13 (A) Iliac oblique view of pelvis obtained with the patient tilted 45 degrees, with the affected hip down and adjacent to the x-ray cassette. The x-ray beam was centered over the affected hip. (B) Iliac oblique radiograph profiles the posterior column and the anterior wall of the acetabulum. (C) Iliac oblique–related landmarks.

A and B from Tornetta P III, Baumgaertner M: *Orthopaedic knowledge update: trauma 3,* Rosemont, IL, 2005, American Academy of Orthopaedic Surgeons, p 263; C from Schemitsch E: *Operative techniques: orthopaedic trauma surgery,* Philadelphia, 2010, Saunders.

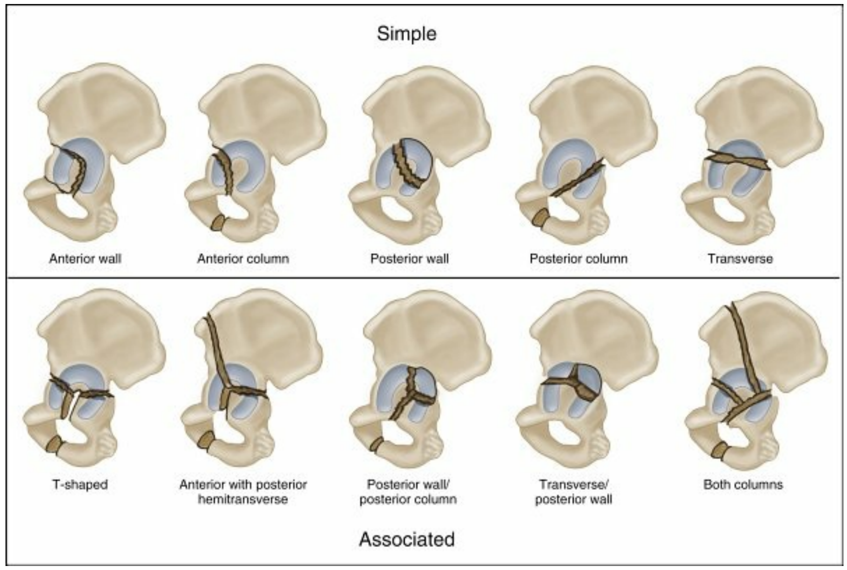


FIG. 11.14 The Letournel classification of acetabular fractures. (Modified with permission from Letournel E, Judet R, editors: *Fractures of the acetabulum,* ed 2, Berlin, 1993, Springer-Verlag.)

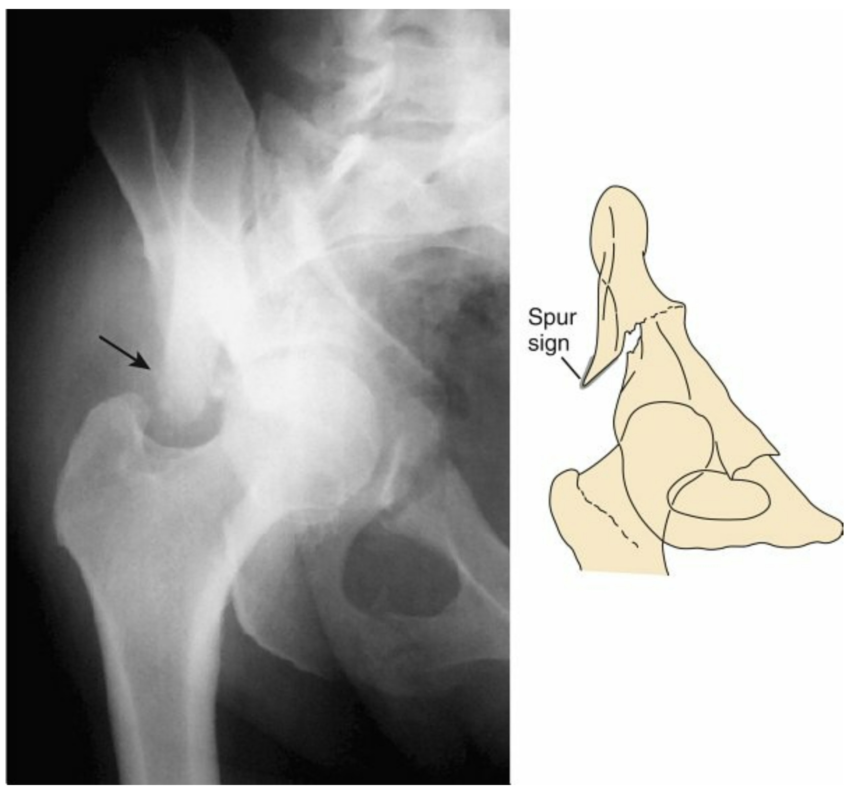


FIG. 11.15 Spur sign. Obturator oblique radiograph *(left)* and drawing *(right)* of a both-column fracture. Note the medial translation of the dome of the acetabulum and the femoral head. The spur sign represents the intact portion of the iliac wing that remains in its anatomic position.

- Prophylaxis with indomethacin (debatable efficacy) or external-beam radiation therapy of 600 cGy within 48 hours of surgery
- Neurologic injury

        - Sciatic nerve injury associated with posterior dislocations, especially peroneal division (<50% with full recovery)
        - Intraoperative monitoring is not associated with reduced iatrogenic nerve injury.
        - Hip extension and knee flexion reduce tension on sciatic nerve.
        - Iatrogenic injury to lateral femoral cutaneous nerve with anterior approach
    - Osteonecrosis—the highest incidence with posterior fractures, especially fracture-dislocations; iatrogenic damage to medial femoral circumflex artery
    - Posttraumatic DJD
        - Highest in patterns with PW involvement
        - Quality of reduction is most important predictor.
    - Malreduction
        - Associated with greater delay to surgery
    - Bleeding—associated with shorter time to surgery
    - Functional deficit—especially abductor weakness (with posterior more than anterior approach)

Femoral and Hip Injuries

- **Hip dislocations**
    - Diagnosis
        - Mechanism of injury—axial load; position of hip determines direction of dislocation
            - Usually high-energy mechanism; very high rate of associated injuries either systemic or musculoskeletal; 93% rate of MRI abnormalities of ipsilateral knee
        - Plain radiographs—AP and lateral views of the hip; AP pelvis and Judet views after reduction to evaluate associated acetabular fractures
        - CT—performed after reduction to evaluate for associated acetabular and/or femoral head fracture and loose bodies in joint
    - Classification—based on direction of dislocation and presence or absence of associated acetabular or femoral head fracture
        - Posterior dislocation—most common; associated with PW acetabular fracture and anterior femoral head fracture—leg flexed, adducted, and internally rotated at hip

            - Ipsilateral associated knee injury; 30% rate of meniscal tear
        - Anterior dislocation—uncommon; leg extended, abducted, and externally rotated at hip
    - Treatment
        - Emergent closed reduction
        - Emergent open reduction if irreducible after closed reduction
            - AVN rate 2%–10% if reduction within 6 hours and greater than 50% if reduction delayed more than 12 hours
            - Almost all cases of AVN appear within 2 years of injury.
        - Stability evaluated after reduction.
        - Traction and/or hip abduction pillow for unstable injuries pending definitive management of associated injuries (e.g., acetabular fracture)
        - Postreduction radiographs (AP pelvis and Judet views) and CT to rule out associated acetabular fracture, femoral head fracture, and intraarticular loose bodies
        - Weight bearing as tolerated (if hip is stable and without associated injuries)
    - Complications
        - Osteonecrosis (up to 15%)
        - Posttraumatic arthritis; less common when associated with PW acetabular fracture
        - Sciatic nerve injury (up to 20%); peroneal nerve division usually most affected
        - Recurrent dislocation (rare)
- **Femoral head fractures**
    - Diagnosis
        - Plain radiographs—AP and lateral views of hip
        - CT—to evaluate location and size of fragment and rule out associated acetabular fracture
    - Classification—Pipkin classification based on location of fracture relative to fovea and presence or absence of associated fractures of the acetabulum or femoral neck
        - Type I—fracture below fovea
        - Type II—fracture above fovea
        - Type III—associated femoral neck fracture
        - Type IV—associated acetabular fracture
    - Treatment
        - General principles
            - Restore articular congruity of weight-bearing

portion of head and hip stability.
            - Remove associated loose bodies.
            - Treat associated acetabular fracture if unstable.
            - Avoid injury to structures involved in blood supply to femoral head.
        - Nonoperative treatment
            - Indications
                - Pipkin type I—small fragment and congruent joint or nondisplaced larger fragment
                - Pipkin type II—nondisplaced; frequent (weekly) radiographs for 3–4 weeks to rule out secondary displacement
            - Protected weight bearing for 4–6 weeks
        - Operative treatment
            - Indications
                - Greater than 1-mm step-off (except small Pipkin type I)
                - Associated loose bodies in joint
                - Associated neck or acetabular fracture requiring surgical management
            - Fixation with headless countersunk lag screws
                - Anterior approach via Smith-Petersen approach for Pipkin types I and II without associated operative posterior wall fracture
                - Posterior approach for Pipkin type IV
            - Hip arthroplasty for older patient
    - Complications
        - Same as those for hip dislocation
        - AVN rate highest for Pipkin type III injuries. Rate of AVN is related to degree of displacement of femoral neck fracture.
- **Femoral neck fractures**
    - Diagnosis
        - Mechanism of injury
            - Low-energy (fall from standing height) in elderly—associated with osteoporosis
            - High-energy in young patients—associated with vertical fracture orientation and femoral shaft fractures
        - Nondisplaced fractures

- Cross-table lateral view should be ordered because frog-leg lateral view could cause fracture displacement
- MRI or bone scan to rule out occult fracture—MRI more sensitive if injury less than 24 hours old

□ Classification

- Garden classification based on orientation of trabecular lines and displacement
    - Garden types I and II considered stable
    - Garden types III and IV considered unstable
- Pauwels classification based on orientation of fracture line
    - Increased vertical orientation associated with more shear force and less inherent stability
    - Nonunion and AVN associated with vertical patterns (Pauwels type III)

□ Treatment

- General principles
    - Rapid preoperative medical optimization
        - Mortality risk reduced if surgery within 48 hours
    - Stable fixation and early mobilization
- Nonoperative treatment
    - Indications
        - Nondisplaced fractures in patients able to comply with weight-bearing restrictions
        - Displaced fractures in patients with extremely limited functional demands and/or those with high risk for surgery
    - Toe-touch weight bearing for 6–8 weeks
- Operative treatment
    - Indications
        - Displaced fractures
        - Most nondisplaced fractures
    - Internal fixation
        - Indicated for Garden types I, II, and III fractures in young patients, occult fractures, and displaced fractures in young patients
        - Three parallel screws for Garden types I and II and occult fractures
            - V pattern of screw

fixation

            - Because neck is devoid of substantial cancellous bone, fracture will settle until screw abuts intact cortical bone. Screws are ideally positioned so that shaft of screw abuts femoral neck fracture inferiorly and posteriorly to resist displacement.
        - Starting point distal to lesser trochanter should be avoided (associated with increased risk of periimplant subtrochanteric fracture).
        - **Varus malreduction is correlated with failure of fixation following cannulated screw fixation of femoral neck fractures.**
    - Sliding hip screw (fixed-angle device) plus derotation screw indicated for basicervical fractures and vertically oriented fractures
    - Open anatomic reduction and internal fixation is the optimal treatment for displaced femoral neck fractures in young patients.
        - Anatomic reduction more critical than reduced time to fixation
        - Closed reduction is an option but less likely to provide anatomic

reduction.

- Decompression of intracapsular hematoma thought to reduce risk of AVN (not proven and controversial)
- Internal fixation associated with decreased perioperative morbidity (vs. hemiarthroplasty)
  - Failure rate for internal fixation up to 30%; failure requires secondary procedure (typically arthroplasty)

- Hemiarthroplasty
  - Indicated for displaced fractures in elderly patients with low functional demands
  - Lower risk of dislocation than in total hip arthroplasty, especially in patients unable to comply with dislocation precautions (e.g., due to dementia, Parkinson disease)
  - Cemented femoral component better than uncemented component in patients with stovepipe-type femoral canals (but higher cardiopulmonary complications with preexisting disease)
  - Functional results of unipolar and bipolar prostheses are similar.
- Total hip arthroplasty
  - Indicated for "active" elderly patients with displaced fractures and provide the best functional outcome
  - Preferred to hemiarthroplasty for patients with preexisting hip arthropathy (osteoarthritis and rheumatoid arthritis) and has been shown to provide the best hip function after displaced femoral neck fracture
  - Higher dislocation rate than hemiarthroplasty

□ Complications

- Osteonecrosis—rate 10%–40%; associated with injury to femoral head blood supply (terminal branch of the medial femoral circumflex artery)
    - Higher risk with greater initial displacement
    - Higher risk with poor or deficient reduction
    - Decompression of intracapsular hematoma may reduce risk (controversial).
    - Reduced time to reduction may reduce risk (controversial).
- Nonunion—occurs in 10%–30% of displaced fractures
    - Higher risk with malreduction (particularly varus)
    - Treatment options include conversion to hip arthroplasty (worse results than those associated with primary arthroplasty) and valgus osteotomy.
- Infection
- Decreased functional status
    - Preinjury cognitive function and mobility predict postoperative functional outcome.
- Mortality—1-year mortality rate in elderly patients approximately 30%
- Treatment of femoral fractures is one of the most common causes of malpractice suits against orthopaedic surgeons.

▪ **Intertrochanteric fractures**

- □ Diagnosis
    - Mechanism of injury: fall from standing height
    - Risk factors: osteoporosis, prior hip fracture, risk of falls
    - More common than femoral neck fracture in patients with preexisting hip arthritis
- □ Treatment
    - General principles
        - Stable fixation to allow early weight bearing
        - Minimize potential for implant failure
        - **Modifiable comorbidities should be corrected and surgery performed within first 48 hours.**
    - Nonoperative treatment
        - Indications
            - Nondisplaced fractures in patients able to comply with non–weight-bearing status

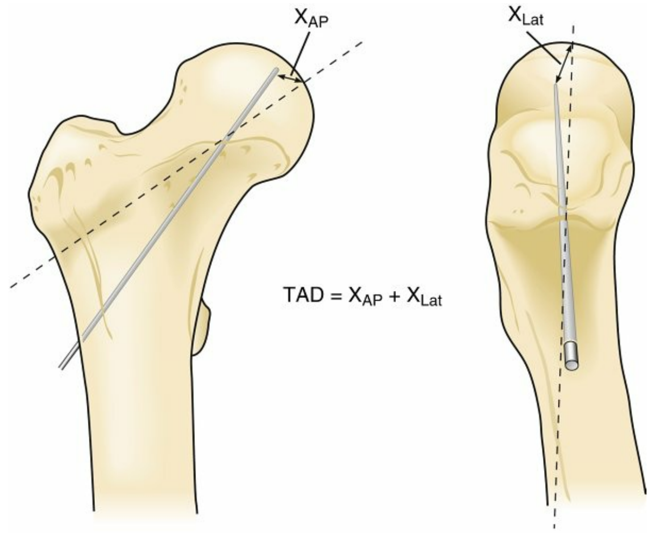


FIG. 11.16 Tip-apex distance (TAD) should be less than 25 mm. Dotted line indicates apex of femoral head.
Redrawn from *Orthopaedic knowledge update: trauma 2,* Rosemont, IL, 2000, American Academy of Orthopaedic Surgeons, p 127.

        - Displaced fractures in patients who are nonambulatory or have prohibitive operative risk
    - Management with toe-touch weight bearing for 6–8 weeks
- Operative treatment
    - Internal fixation indicated for the vast majority of intertrochanteric fractures
        - Sliding hip screw device
            - Indicated for most intertrochanteric fractures except reverse oblique fractures, subtrochanteric fractures, and fractures without an intact lateral femoral cortex
            - High union rate
            - Associated with moderate amount of collapse, resulting limb shortening, and medialization when used for unstable fractures; more collapse than that seen with IM implants.

        - Lag screw placed in center—center position **with tip-apex distance of less than 25 mm associated with lowest screw failure rate** (Fig. 11.16)
        - Two-hole side plate sufficient for stable fractures
        - **Higher revision rates than IM nail in transverse/reverse oblique trochanteric fractures**
- IM nail
    - Valid option for most intertrochanteric fractures, but best option for reverse oblique fractures, subtrochanteric fractures, and fractures without an intact lateral femoral cortex
    - Less collapse than with sliding hip screw plate devices due to IM buttress effect of nail
    - Short nails indicated for standard oblique fractures, with distal interlocking optional
    - Long nails indicated for standard oblique, reverse oblique, and subtrochanteric fractures
        - Risk of distal anterior perforation due to mismatch of anterior bow between femur and nail
        - **Distal anterior cortical perforation also associated with a posterior starting point**
        - **Long nails cost more than short nails.**
    - Multiple screws into head fragment

- may provide improved rotational control (advantage controversial).
- Single lag screw design should aim for center—center in head with less than 25 mm tip-apex distance (see Fig. 11.6) to minimize risk of screw cutout
- A 95-degree fixed-angle plate device or locking proximal femoral plate indicated for reverse oblique fracture, comminuted fracture, and nonunion repair

- ☐ Complications
  - Excessive collapse
    - Results in limb shortening and medialization of shaft
    - Reduced abductor moment arm may cause functional deficit.
    - Associated with displacement of lesser trochanter
    - More collapse associated with sliding hip screw device than with IM implant.
    - May result in painful, prominent hardware
  - Implant failure/cutout—associated with tip-apex distance (see Fig. 11.16) greater than 25 mm
  - Periimplant fracture
    - More common with nails than plates
    - Low risk with current nail designs
      - Smaller distal interlocking screws further from tip of nail than earlier designs
      - Reduced trochanteric bend than with earlier designs
  - Infection
  - Death (often due to medical comorbidities)
    - American Society of Anesthesiologists (ASA) classification predicts mortality.

- ▪ **Subtrochanteric fractures**
  - ☐ Classification—Russell-Taylor classification based on involvement of lesser trochanter and piriformis fossa
    - Type IA—fracture below lesser trochanter
    - Type IB—fracture involves lesser trochanter; greater trochanter intact
    - Type IIA—greater trochanter involved; lesser trochanter intact

- Type IIB—greater and lesser trochanters involved

□ Treatment
- General principles
  - Restore limb length alignment and rotation.
  - Indirect reduction techniques obviate the need for bone grafting in acute fractures.
- Operative treatment: implant must withstand high medial compressive loads and high lateral tensile loads.
  - IM fixation
    - Indirect reduction preserves biologic environment.
    - Standard proximal interlocking for fractures with intact lesser trochanter
    - Reconstruction interlocking for fractures with involvement of lesser trochanter
    - Piriformis entry nail contraindicated for fractures involving piriformis fossa
      - Apex anterior and varus angulation are the most common deformities.
  - The psoas and abductors lead to flexion, abduction, and external rotation of the proximal fragment.
    - Open or percutaneous reduction indicated when closed reduction inadequate (frequent); union rates same as with closed reduction
      - Lateral positioning allows easier alignment of the distal segment to the flexed proximal segment.
    - Fixed-angle plate fixation/proximal femoral locking plates
      - Indicated for fractures with proximal comminution and nonunion
      - 95-degree devices
        - Devices of 135 degrees

contraindicated
- Must avoid soft tissue stripping
- Acute bone grafting usually not required when biologic plating techniques are used

- ▫ Complications
  - Nonunion—minimized with IM nailing and biologic plating
  - Malalignment—varus and apex anterior angulation with IM nailing. Consider adjunctive reduction aids and percutaneous reduction.
  - Infection—associated with increased soft tissue dissection

- **Femoral shaft fractures (** Table 11.3)
  - ▫ Diagnosis
    - Mechanism of injury: often high-energy
    - Associated fractures and other injuries are common.
    - Associated neck fractures are uncommon (<10%), but when present, they are often missed (up to 50%). Any patient who complains of hip pain during the early postoperative period following treatment of a femoral shaft fracture should receive dedicated hip x-rays.
  - ▫ Plain radiographs
    - AP and lateral views of femur
    - AP and cross-table lateral hip to rule out femoral neck fracture
  - ▫ CT scan to rule out occult femoral neck fracture
    - If the scan is obtained for abdominal or pelvic evaluation, it should be reviewed for femoral problems.
    - Dedicated thin-cut CT should be considered.
  - ▫ Treatment
    - General principles
      - Restore limb length, alignment, and rotation.
      - Early stabilization reduces systemic complications associated with multiply injured patients.

- Nonoperative treatment (rarely indicated)
  - Long-leg cast or brace for nondisplaced distal shaft fracture
  - Pillow splint for nonambulatory individuals
- Operative treatment—indicated for most fractures
  - IM nail
    - Indicated for most femoral shaft fractures
    - High union rates (>95%)

- More hip problems with antegrade than retrograde insertion (pain/weakness).
- **Quadriceps and abductors are weakest after antegrade femoral nailing.**
- **More knee problems with retrograde than with antegrade insertion (pain and chondral injury to patella if nail left proud)**
- Relative indications for retrograde femoral nail: morbid obesity, bilateral femoral shaft fractures (can be done without need to reposition patient), pregnancy (reduced abdominal radiation), ipsilateral tibial shaft fracture that will be treated with an IM nail, displaced ipsilateral femoral neck fracture that will be fixed with ORIF, ipsilateral acetabular fracture (to avoid contaminating acetabular surgical approach), multiply injured patient

Table 11.3

Adult Femoral Shaft Fractures

Injury	Classification	Treatment	Complications
Femoral fracture (2.0 cm below lesser trochanter to 8 cm from knee joint)	Winquist—based on degree of comminution and amount of cortical continuity I—transverse, comminution <25% of circumference (e.g., butterfly fragment) II—comminution 25%–50% of circumference III—comminution >50% of circumference (unstable) IV—extensive (100%) comminution, no cortical contact,	Most often high-energy mechanism; early stabilization as patient status permits; most fractures are treated by closed IM nail; statically locked, reamed nail for most fractures; antegrade (piriformis or trochanter) or retrograde; obesity a relative indication for trochanteric entry nail; in patients with multitrauma, temporized with external fixation	Infection (<5% closed fractures), nonunion (<5% closed fractures; tre with exchan nail vs. ORIF/ICBG) delayed unio (exchange n vs. dynamizatio malalignmer (malrotation LLD), hip pain/weakne (antegrade nail), knee pain (retrograde nail), puden nerve injury (excessive traction

	unstable V—segmental bone loss (unstable)	(damage control), converted to IM nail later; plate fixation for neck/shaft fractures, periprosthetic treatment (lower union and higher infection rates, longer time to weight bearing)	through pos missed knee ligament injury, knee stiffness (especially with distal external fixation), refracture, failure of fixation, dee venous thrombosis, pulmonary embolism, ARDS
Femoral neck and shaft fractures	Garden or Pauwels/Winquist (2.5%–5.0% of femoral shaft fractures, but ≈30% are missed)	Neck takes priority; 135-degree fixed-angle device vs. parallel screws for neck, retrograde nail vs. plate for shaft; reconstruction nail for nondisplaced neck or intertrochanteric and shaft fractures	Infection, delay union, nonunion, lo of fixation, avascular necrosis
Femoral and tibial shaft fractures (floating knee)		Retrograde nail for femur, antegrade nail for tibia	Multiple other injuries, fat emboli syndrome, ARDS

ICBG, iliac crest bone graft.

- Piriformis entry contraindicated when fracture extends to piriformis fossa
- Anterior starting point in piriformis fossa associated with increased hoop stress and risk of iatrogenic comminution
- Trochanteric starting point risks (1) medial comminution of shaft due to off-axis starting point and (2) varus if straight (no trochanteric bend) nail

used

- Static interlocking for most fractures
- Reamed nailing for most fractures
  - Higher union rates than with unreamed nails
  - Unreamed nails associated with decreased fat embolization rate; clinical relevance unclear
  - Appropriate reaming technique includes sharp reamers, slow advancement, less heat generation, and less embolization.
  - Minimum cortical reaming preferred
  - Nail diameter 1–2 mm smaller than largest reamer
- Multiply injured patients may benefit from delayed nailing with immediate provisional external fixation (damage control principles).
  - Benefits include reductions in blood loss, hypothermia, and inflammatory mediator release.

- External fixation
  - Indicated for provisional fixation
    - Application of damage control principles
    - Severe contamination requiring repeated access to medullary canal
    - Vascular injury
  - Safely converted to IM nail in absence of pin tract infection up to at least 3 weeks after injury with equal union and infection rates
- Plate fixation
  - Indicated for periprosthetic fractures
  - Indicated for shaft component of associated neck-shaft fractures
  - Reduced union rate, higher infection and implant failure rates, and longer time to weight bearing than with use of IM nail

□ Complications

- Infection—less than 5% of closed fractures
- Nonunion—less than 5% of closed fractures
  - Exchange nailing less successful than repair with plate and screws and bone grafting

- Delayed union—less than 5% of closed fractures
    - Dynamization less successful than exchange nailing
- Malalignment
    - Proximal fracture more often malaligned with retrograde than with antegrade nailing
    - Distal fractures more often malaligned with antegrade than with retrograde nailing
- **Malunion (rotation and length) is the most common complication following IM nailing of highly comminuted femoral shaft fractures.**
- Malrotation difficult to diagnose, especially with comminuted fractures
    - Should be compared with contralateral limb before patient leaves operating room
    - Supine nailing has a higher incidence of internal rotation.
    - Lateral nailing has a higher incidence of external rotation.
    - Use of a fracture table has a higher incidence of internal rotation than manual traction.
- Leg or limb length discrepancy (LLD) is associated with comminuted fractures.
- Hip pain/weakness is associated with antegrade nailing.
- Knee pain is associated with retrograde nailing.
- Patellar chondral injury is associated with retrograde nailing, if nail left protruding into the knee joint.
- Pudendal nerve injury is associated with excessive traction.
- HO is associated with antegrade nailing (rarely clinically relevant).
- Osteonecrosis in adolescents with open physes treated with piriformis-starting IM nails
- Significant shortening (i.e., 4 cm) results in medial mechanical axis deviation.

□ Special circumstances

- Obese patients
    - Higher complication rates with piriformis nailing
    - Relative indication for retrograde nailing
- Ipsilateral femoral neck and shaft fractures
    - Uncommon (<10%), but when present, missed in up to 50% of cases
    - Neck fracture management has the highest priority and should be fixed first, generally

followed by retrograde femoral IM nail or plate fixation for treatment of shaft fracture.
        - Neck fracture often nondisplaced, vertical, and basicervical
        - Use of 135-degree sliding hip screw or parallel screws preferred for femoral neck
        - Reconstruction nail can be used for nondisplaced neck fractures or associated intertrochanteric and shaft fractures.
        - Use of a cephalomedullary IM nail for fixation of displaced ipsilateral femoral neck and shaft fractures is associated with increased risk of femoral neck malreduction and AVN.
    - Multiply injured patient—damage control principles must be considered.
        - Provisional external fixator with conversion to IM nail when stable (within 3 weeks)
            - May be more applicable with associated lung/chest injury
    - Periprosthetic fracture (see Chapter 5, Adult Reconstruction.)

- **Supracondylar and intracondylar fractures**
    - □ Diagnosis
        - Mechanism of injury—high-energy in young patients and low-energy in older patients
        - CT
            - If intracondylar extension
            - Coronal fracture (Hoffa fracture) incidence—40%
            - Lateral femoral condyle fracture incidence—80%
        - Plain radiographs frequently miss this injury.
    - □ Treatment
        - General principles
            - Restore articular congruity.
            - Rigid stabilization of articular fracture
            - Indirect reduction of metaphyseal component to preserve vascularity to fracture fragments
            - Stable (not necessarily rigid) fixation of articular block to shaft
            - Early knee ROM
        - Nonoperative treatment—indicated for nondisplaced fractures
            - Brace or knee immobilized
            - Full-time bracing for 6–8 weeks
            - Closed-chain ROM exercises at 3–4 weeks

- Operative treatment—indicated for most displaced fractures
  - Plate fixation—indicated for most fractures
    - Fixed-angle plates required for metaphyseal comminution
    - Traditional 95-degree devices are limited by number and location of distal fixation(s) and are contraindicated in cases of associated Hoffa fractures.
    - **Locked plates** offer multiple fixed-angle points of fixation in distal fragment in multiple planes and **offer the advantage of use in cases with associated coronal (Hoffa) fractures.**
    - Non–fixed-angle plates prone to varus collapse, especially in metaphyseal comminution
  - High union rates (>80%) with indirect reduction technique without bone graft
    - Lateral approach—indirect reduction of metaphyseal fracture and arthrotomy with direct reduction of articular component
    - Sagittal intraarticular split most common
    - Condyles are malrotated in sagittal plane with respect to each other.
    - Coronal (Hoffa) fractures require interfragmentary lag screws.
    - Laterally applied condylar plate spans fracture (locked plate preferred).
  - Retrograde IM nail
    - Indicated for extraarticular fractures and simple intraarticular fractures
    - Reduced stability compared with plate fixation for osteoporotic fractures, especially those with wide metaphyseal flares
      - Blocking screws can help provide reduction and improved stability.
      - Fixed-angle distal

interlocking screws may provide improved stability.
        - Long nails that cross the femoral isthmus are preferred to short "supracondylar" nails.
    - Arthroplasty
        - Indicated in patient with preexisting joint arthropathy and in selected cases in which stable internal fixation is not achievable
        - Usually requires distal femoral replacement prosthesis
        - Reduced longevity compared with internal fixation
        - Allows immediate weight bearing

□ Complications
- Nonunion—associated with soft tissue stripping in metaphyseal region
- Malalignment
    - Valgus malreduction most common (plate fixation) in coronal plane; hyperextension malreduction most common in sagittal plane
    - Malalignment more common with IM nails
- Loss of fixation
    - Varus collapse most common
        - Plate fixation associated with toggle of distal non–fixed-angle screws used for comminuted metaphyseal fractures
        - IM nail fixation
    - Proximal (diaphyseal) screw failure associated with short plates and nonlocked diaphyseal fixation. Plate fixation is associated with toggle of distal non–fixed-angle screws used for comminuted metaphyseal fractures.

Table 11.4

Adult Knee Fractures and Dislocations

Injury	Classification or Diagnostic Information	Treatment	Co

Supracondylar fracture (Hoffa fracture [OTA 33-B3])	AO/OTA—degree of comminution and articular involvement 33-A—extraarticular 33-B—partially articular (unicondylar) 33-C—intraarticular	Restoration of articular congruity, rigid stabilization of articular fracture, preservation of vascularity, stable fixation of joint to shaft, early ROM Nonoperative: brace or knee immobilizer, non–weight-bearing status for 6–8 wk, closed-chain ROM exercises at 3–4 wk Plate fixation: most fractures; fixed-angle plate for metaphyseal comminution (nonfixed: varus collapse) Retrograde IM nail: extraarticular or simple intraarticular fractures, long nail preferred Arthroplasty when fixation not achievable, arthropathy present	No
Patella fracture	Nondisplaced, transverse, proximal or distal (30%) pole, comminuted, vertical (nonoperative)	Nonoperative: nondisplaced (<2 mm) with intact extensor mechanism; hinged knee brace in extension, progress in flexion after 2–3 wk ORIF (tension band wiring, screws) if patient cannot actively extend knee (extensor mechanism rupture) or there is >2-mm separation or incongruent articular surface (>2-mm step-off); excision of fragments that are	Syn

		extremely comminuted; patellectomy should be avoided	
Patella dislocation	Acute, recurrent, subluxation, habitual, usually lateral	Immobilization, controlled motion for 6 wk; arthroscopy for displaced or osteochondral fracture. Recurrent: lateral release, medial plication (repair/reconstruction of MPFL); bony transplant if abnormal Q angle Surgery should be avoided in patient with habitual dislocation	Rec
Knee dislocation	Anterior (30%–40%), posterior (30%–40%), lateral, medial, rotatory (anteromedial, anterolateral, posteromedial, posterolateral)	May be spontaneously reduced at presentation—easily missed Emergent reduction of dislocations; open reduction if needed (posterolateral rotation) Arteriogram based on physical examination findings (absent/asymmetric pulses); repair of vascular injuries (5%–15%). Ligament repair (within 2–3 wk) or reconstruction, allograft vs. autograft, early motion	Vas
Quadriceps tendon rupture	Patients generally >40 yr and have metabolic disorders (chronic renal failure, rheumatoid	Incomplete rupture: nonoperative management Complete rupture: repair through osseous drill holes or suture anchors; repaired acutely: >2 wk or ≤5-	Str

	arthritis, steroid use) Affects M ≫ F	cm retraction	
Patellar tendon rupture	Patients <40 yr with overload of extensor mechanism; risk increased with metabolic disorders (rheumatoid arthritis, diabetes mellitus, infection)	Direct repair with nonabsorbable suture and locking (Krackow) stitch through drill holes; repair can be protected with cerclage	Mi

MPFL, medial.

- Infection—occurs in diabetic patients, especially those with active foot ulcers
- Knee pain/stiffness
- Painful hardware—prominent medial screws should be avoided.

Knee Injuries (Table 11.4)

- **Dislocation**
  - Diagnosis/classification
    - Direction (Kennedy) —anterior (30%–40%), posterior (30%–40%), medial, lateral, and rotatory (posterolateral the most common) (Fig. 11.17)

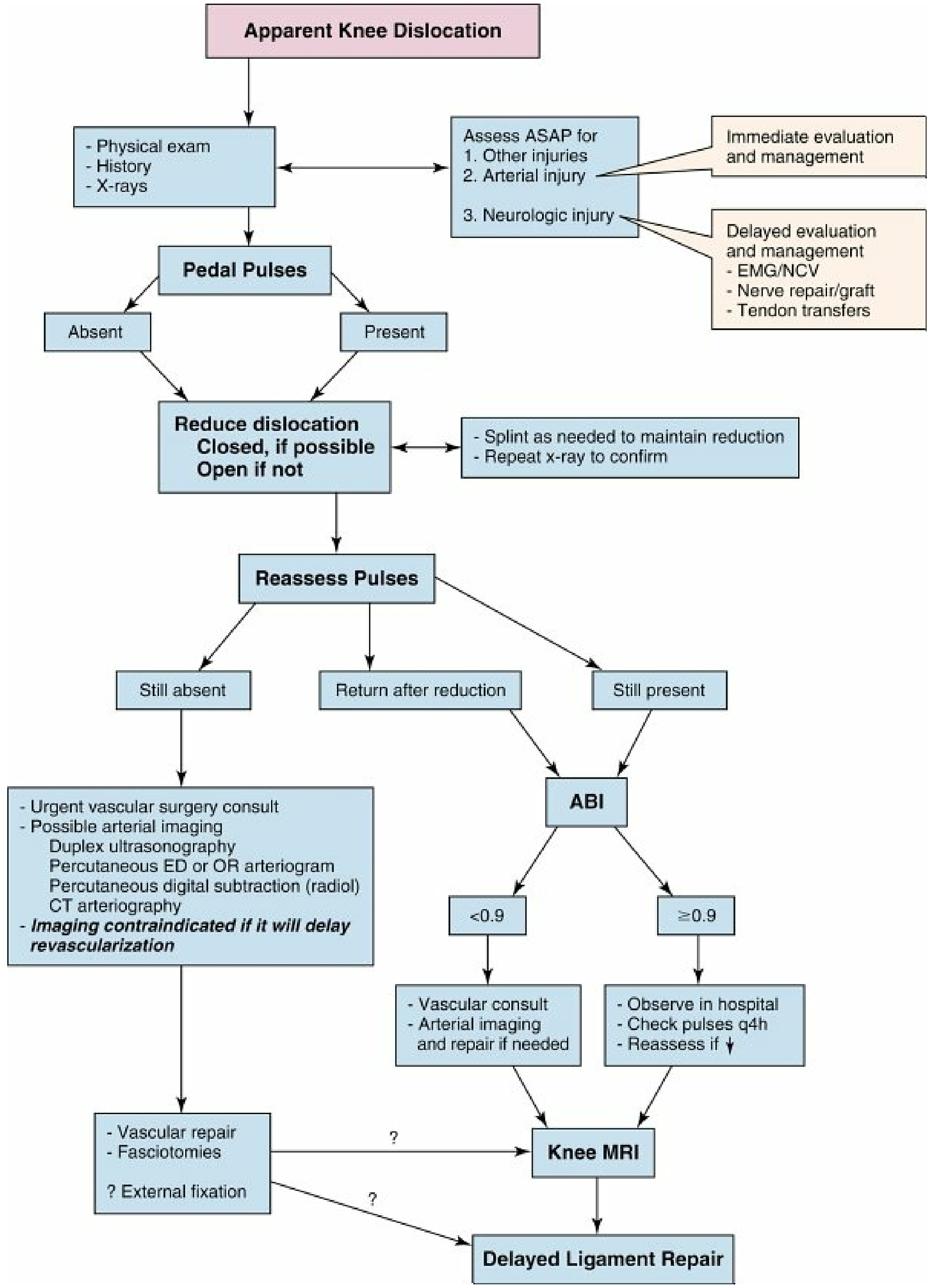


FIG. 11.17 Treatment algorithm for dislocation of the knee. *NCV,* Nerve conduction velocity. (From Browner BD et al, editors: *Skeletal trauma,* ed 4, Philadelphia, 2008, Elsevier.)

- Schenck anatomic classification of knee dislocation (KD)
  - KD I—dislocation with either anterior cruciate ligament (ACL) or posterior cruciate ligament (PCL) still intact (variable collateral involvement)
  - KD II—torn ACL/PCL
  - KD III—most common
    - Torn ACL/PCL and either posterolateral corner (PLC–KD IIIL) or posteromedial corner (PMC–KD IIIM) injury

- KD IV—torn ACL/PCL/PLC/PMC
- KD V—fracture-dislocation
- More than 50% reduced at presentation (easily missed diagnosis)
- Vascular injury—rate 5%–15% in newer studies
    - Selective arteriography with use of a physical examination (including ABI) rather than an immediate arteriogram is now the standard of care.
    - Most common finding in patients with vascular injury is a diminished or absent pedal pulse.
- Significant soft tissue injuries

□ Treatment
- Emergent reduction if patient did not present with fracture reduced
- Revascularization within 6 hours if there is significant arterial injury.
- Care for soft tissue injuries (open-knee dislocations)
    - Ligament repair or reconstruction
    - Reconstruction with allograft becoming the most common
    - Immediate reconstruction may be better than delayed reconstruction.
    - Early motion rehabilitation
    - Possible role for hinged external fixator

□ Complications
- Vascular injury—highest with KD IV; ABI greater than 0.9 associated with an intact artery
- Neurologic injury—peroneal nerve injury common (≈25%), but up to 50% recover at least partially; may benefit from neurolysis.
- Stiffness/arthrofibrosis—most common complication (38%)
- Ligamentous laxity also very common (37%)

▪ **Patella fractures**

□ Diagnosis/classification
- Descriptive—transverse, vertical (rarely requires surgical treatment), comminuted, proximal or distal (30%) pole, and nondisplaced
- Patient inability to extend knee or do a straight-leg raise demonstrates an incompetent extensor mechanism.
- Displaced fracture is 3-mm fragment separation or 2-mm step-off.

□ Treatment: preserve patella whenever possible (maintains lever arm for quadriceps function).

- Nonoperative treatment: for nondisplaced with intact extensor mechanism, hinged knee brace in extension, and progressive flexion after 2– 3 weeks
- Tension band wiring: most common technique for simple fracture patterns; can be done with K-wires or cannulated screws (biomechanically stronger); wire or braided nonabsorbable suture may also be used (less hardware irritation)
    - K-wires may migrate if tendon fibers are interposed. Burying bent wire deep to tendon or **bending K-wires both proximally and distally may prevent wire migration.**
    - **Increasing age significantly predicts failure of patella fracture fixation.**
- Cerclage and tension band wiring: for minimally displaced stellate fractures with significant comminution
- Partial patellectomy: useful with extraarticular distal pole fractures and also used with severely comminuted fractures; the largest pieces should be preserved and the patella ligament reattached (Fig. 11.18).
- **ORIF, when possible, is associated with better outcomes than partial patellectomy in comminuted and displaced fracture of the inferior pole of the patella.**

□ Complications: **symptomatic hardware (very common)**, loss of reduction (22%), nonunion (<5%), infection, arthrofibrosis/stiffness

▪ **Patella dislocation**

□ Diagnosis: frequently involves young adults or adolescents, is usually lateral, and involves injury to the medial patellofemoral ligament

□ Treatment: reduction and immobilization with controlled motion for 6 weeks

□ Complications: redislocation

▪ **Patellar tendon rupture**

□ Diagnosis/classification: occurs in patients younger than 40 years with overload of extensor mechanism during athletic activity

- Increased risk with metabolic disorders, rheumatologic disease, renal failure, corticosteroid injection, patellar tendinitis, and infection. Diagnosis is frequently missed.

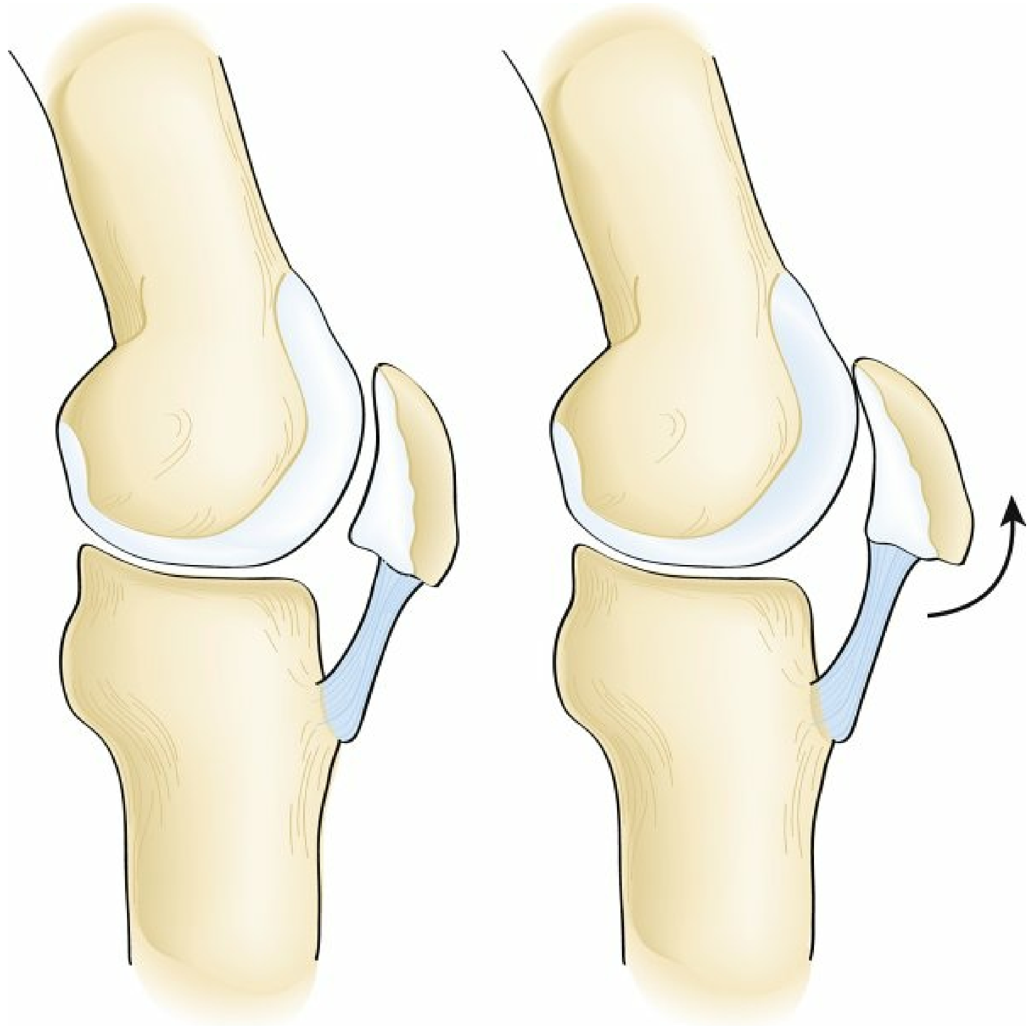


FIG. 11.18 Anterior reattachment of the patellar ligament, which is recommended to prevent superior tilting of the patella.
Redrawn with permission from Marder RA et al: Effects of partial patellectomy and reattachment of the patellar tendon on patellofemoral contact areas and pressures, *J Bone Joint Surg Am* 75:35–45, 1993.

- □ Treatment: direct primary repair with a nonabsorbable suture and locking (Krackow) stitch through patellar drill holes; can be supplemented with semitendinosus graft and/or cerclage wire/suture to protect repair
- □ Complications: stiffness and extensor weakness

▪ **Quadriceps tendon rupture**

- □ Diagnosis: patients may be younger than 40 years, but this condition most commonly occurs in older patients with medical problems.
  - • Association with renal failure, diabetes, rheumatoid arthritis, hyperparathyroidism, connective tissue disorders, steroid use, intraarticular injections (20%– 33%)
  - • Males are affected more often (up to 8:1); nondominant limb affected two times more often than dominant limb
- □ Treatment
  - • Incomplete rupture: nonoperative management; patient warned of risk for future rupture.
  - • Acute unilateral rupture: repair through osseous drill holes

or suture anchors. Repair should be immediate; ruptures more than 2 weeks old may be retracted 5 cm.
    - Bilateral ruptures: identification of underlying medical problem; otherwise, treated same as a unilateral rupture. Non–weight-bearing status and DVT prophylaxis are required.
    - Chronic tendon rupture repair—less successful with acute rupture; may require Codivilla procedure (V-Y lengthening) or quadriceps tendon lengthening
- ▫ Complications: strength deficit (33%–50% of patients), stiffness, inability to resume prior level of athletic/recreational activity (50%)
    - Suture anchor fixation shown to have less gap formation during cadaveric cyclic loading and higher strength than transosseous suture fixation.

Table 11.5

Adult Tibia Fractures and Dislocations

Injury	Classification	Treatment	Complic
Tibial plateau fracture	Schatzker classification I—split II—split depression III—pure depression IV—medial plateau split V—bicondylar with intact metaphysis VI—bicondylar with metaphyseal/diaphyseal dissociation AO/OTA classification: 41-A—extraarticular fracture 41-B—partial articular fracture (Schatzker I–IV) 41-C—complete articular/bicondylar (Schatzker V and VI)	MRI can change treatment or classification in most cases (soft tissue injury); medial collateral ligament > ACL; lateral > bicondylar > medial (think dislocation with medial); spanning external fixation for high-energy injuries (soft tissue stabilization) Nonoperative: stable knees (<10 degrees varus/valgus in full extension, <3 mm articular	DJD, inf (surgi appro impo factor malu collap nonop treatr conve plates fractu ligam instab peron injury comp syndr stiffn reduc avasc necro

		step-off); cast brace, early ROM, weight bearing delayed for 4–6 wk ORIF if articular step-off >3 mm, condylar widening >5 mm, knee unstable, medial and bicondylar; plate fixation (locked vs. nonlocked, single vs. dual [posteromedial] incision) vs. external fixation (bicondylar or severe soft tissue injury, wires >15 mm from joint)	
Tibial spine fracture	I—anterior tilt II—complete anterior tilt III—no contact: A—no rotation B—rotated	I/II/IIIA closed reduction, long-leg cast for 6 wk if knee can be brought into full extension; IIIB and all irreducible types require open reduction	Block to r (arthr remo bodie laxity
Tibial tubercle fracture		ORIF with screw or staple	Loss of fi quadı weak
Tibial stress fracture		Activity modification for 6–10 wk	Progressi comp fractu
Tibial shaft fracture	Gustilo and Anderson open fracture grade Grade I—no periosteal stripping, <1-cm wound	Stress fractures that fail to heal may require IM nailingInail for	Delayed wk increa greate

	Grade II—no periosteal stripping, >1-cm wound Grade IIIA—periosteal stripping, no flap required Grade IIIB—periosteal stripping, flap required Grade IIIC—periosteal stripping, flap required, vascular injury requiring repair	transverse oblique fracture of middle third or segmental and also for vascular injury, bilateral injury, pathologic fractures, severe ligamentous injuries to knee (statically locked IM nail) Open fractures: unreamed nail up to and including some IIIB injuries, early flap coverage, delayed bone grafting Early amputation should be considered in grade IIIC injuries, posterior tibial nerve injury, warm ischemia >6 h, and severe ipsilateral foot injury (unreconstructible limb)	displa and r third treatr incluc fibule poster bone nonu (poste bone ream infect (flap/ ampu malu (varu short degre varus <10 d anter angul accep vascu (uppe anter artery comp syndr peron injury
Tibial plafond fracture (pilon)	Ruedi and Allgöwer: I—minimally displaced II—incongruous III—comminuted	Long-leg cast and non–weight-bearing status ORIF if displaced and ankle involved; minimally invasive small-pin external fixation should be	DJD (ma late fu infect varus angul slough

		considered	
Fibular shaft fracture	Middle to lower third (athletes)	Casted only if needed for pain relief	Missed sy injury
Proximal fibula fracture		Open if unstable	Injury to peron
Proximal tibia-fibula dislocation	Anterior (most common), posterior, superior	Reduced (90 degrees flexion) Posterior and superior dislocations, along with failed closed reduction of anterior injuries treated with ORIF	
Chondral/osteochondral fracture	Endogenous vs. exogenous	Arthroscopic evaluation of locked, acute condylar defects; removal of small fragments (pinning of large fragments)	DJD

PTB, Patellar tendon–bearing cast.

Tibial Injuries (Table 11.5)

- **Plateau fracture**
    - Diagnosis/classification
        - Schatzker classification (Fig. 11.19)
            - Type I—split
            - Type II—split depression
            - Type III—pure depression (rare)
            - Type IV—medial tibial (highest risk of associated vascular injury)
            - Type V—bicondylar with intact metaphysis
            - Type VI—bicondylar with metaphyseal/diaphyseal dissociation

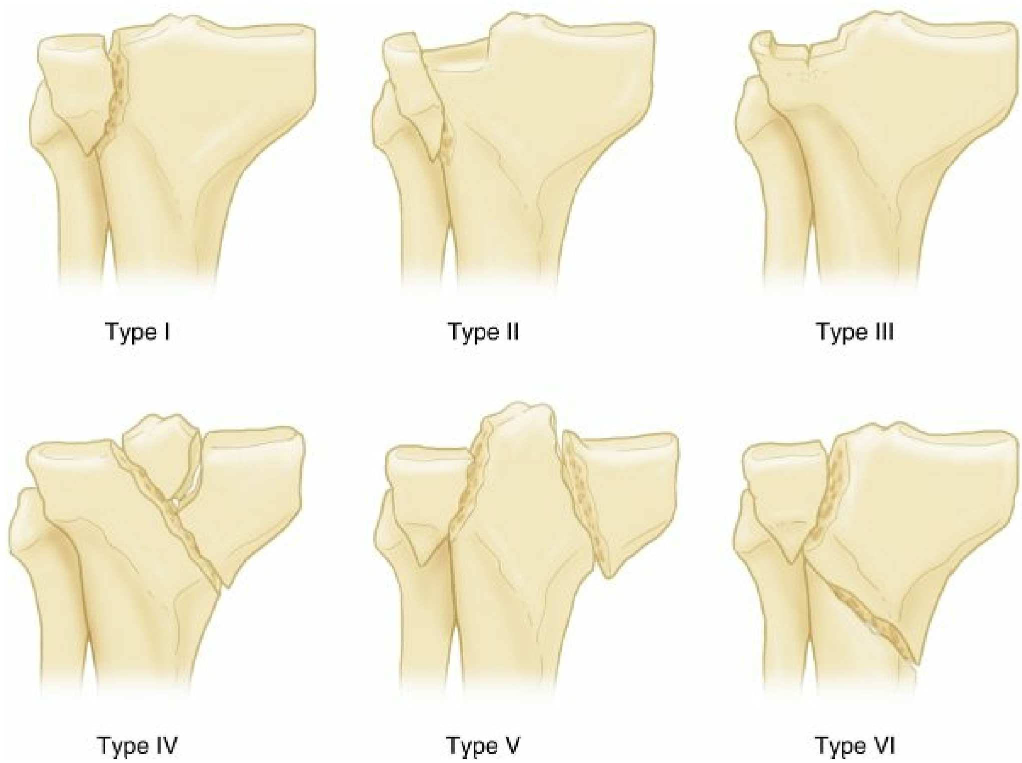


FIG. 11.19 Schatzker classification of tibial plateau fractures.
Adapted from Lubowitz J et al: Part I: arthroscopic management of tibial plateau fractures, *Arthroscopy* 20:1063–1070, 2004.

- MRI changes treatment or classification in most cases.
  - Soft tissue injury is demonstrated (50%–90% incidence).
  - MCL and ACL injuries in 30%–50%
  - Meniscus tears in over 50% of cases
    - Lateral tears more common medial tears
      - Lateral meniscus tears most common in split depression (Schatzker type II) fractures
    - Peripheral tears most common type
    - Order of frequency—lateral greater than bicondylar greater than medial **(think *knee dislocation* with medial plateau fractures)**
  - The elderly osteoporotic patient is less likely to suffer associated ligamentous injury, because the bone fails before the ligament.
  - The lateral plateau is more convex and situated more proximal than the medial plateau, which is more concave.

□ Treatment

- Nonoperative treatment indicated in stable knees (<10 degrees coronal plane instability with the knee in full extension) with <3-mm articular step-off. Cast brace, early ROM, and delayed weight bearing for at least 4–6 weeks.

- Operative treatment indicated with articular step-off more than 3 mm, condylar widening more than 5 mm, instability of the knee, and all medial and bicondylar plateau fractures.
    - The goal of treatment is restoration of normal alignment.
    - **Maintenance of mechanical axis correlates most with a satisfactory clinical outcome.**
    - Development of arthritis does not correlate with articular step-off.
    - ORIF
        - Plate fixation with early motion
        - **Posteromedial coronal fragment** may not be captured via a lateral plate. **Use** a separate posteromedial incision and **posteromedial plate.**
        - Use of bone void fillers
            - **Calcium phosphate cement** has highest compressive strength.
            - **Lower rate of subsidence compared with autograft or allograft**
            - Best treatment to prevent loss of articular reduction in a split-depression tibial plateau fracture consists of a lateral plate, rafting screws, and calcium phosphate cement.
    - External fixation—ring fixation useful for bicondylar fractures with severe soft tissue injuries. Small wires must be kept at least 15 mm from the joint to avoid a septic joint.
        - Spanning external fixators—used temporarily in selected high-energy injuries to allow for a reduction in soft tissue swelling before definitive

fixation

- Complications: DJD, infection (surgical approach the most important factor), malunion (varus collapse with nonoperative or conventional plates in severe bicondylar fractures), ligament instability (left untreated, has an adverse impact on outcome), peroneal nerve injury
    - Compartment syndrome—increased risk with more proximal fractures. Anterior and lateral compartments are at highest risk.

- **Shaft fractures**
    - Diagnosis
        - Mechanism of injury
            - Low-energy
                - Spiral oblique fracture
                - Tibia and fibula at different levels
                - Closed fracture with minor soft tissue trauma
                - **There is a high association of posterior malleolus fractures with spiral distal tibia fractures.**
            - High-energy
                - Comminuted fracture
                - Tibia and fibula at same level
                - Transverse fracture pattern
                - Diastasis between tibia and fibula
                - Segmental fracture
                - Open fracture or closed with significant soft tissue trauma
        - Most common long bone fracture
        - Often associated with soft tissue injuries
            - Soft tissue management critical to outcome
            - Open fractures may require repeated incision and drainage.
                - Number of débridement sessions, type of irrigation, and pressure of irrigant controversial
                - Sharp débridement of nonviable soft tissue and bone the most important aspect of incision and drainage
                - **Severity of muscle injury has the highest impact on need for amputation.**
    - Treatment
        - General principles

    - With nonoperative management, the extent of shortening and translation seen on injury radiographs can be expected to be present at union.
    - Angular and rotational alignment well controlled with cast
    - **Shortening is most difficult to control with nonoperative treatment in oblique and comminuted fractures involving both tibia and fibula.**
    - Timely and thorough soft tissue management critical to outcome
    - Restoration of limb length, alignment, and rotation
    - Stable fixation
    - Early ROM of knee and ankle
    - **Prompt administration (within 3 hours of injury) of antibiotics for open fractures is the most important factor in minimizing the risk of infection.**
    - Use of bone morphogenic protein type 2 (**BMP-2)** is approved for open tibia fractures treated with IM fixation and has been **shown to lead to fewer reoperations in acute open tibia fractures.**
    - BMP-7 is approved for treatment of tibial nonunion when autogenous bone graft is not feasible.
- Nonoperative treatment
    - Indications
        - Low-energy fractures
        - Shortening less than 1 or 2 cm
        - Cortical apposition more than 50%
        - Angulation maintained with cast
            - Varus—valgus less than 5 degrees
            - Flexion—extension less than 10 degrees
    - Long-leg cast
        - Can control varus/valgus, flexion/extension, and rotation
        - Shortening and cortical apposition seen on injury radiograph are equivalent to shortening at union.

- Converted to functional brace at 4–6 weeks.
- Non–weight-bearing status for 4–6 weeks
- IM nailing
  - Shorter immobilization time than cast management
  - Earlier weight bearing than that achieved with cast
  - Union rate more than 80% for closed injuries
  - Reamed nailing achieves higher union rates than nonreamed nailing
    - Reamed nailing safe for open fractures
    - Severity of soft tissue injury more prognostic than reaming status
  - Static interlocking indicated for stable and unstable fractures
  - Dynamic interlocking indicated only for stable fracture (Winquist I or II)
  - Gaps at fracture site associated with nonunion
  - **Proximal-third tibial fractures associated with valgus and apex anterior angulation**
  - Avoidance of malreduction of proximal-third fractures achieved by the following:
    - Ensuring a laterally based **starting point** and anterior insertion angle; entry site should be **in line with medial border of lateral tibial eminence.**
    - **Blocking screws placed in the metaphyseal segment at the concave side of the deformity narrow the available intramedullary space**

and direct the nail toward a more centralized position (Fig. 11.20).
            - **To prevent an apex anterior deformity, a blocking screw can be placed posterior to the nail in the proximal fracture.**
            - Provisional unicortical plates
            - Semiextended position for nailing
- External fixation
    - Temporary during application of damage control principles
    - Temporary or definitive for highly contaminated fractures
        - For type III open tibia fractures, significantly longer time to union and poorer functional outcomes seen after definitive fixation with external fixation than after IM nailing.
    - Higher incidence of malalignment than IM nails
    - Circular frames indicated for very proximal and distal shaft fractures and when these fractures are associated with severe soft tissue injury
    - Can be safely converted to IM nail within 7–21 days (newer studies show longer than 7-day delay acceptable, but exact safe timing unknown)
- Plate fixation
    - For extreme proximal and distal shaft fractures
    - Higher infection risk than that for IM nailing in open fractures

- Use of **a long 13-hole percutaneous plate places the superficial peroneal nerve at risk during percutaneous screw insertion for holes 11, 12, and 13.** A larger incision with blunt dissection should be used for insertion of screws in this region.

□ Complications

- Nonunion
  - Infection must be ruled out.
  - Dynamization if axially stable
  - **Reamed-exchange nailing is preferred treatment for middiaphyseal tibial nonunions.**
  - Bone graft for bone defects
- Malunion
  - Most common with proximal-third fractures
    - Valgus and apex anterior

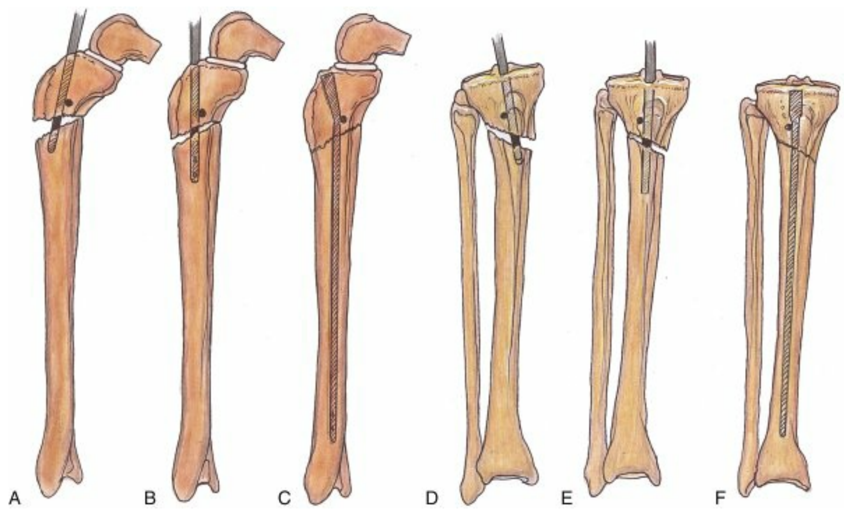


FIG. 11.20 Shaft fractures. (A–F) Blocking screws placed posteriorly and laterally to the central axes of the proximal fragment.

Reprinted with permission from Hiesterman TG et al: Intramedullary nailing of extra-articular proximal tibia fractures, *J Am Acad Orthop Surg* 19:690–700, 2011. © 2011 American Academy of Orthopaedic Surgeons.

- May increase long-term risk of arthrosis, particularly in the ankle
- More common with varus deformity
- Rotational malalignment is common with distal-third fractures.
- Delayed union
  - Risk factors for reoperation to achieve bony union within first postinjury year:

        - Transverse fracture pattern
        - Open fracture
        - Cortical contact less than 50%
    - Infection
        - Risk rises with increasing severity of soft tissue injury and longer time to soft tissue coverage
        - Use of vacuum-assisted closure for wound does not alter risk of infection.
    - Compartment syndrome, which can occur even with open fractures
    - Anterior knee pain—occurs in more than 30% of cases treated with IM nailing; resolves with removal of nail in 50% of cases
- **Ipsilateral femoral shaft and tibial shaft fractures (floating knee) —treated with retrograde femoral nailing and antegrade tibial nailing**
- **Tibial plafond fractures (pilon fractures) (see** Chapter 6, Disorders of the Foot and Ankle)
- **Ankle and foot fractures (see** Chapter 6, Disorders of the Foot and Ankle)

Section 4 Pediatric Trauma

Introduction

- **Several features of fractures and dislocations in children are not found in adults.**
- **Children's bones are more ductile than adults' bones, and bowing is thus unique to children.**
- **The terms** *greenstick* and *torus* imply a partial fracture with some part of the bone intact.
- **The periosteum in children is much thicker and often remains intact on the concave (compression) side, allowing for less displacement and better reduction of fractures.**
- **Children's fractures heal more quickly and with less immobilization than adults' fractures. Contractures are also less likely.**
- **Because bones are actively growing in pediatric fractures, malunion and growth plate injuries are important concerns. Remodeling is more thorough; thus, displacement and angulation that would not be acceptable in an adult are often acceptable in children.**
  - The exception to this rule is an intraarticular fracture. The same axioms apply, but the presence of nearby physeal structures can affect fixation options.

Child Abuse

- **Introduction**
  - One must always be alert for the battered child.
  - All states now require physicians to report suspected child abuse. For any abused child for whom the abuse is not diagnosed and reported, there is a 30%–50% chance of repeat abuse and a 5%–10% chance of death from subsequent abuse.

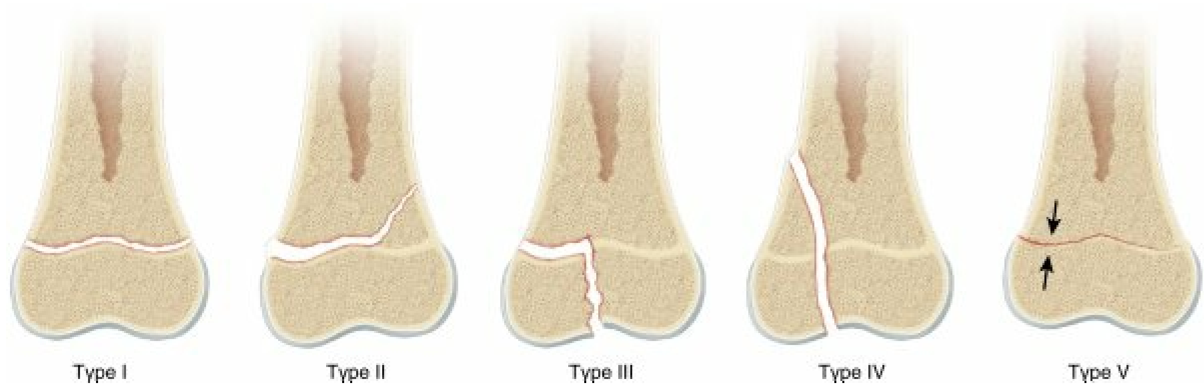


FIG. 11.21 Salter-Harris classification of physeal fractures.
From Herring J: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2007, Saunders.

- □ Suspicion should rise when fractures are seen in children who are younger than 5 years (90% of fractures due to abuse occur in children <5 years), or who have multiple healing bruises, skin marks, burns, unreasonable histories, or signs of neglect, among other indications.
- □ Abuse accounts for 50% of fractures in children younger than 1 year and 30% of fractures in children younger than 3 years.
- □ The most common cause of femur fractures in nonambulatory children is abuse.
- □ Osteogenesis imperfecta is often in the differential diagnosis in a child with multiple fractures.

- **Fracture location**
  - □ **The most common locations of fractures in abused children are the humerus, tibia, and femur, in that order.**
    - Spiral humerus fractures and distal humeral physeal separations are highly suggestive of child abuse.
    - Spiral femur fractures in nonambulatory children are also highly suspicious.
  - □ If suspicion is high, skeletal surveys are appropriate in children with delayed development and in some with metaphyseal and spiral fractures.
  - □ **Corner fractures (at junction of metaphysis and physis) and posterior rib fractures are described as pathognomonic for abuse.**
  - □ However, diaphyseal fractures are more common in abuse cases (four times as likely as metaphyseal fractures).
  - □ Skeletal surveys are not as helpful in children older than 5 years. Instead, bone scanning may be done as an alternative or adjunctive study.
  - □ Nonorthopaedic injuries found in the abused child include skin injuries, head injuries, burns, and blunt abdominal visceral injuries.
- **Treatment**
  - □ In addition to normal fracture care, early involvement of social workers and pediatricians is essential to evaluate for possibility of child abuse and initiate necessary protective actions.

Physeal Fractures

- **Introduction**
  - Fracture of the physis, or growth plate, is more likely than injury to attached ligaments; thus, a fracture of the physis should be assumed until evidence proves otherwise (young children rarely get sprains).

Table 11.6

Salter-Harris Classification of Physeal Injuries

Type	Description	Prognosis
I	Transverse fractures through physis	Excellent
II	Fractures through physis, with metaphyseal fragment	Excellent
III	Fractures through physis and epiphysis	Good but with potential for intraarticular deformity; may require ORIF
IV	Fractures through epiphysis, physis, and metaphysis	Good but unstable; fragment requires ORIF
V	Crush injury to physis	Poor, with growth arrest
VI	Injury to perichondrial ring	Good; may cause angular deformities

- **Characteristics**
  - Although physeal fractures are classically thought to be through the zone of provisional calcification (within the zone of hypertrophy) of the growth plate, the fracture can be through many different layers.
  - Blood supply of epiphysis is tenuous, and injuries can disrupt small physeal vessels supplying the growth center. This can lead to many complications associated with these injuries (e.g., LLD, malunion, bony bars).

- Most common physeal injuries occur in distal radius, followed by distal tibia

- **Classification**
  - The Salter-Harris (SH) classification modified by Rang is the gold standard for physeal injuries (Fig. 11.21; Table 11.6).
    - It can be recalled using the mnemonic SALTR
      - I—*s*lipped—separation physis
      - II—*a*bove—metaphysis and physis
      - III—*l*ower—epiphysis and physis
      - IV—*t*hrough—metaphysis, physis, epiphysis
      - V—*r*uined—crushed physis
    - SH I fracture is through the zone of hypertrophic cells of the

physis.

- **Treatment and results**
  - Gentle reduction should be attempted initially for SH I and II fractures, sometimes with use of conscious sedation protocols. With reduction and immobilization, these fractures do well without a significant amount of growth arrest (except in the distal femur).
  - SH III and IV fractures are intraarticular by definition and usually require ORIF. Follow-up radiographs are required for all physeal injuries.
  - Remodeling is also common in pediatric fractures (up to 20 degrees), depending on the location of the fracture and the age of the patient.
  - Harris-Park growth arrest lines (transverse radiodense lines) may be the only evidence of a physeal injury on follow-up radiographs.
- **Partial growth arrest**
  - Physeal bars or bridges occur from growth plate injuries that arrest a part of the physis and leave the uninjured physis to grow normally resulting in angular growth and deformity.
  - Physeal bridge resection with interposition of a fat graft or artificial material is reserved for patients with more than 2 cm of growth remaining and less than 50% physeal involvement.
  - Treatment of smaller peripheral bars in young patients has the highest success rate.
  - MRI and CT can help define the location and amount of physeal closure.
  - Arrest involving more than 50% of the physis should be treated with ipsilateral completion of the arrest and contralateral epiphysiodesis or ipsilateral limb lengthening.

Pediatric Polytrauma

- **Introduction**
  - Trauma is the most common cause of death in children older than 1 year.
    - Death and long-term morbidity are most closely associated with the severity of traumatic brain injury.
  - Most common causes of polytrauma are fall from height and motor vehicle collision.
- **Treatment**
  - Children may remain hemodynamically stable for some time despite significant blood loss.
    - Intraosseous infusion may be needed owing to difficulty in quickly obtaining IV access: Crystalloid fluid bolus 20

mL/kg.
    - If hemodynamic instability recurs or persists despite 2 or 3 boluses, blood transfusion should be started (10 mL/kg). Estimate of pediatric blood volume is 75 to 80 mL/kg.
  - Cervical spine immobilization for children younger than 6 years requires use of a backboard with occipital cutout because of the large head size in children.
    - Use of an adult backboard can result in neck flexion.
  - Timing of orthopaedic management
    - Early operative fixation (within 2–3 days) decreases intensive care unit and overall hospital stays.

Shoulder and Arm Injuries

- **Clavicle fracture**
  - Principles and presentation
    - Most frequent fracture in children
    - 90% of obstetric fractures; often associated with brachial plexus palsies
    - Mechanisms
    - Birth injury—direct pressure from symphysis pubis
    - Older children—fall on an outstretched hand; direct trauma to clavicle or acromion
  - Diagnosis and radiographs
    - Ultrasound for obstetric fractures
    - Cephalic tilt views (cephalic tilt of 35–40 degrees)
    - Apical oblique view (ipsilateral side rotated 45 degrees and cephalic tilt of 20 degrees toward beam)
    - Axial CT for medial clavicle fractures and physeal separation evaluations
  - Treatment
    - Newborn: nonoperative treatment
    - Adolescents: nonoperative treatment (standard of care)
    - Sternoclavicular physeal fracture-dislocations
      - Anterior: closed reduction, often unstable but can remodel
      - Posterior: reduction with CT surgery backup after CT scan to evaluate for mediastinal impingement
    - Operative treatment controversial for middle-third clavicle fractures
      - Absolute indications: open fractures, neurovascular compromise

- Relative indications: nonunion, malunion, displacement more than 2.0 cm
- Pin fixation should be avoided.
- Plate fixation and intramedullary nailing acceptable operative options

□ Complications

- Nonunion (1%–3%)—rare in children; orthopaedist should beware of congenital pseudarthrosis
- Malunion—rare in younger populations; rates increase as age increases.
- Neurovascular compromise
- Pneumothorax

▪ **Proximal humerus fractures**

□ Principles and presentation

- In 80%–90% humeral growth occurs at proximal physis; increased remodeling potential
- Three ossification centers (humeral head, greater and lesser tuberosities) coalesce at age 6–7 years.
- Proximal fragments rotated into abduction and external rotation by rotator cuff muscles
- Distal fragments pulled into adduction and shortened by the pectoralis major and deltoid
    - Accordingly, gravity can be a useful reduction aid.
- Blocks to closed reduction can include long head of biceps tendon, joint capsule, and periosteum.

□ Classification

- SH classification commonly applied to these fractures
- SH I fractures most common in children younger than 5 years
- SH II fractures most common in children older than 12 years
- Metaphyseal fractures common in children between 5 and 12 years
- Little Leaguer shoulder represents an SH I fracture.

□ Treatment

- Nonoperative treatment with temporary immobilization is usual treatment owing to remodeling potential

□ Indications for operative treatment

- Absolute: open fractures, neurovascular injuries, intraarticular extension
- Relative: young children (<12 years); 70 degrees and 100% displacement acceptable
- Age older than 12 years: controversial, 30–40 degrees, and 50% displacement

- Complications
  - Malunion—varus deformity well tolerated owing to shoulder motion
- **Diaphyseal humerus fractures**
  - Principles and presentation
    - Uncommon in children
    - Radial nerve palsy can accompany middle- or distal-third fractures; usually neurapraxia and transient
  - Treatment
    - Nonoperative treatment with immobilization in sling or clam-shell type splint
    - Operative indications: open fractures, vascular compromise after reduction
  - Complications
    - Radial nerve palsy—usually transient; exploration rarely indicated

Elbow Injuries (Table 11.7)

- **Principles of elbow fractures**
  - Skeletal anatomy (Fig. 11.22)
    - Secondary ossification centers in order of ossification can be recalled using the mnemonic *CRITOE*, and age at ossification of these centers can be roughly estimated on the basis of odd numbers 1–11 (e.g., capitellum at 1 year):
      - *C*apitellum
      - *R*adial head
      - *I*nternal (medial) epicondyle
      - *T*rochlea
      - *O*lecranon
      - *E*xternal (lateral) epicondyle
    - Radial head, trochlea, and olecranon may appear as multiple ossification sites.
  - Radiographic anatomy
    - A five-part systematic approach is key to avoiding missing an injury (Fig. 11.23):
      - Proximal radius should align with capitellum in all views.
      - Long axis of ulna should align and be slightly medial to humerus on AP radiograph.
      - Anterior humeral line should bisect capitellum on true lateral radiograph.

            - Humeral-capitellar (Baumann) angle should be in valgus and fall between 9 and 26 degrees.
            - Soft tissue shadows may demonstrate an anatomic anterior fat pad.
        - Abnormalities in radiographic anatomy are summarized in Table 11.8.
    - Complications
        - Fishtail deformity of distal humerus may result from malunion, osteonecrosis, growth arrest, or some combination of these factors. Uncommon but challenging complication to treat that may be seen following both supracondylar and lateral condylar fractures. Results in loss of motion with proximal forearm migration, ulnotrochlear incongruity, and radial head dislocation.
- **Distal humerus fractures**
    - Distal humeral physeal separation (Fig. 11.24)
        - Principles and presentation
            - Usually occur in pediatric patients younger than 6–7 years
            - **Evaluation for child abuse should be considered in young patients with questionable presentation.**
            - Young patients may present with pseudoparalysis.
            - Often confused for elbow dislocations (which are rare in young children)
        - Diagnosis and radiographs
            - Radiographs demonstrate intact relationship between radius and capitellum. Radius and ulna lose normal relationship with distal end of humerus.
            - Ultrasound or MRI evaluation may be necessary for young children.
            - Arthrography can be used to evaluate for intraarticular extension.
        - Treatment
            - Closed reduction and percutaneous pinning
            - Avoid closed reduction if diagnosis is made late to avoid iatrogenic injury to the physis.

- Complications
    - Misdiagnosis is most common, and these injuries can be mistaken for elbow dislocations or soft tissue injuries.
    - Physeal separations are typically medial, whereas elbow dislocations are typically lateral.

□ Supracondylar humerus fractures

- 50%–60% of fractures
- 95%–98% are extension type; typically occur from a fall on outstretched hand with elbow in extension or hyperextension
- 2%–5% are flexion type; typically occur from a fall onto the flexed elbow
- Peak incidence in children between ages 5 and 8 years
- 1% associated with vascular injuries
- **Anterior interosseous nerve (AIN) injury most common for extension-type fractures; usually neurapraxia**
- Ulnar nerve injury usually iatrogenic from medial pinning and also the most common nerve injury from flexion type
- Posteromedial angulation associated with radial nerve injury (the second most common neurapraxia after AIN palsy)
- Posterolateral angulation associated with brachial artery and median nerve injury
- Immediate surgery indicated in presence of vascular compromise (pale, cool hand)
- Most injuries can be splinted in a nonflexed position and treated the following day with no adverse impact on outcome.
- Diagnosis and radiographs
    - AP and lateral radiographs essential
        - AP view should be examined for Baumann angle; may need to be compared with contralateral arm
        - Lateral radiograph should be examined to

see whether the anterior humeral line intersects the middle third of the capitellar ossification center.

- Anterior and posterior fat pad signs should be sought.
  - Anterior fat pad displacement has low specificity and can be normal.
  - Posterior fat pad displacement is always pathologic and can indicate a nondisplaced fracture.
- Extension type fracture
  - Classification and treatment—Gartland classification

Table 11.7

Pediatric Elbow Trauma

Injury	Classification
Supracondylar fracture (age 6–8 yr)	I—extension (98%), nondisplaced
	II—displaced (posteri cortex intact)

	III—displaced (poster periosteal hinge intact)
	IV—displaced (poster periosteal hinge disrupted)
	Flexion (distal fragme anterior)
Lateral condyle fracture (age 6 yr) (see Fig. 11.25)	Milch I—SH IV Milch II—SH II in trochlea
Medial condyle fracture (age 9–14 yr)	Nondisplaced—<2 mm displacement Displaced—>2 mr displacement
Entire distal humeral physis fracture (age <7 yr)	A—infant (SH I) B—age 7 mo–3 yr (SH I) C—age 3–7 yr (SH II)
Medial epicondylar apophysis fracture (Little Leaguer's elbow; age 11 yr) (see Fig. 11.26)	I–acute injuries
	A—nondisplaced
	B—minimally displac
	C—significantly displaced (may be dislocated)

	D—entrapment of fragment in joint
	E—fracture through epicondylar apophysis
	II—chronic tension stress injury
T condylar fracture	Based on fracture
Radial head and neck fractures (age <4 yr)	A—SH I or II physeal fractur B—SH IV fracture C—transmetaphys fracture D and E—with elbow dislocati
Proximal olecranon physis fracture (rare)	I—physeal-metaphyseal border (young children) II—physis with lar metaphyseal fragment (olde children)
Olecranon metaphysis fracture	A—flexion
	B—extension
	C—shear
Elbow dislocation (age 11–20 yr)	Based on direction of dislocation

Radial head subluxation (nurse-maids elbow; age 15 mo–3 yr)	

FIG. 11.22 Ossification centers of the elbow in order of appearance and approximate age of ossification.

- Type I—nondisplaced
  - Treated closed in a long-arm cast for 2–3 weeks
- Type II—displaced with intact posterior cortex
  - Closed treatment for type II fractures is appropriate if all of the following criteria are met:
    - No significant swelling

        - Anterior humeral line intersects the capitellum
        - No medial distal humeral cortical impaction
- Otherwise, closed reduction and percutaneous pinning are appropriate for type II fractures, with postoperative long-arm immobilization at 90 degrees of flexion.
- Type III—completely displaced; displacement can be posteromedial or posterolateral
    - Treated with closed reduction and percutaneous pinning
    - ORIF rarely needed
        - Used for rotationally unstable fractures, open fractures, and fractures

associated with neurovasc injuries

- Anterior approach preferred
- Crossed pin and lateral-entry pin configurat often used
  - Cross pin consic more stable biome
  - Media pin can risk iatrog ulnar nerve injury (3%–8%).
  - Latera entry pin config has shown simila clinica result to

those of crosse pin fixatio when there is appro pin spread and engag of both hume colum **A diverg wire techn shoul be used, with wires placed latera to minim comp and maxim the likelih of succes outco**

- Flexion type fracture
    - Management similar to that of extension type and based on degree of displacement

        - Minimally displaced: treated with immobilization in extension
        - Displaced: treated with closed reduction and percutaneous pinning
- Fracture with associated vascular injury
    - Well-perfused hand, absence of pulse ("pink, pulseless hand") (controversial)
        - Urgent closed reduction and percutaneous pinning
        - Pulse returns in majority of cases. If not, inpatient observation and splinting of extremity.
        - If hand becomes poorly perfused, vascular consultation should be obtained and intervention considered.
    - Poorly perfused hand, absence of pulse
        - Urgent closed reduction and percutaneous pinning. Arteriography generally not warranted;

location of injury is usually known.
- If perfusion restored, inpatient observation
- If hand remains poorly perfused, vascular consultation should be obtained.

- Complications
  - Iatrogenic ulnar nerve injury with medial pin use (3%–8%)
  - Compartment syndrome
    - Volkmann ischemic contracture is the most serious complication; orthopaedist should beware of antecubital swelling and pressure from splint or cast.
  - Angular deformity
    - Cubitus varus is typically the result of malunion, not growth arrest. It results in a gunstock deformity associated with poor cosmesis but does not generally affect function.
    - Cubitus valgus is the result of malunion and can lead to tardy ulnar nerve palsy.
    - Recurvatum is poorly tolerated.
  - Stiffness—rare if cast removal is done appropriately

□ Lateral condyle fractures
- 17% of distal humeral fractures
- Peak incidence around age 6 years
- Loss of motion can be severe owing to intraarticular extension if the diagnosis is missed.
- Increased incidence of growth disturbance
- Diagnosis and radiographs
  - AP, lateral, and oblique radiographs (especially internal oblique—most likely to accurately show maximum degree of displacement)
  - Arthrogram can help distinguish transphyseal fractures from lateral condyle fractures.

- Classification
    - Milch (historical; does not dictate treatment) (Fig. 11.25)
        - Milch I—SH type IV fracture; fracture courses through ossific center of capitellum; less common
    - Milch II—SH type II fracture; fracture courses medial to ossific center of capitellum; more common
    - Jakob (more clinically useful)
        - Type I—less than 2-mm displacement; intact intraarticular cartilage hinge
            - Can be treated with long-arm immobilization but can become displaced; needs to be followed closely
        - Type II—2- to 4-mm displacement
            - Generally treated with closed reduction and percutaneous pinning

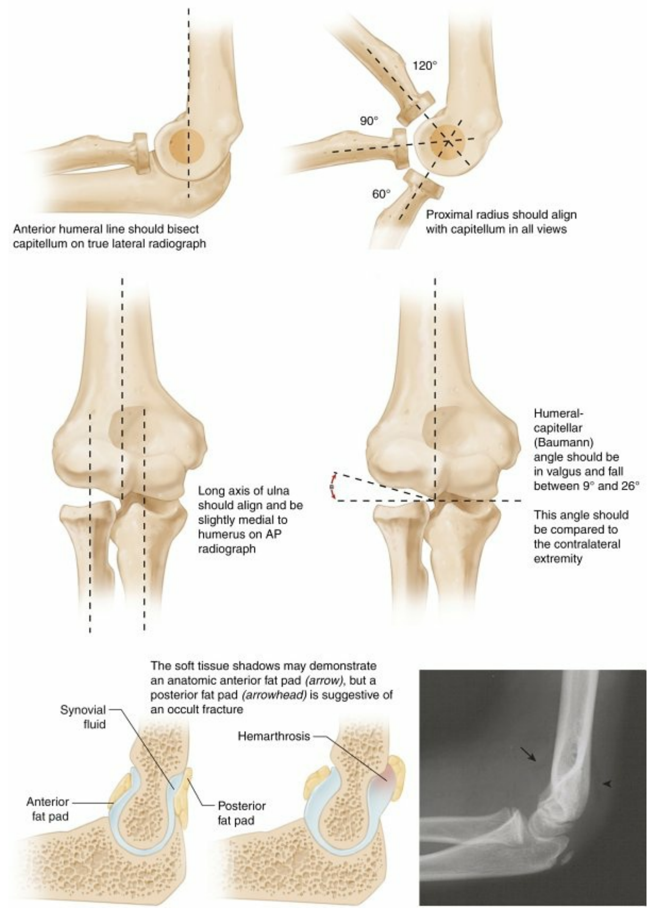


FIG. 11.23 Five-part systematic approach to evaluation of the radiographic anatomy of the pediatric elbow. The soft tissue shadows may demonstrate an anatomic anterior fat pad *(arrow)*, but a posterior fat pad *(arrowhead)* is suggestive of an occult fracture.

- Type III—greater than 4-mm displacement
  - Closed reduction and percutaneous pinning if intraarticular reduction confirmed on arthrogram
  - Open reduction can be necessary to ensure intraarticular reduction
    - Posterior blood supply must be preserved
- Complications
  - Lateral overgrowth or prominence (spurring) occurs in up to 50% of cases
    - Correlated with greater initial

fracture displacement. May be diminished with accurate lateral periosteal alignment. Does not affect function.

Table 11.8

Abnormalities in Pediatric Radiographic Anatomy

Radiographic Abnormality	Likely Injury
Radius does not point to capitellum	Lateral condyle fracture Radial neck fracture Monteggia fracture or equivalent Elbow dislocation
Long axis of ulna not in line or not slightly medial to long axis of humerus	Radial head and capitellum correctly aligned → transphyseal injury or displaced supracondylar Radius not pointing to capitellum → elbow dislocation
Anterior humeral line does not bisect capitellum	First, true lateral radiograph must be ensured Center of capitellum posterior → extension-type supracondylar fracture Center of capitellum anterior → flexion-type supracondylar fracture
Baumann angle abnormal	Inadequate reduction of supracondylar fracture
Posterior fat pad present	76% rate of occult fracture when no other radiographic abnormality identified

- High incidence of delayed union or nonunion
    - Fracture fragment bathed in synovial fluid; relatively tenuous blood supply and primarily cartilage
- Stiffness
    - Because of longer immobilization often needed and intraarticular extension
- Angular deformity
    - Cubitus valgus more common; due to lateral growth arrest
    - Tardy ulnar nerve palsy may result.
- Osteonecrosis of lateral condyle

- Iatrogenic—dissection posterior to fragment must be avoided to reduce risk of damaging blood supply.

□ Medial condyle fractures
- Principles and presentation
  - Rare injury, less than 1% of elbow fractures
  - Patients 8–12 years old
  - Can be mistaken for more common medial epicondylar fractures
- Diagnosis and radiographs
  - AP, lateral, oblique views
  - In young children, arthrogram may help show intraarticular component.
- Classification—Milch (same as for lateral condyle fractures)
  - Type I—through apex of trochlea (SH type II); very rare
  - Type II—through groove between capitellum and trochlea (SH type IV)
- Treatment
  - Protocol similar to that for lateral condyle fractures
- Complications
  - Missed diagnosis; usually confused for a medial epicondyle fracture

□ Medial epicondyle fractures
- Principles and presentation
  - Traction injury resulting in an avulsion of the apophysis by the medial collateral ligament and flexor mass
  - Last ossification center to fuse with metaphysis
  - Associated with elbow dislocation approximately 50% of the time (most common fracture associated with an elbow dislocation in children)
    - Valgus force with contraction of flexor-supinator mass (same mechanism as in elbow dislocation)
  - Can be incarcerated after reduction in 15%–18% of cases (Fig. 11.26)
  - Little Leaguer elbow is an overuse injury akin to SH I injury of the medial epicondyle physis.
  - Ulnar nerve symptoms can accompany injury secondary to stretch during trauma or to swelling.
- Diagnosis and radiographs

- AP, lateral, oblique views
- If apophysis is missing from an AP view, lateral and oblique views should be carefully evaluated for possible incarceration.

- Classification
  - Based on the amount of displacement and whether fragment is incarcerated in the joint
- Treatment
  - Most cases can be treated nonoperatively with excellent functional results.
  - The amount of displacement that would necessitate surgical reduction and fixation in young athletic patients is controversial.
    - More than 5 mm was a traditional amount of acceptable displacement; however, assessing the true displacement on standard radiographs has been shown to be difficult.
  - Incarceration of the fragment is an indication for surgical treatment.
- Complications
  - Missed incarceration
  - Ulnar nerve symptoms (10%–16%)
  - Nonunion—reported to occur in up to 60% of cases, but good functional outcomes reported even with radiographic nonunion
  - Loss of extension—20%

▪ **Radial head and neck fractures**

- □ Principles and presentation
  - 5% of pediatric elbow fractures
  - 90% are physeal or metaphyseal; rarely involve the head
  - Often valgus injuries
  - Associated with elbow dislocations and medial epicondyle fractures
- □ Diagnosis and radiographs
  - AP, lateral, oblique views
  - Radiocapitellar view (Greenspan) —oblique lateral directed 40 degrees proximally
- □ Treatment
  - Multiple closed reduction maneuvers
    - Patterson maneuver
    - Israeli technique

- Indications for surgery
    - Less than 20–30 degrees of angulation and no translation are acceptable; treated in long-arm immobilization
    - More than 30 degrees of angulation, more than 3–4 mm of translation, and more than 45 degrees of rotation are indications for surgical intervention.
- Surgical treatment using percutaneous wire correction or retrograde insertion of a wire with rotation of the wire accounting for reduction (Metaizeau)
- Open reduction through a lateral approach occasionally needed

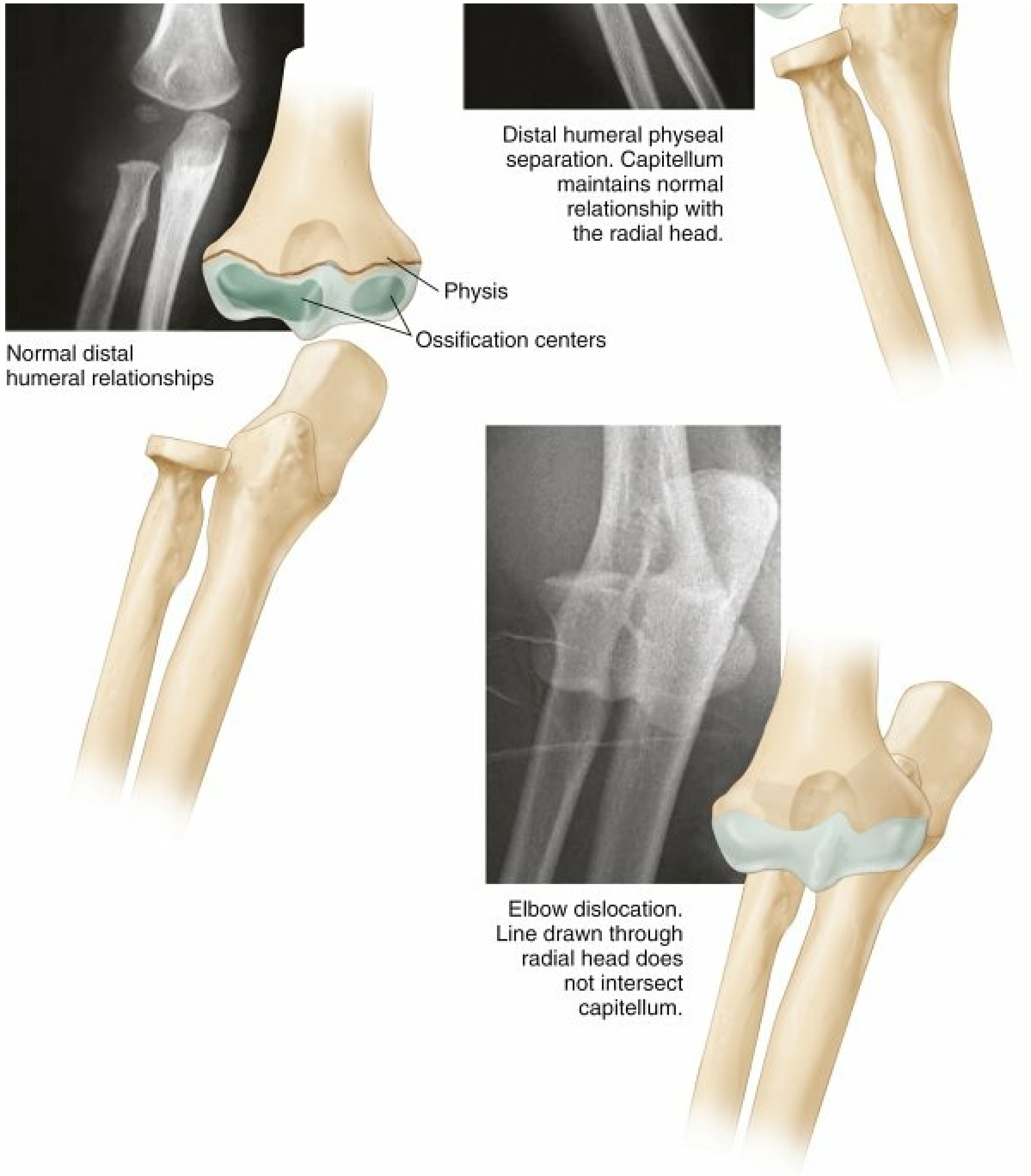


FIG. 11.24 Injuries about the distal end of the humerus, with comparison of distal humeral physeal separations and elbow dislocations.

- ▫ Complications
  - Decreased ROM: usually loss of pronation and supination
  - Radial head overgrowth (20%–40%)
  - Physeal arrest—can lead to cubitus valgus deformity
  - AVN of the radial head—70% of cases associated with open reduction
  - Neurologic injury—PIN most commonly injured
  - Radioulnar synostosis—associated with open reduction
- **Radial head subluxation**
  - ▫ Also known as nursemaid's elbow
  - ▫ Mechanism is usually traction on an extended elbow in children younger than 5 years; peak age is 2–3 years.

□ Arm usually held in slight flexion and pronation
□ Annular ligament subluxates over the radial head.

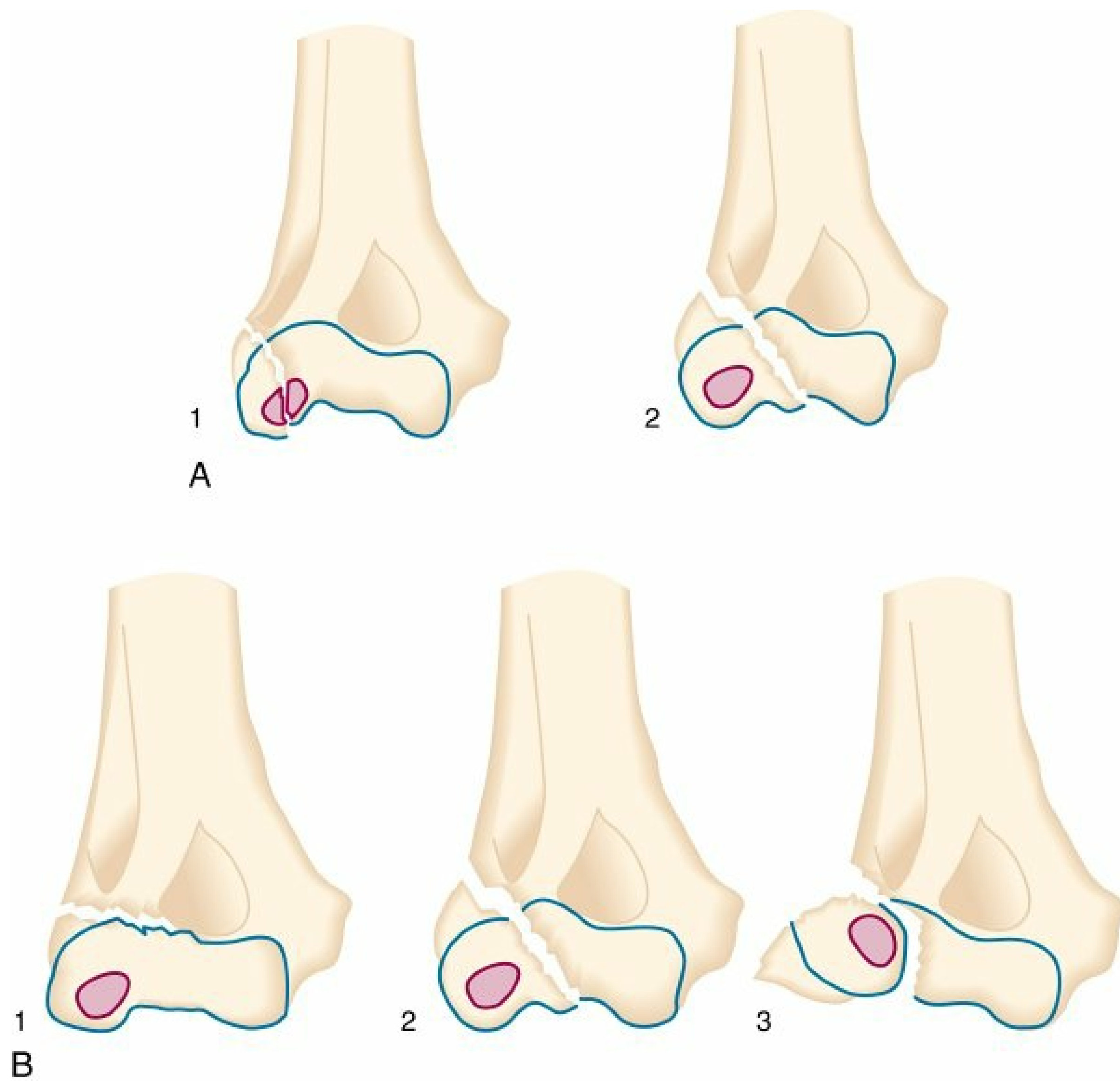


FIG. 11.25 (A) Lateral condyle drawing—Milch classification. *(1)* Milch type I fracture; the fracture line is through the ossific center of the capitellum; *(2)* Milch type II fracture; the fracture line is lateral to the ossific center of the capitellum. (B) Lateral condyle drawing—Jakob classification. *(1)* Type I fracture; the fracture line does not enter the articular surface, permitting it to remain stable. *(2)* Type II fracture; fracture extends into the articular surface but is minimally displaced. *(3)* Type III fracture; fracture extends into the articular surface and is highly displaced.
From Miller MD et al, editors: *DeLee & Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2009, Saunders.

FIG. 11.26 Medial epicondyle fracture following elbow dislocation. (A) Lateral view with intraarticular medial epicondyle fragment. (B) Anteroposterior view after reduction with incarcerated fragment. (C) Internal fixation with a single cannulated 3.5-mm screw and washer.
From Miller MD et al, editors: *DeLee & Drez's orthopaedic sports medicine,* ed 3, Philadelphia, 2009, Saunders.

- □ Treatment
  - Closed reduction achieved by placement of orthopaedist's thumb over radial head as elbow is progressively supinated and flexed
  - Immobilization is generally not needed.
- □ Complications
  - Recurrence can be common in young patients but uncommon after age 5 as the distal attachment of the annular ligament strengthens.

▪ **Monteggia fractures**

- □ Principles and presentation
  - Proximal ulna fracture associated with a radial head dislocation
  - Radial head dislocation in children without an obvious fracture can often be secondary to plastic deformation of the ulna.
  - Peak incidence between ages 4 and 10 years
- □ Diagnosis and radiographs
  - All forearm fracture radiographs should be accompanied by elbow radiographs to evaluate for radial head dislocation; all radial head dislocation radiographs should be accompanied by forearm radiographs.
- □ Classification—Bado
  - Anterior radial head dislocation and apex anterior proximal ulna fracture
  - Posterior radial head dislocation and apex posterior proximal ulna fracture
  - Lateral radial head dislocation and apex lateral proximal ulna fracture

- Radial head fracture-dislocation and proximal ulna fracture

□ Treatment

- Nonoperative treatment usually unsuccessful in adults
- If ulnar length restored by either closed reduction or intramedullary fixation, radial head reduction can be successfully maintained
- Chronic Monteggia fractures may require ulnar osteotomy and annular ligament reconstruction.

□ Complications

- Neurovascular—PIN neurapraxia (10%)

Forearm Fractures

▪ **Diaphyseal ulna and radius fractures**

□ Principles and presentation

- Forearm fractures make up 45% of all pediatric fractures; male predominance.
- 80% occur after age 5 years
- Mechanism is usually a fall on an outstretched hand.
  - Pronation can lead to a flexion injury with dorsal angulation.
  - Supination can lead to an extension injury with volar angulation.

□ Treatment

- Nonoperative treatment with closed reduction and long-arm immobilization is usually successful in children.
  - In general, apex dorsal angulation should be accompanied by immobilization in supination.
  - In general, apex volar angulation should be accompanied by immobilization in pronation.
  - Location of the fracture and associated deforming forces may dictate the proper arm rotation for immobilization:
    - Proximal-third fractures in supination
    - Middle-third fractures in neutral
    - Distal-third fractures in pronation
- Indications for surgery include open fracture, neurovascular compromise, compartment syndrome, more than 15–20 degrees of angulation in patients younger than 10 years, more than 10 degrees of angulation or bayonet apposition in patients older than 10 years, and more than 30 degrees of malrotation in patients of any age.

- Fixation can be with plate/screws or intramedullary rods.
  - For ulnar shaft fractures the IM rod is inserted into the olecranon and advanced distally.
  - For radial shaft fractures the IM rod is inserted into the dorsal aspect of the distal radius through a small longitudinal incision placed over the fourth extensor compartment and advanced proximally.

□ Complications
- Compartment syndrome
  - Caution should be used with multiple false-pass attempts with the IM rod across the fracture site
  - A low threshold for opening the fracture site should be observed if there is difficulty passing the IM rod across the fracture site.
- Malunion
  - Contributing factors include quality of initial reduction, quality of initial reduction in relation to initial displacement, and delay in diagnosis.
- Mild loss of supination and/or pronation
- Refracture—5%–12%

▪ **Distal ulna and radius fractures**

□ Principles and presentation
- Very common in pediatric patients
- Important that forearm and elbow be evaluated for associated injuries

□ Treatment
- Generally treated with closed reduction and immobilization
- Acceptable sagittal angulation is up to 30 degrees in patients with more than 5 years of growth remaining, with 5 degrees less being accepted for each year less than 5 years of growth remaining.
- Acceptable coronal angulation is up to 10–15 degrees in patients with more than 5 years of growth remaining.
- Surgical indications to pin these fractures include failure to maintain adequate closed reduction with casting alone, ipsilateral distal humerus fracture requiring operative intervention, and soft tissue concerns that would not allow casting.

□ Complications
- Similar to those for diaphyseal forearm fractures
- Distal ulnar physeal fractures are uncommon but have a 50% rate of physeal arrest, compared with 4% for distal radius

physeal fractures.
- Loss of reduction can occur with a poorly molded cast. Loss of reduction is associated with a cast index (sagittal width/coronal width) above 0.84

Pediatric Scaphoid Fracture

- **Scaphoid (navicular) bone: most lateral of proximal row of carpal bones**
- **Principles and presentation**
  - Usually due to a fall on an outstretched hand
  - Patient presents with snuffbox tenderness
  - Usually avulsion injuries of the distal pole
- **Diagnosis and radiographs**
  - If fracture suspected but not apparent on plain x-ray, CT scan should be obtained
- **Treatment**
  - Thumb spica cast for 4–8 weeks
  - Displaced midwaist fractures can result in AVN or nonunion and should be managed operatively.

Lower Extremity Injuries

- **Pelvis fractures**
  - Principles and presentation
    - Less common in pediatric patients but associated (>50%) with multiple injuries and visceral injuries in the polytrauma patient

FIG. 11.27 Ischial avulsion.
From Adam A et al: *Grainger & Allison's diagnostic radiology*, ed 5, Philadelphia, 2008, Churchill Livingstone.

- Avulsion fractures can be seen in adolescence, especially in athletes.
  - Ischial avulsions result from the pull of the hamstring or adductors (Fig. 11.27).
  - Anterior superior iliac spine avulsions result from the pull of the sartorius.
  - Anterior inferior iliac spine avulsions result from the pull of the rectus femoris.
  - Iliac crest avulsions result from the pull of the abdominal muscles and tensor fascia lata.
  - Lesser trochanter avulsions result from the pull of the iliopsoas.

□ Diagnosis and radiographs
- AP, Judet views (acetabulum), inlet/outlet views (pelvic ring)
- CT often necessary because 50% of all pelvic fractures may be missed on plain AP pelvis views

□ Classification—Tile
- Type A—stable
- Type B—rotationally unstable but vertically stable
- Type C—rotationally and vertically unstable

□ Treatment

- Pelvic ring fractures in the polytrauma patient who is hemodynamically unstable may necessitate placement of external fixation.
- Vertical instability and intraarticular displacement of acetabular fractures in pediatric patients are indications for surgical fixation.
- Nonoperative treatment with gradual return to athletics is usually indicated for avulsion fractures.
- Operative treatment of an avulsion fracture may be necessary if it progresses to symptomatic nonunion.

□ Complications

- Premature closure of the triradiate cartilage
- LLD
- Neurovascular injuries
- Heterotopic ossification

▪ **Hip dislocations**

□ Principles and presentation

- More common than hip fractures in pediatric patients
- New research may suggest an association with femoral acetabular impingement in athletes sustaining these injuries without high-energy trauma.
- Posterior dislocations are 10 times more common than anterior dislocations.

□ Treatment

- Gentle closed reduction with sedation as soon as possible to reduce risk of AVN
- Caution should be exercised so as not to cause a physeal fracture of the proximal femur by using too much force (usually because of inadequate sedation).
- Open reduction is indicated for failure of closed reduction, nonconcentric reduction, or dislocation with associated femoral head, neck, or acetabular fracture.

□ Complications

- AVN—8%–10%
    - Decreased incidence in patients younger than 5 years
    - Increased incidence with delay in reduction

▪ **Femoral neck fractures**

□ Principles and presentation

- Rare in pediatric patients
- Usually the result of severe high-energy trauma (75%–80%)

□ Classification—Delbet

- Type I—transphyseal fractures

- Very high risk of AVN (approaches 100%)
- Type II—transcervical fractures
  - Moderate risk of AVN (50%)
- Type III—basicervical or cervicothoracic fractures
  - Low risk of AVN (20%–30%)
- Type IV—intertrochanteric fractures
  - Very low risk of AVN (10%–15%)

- Treatment
  - Types I–III represent surgical emergencies and should be treated with ORIF; smooth pins should be used in younger patients and threaded pins in adolescent patients.
  - Postoperative spica casting may be necessary in some cases, especially younger children and more severe injuries
- Complications
  - AVN
  - Coxa vara
  - Nonunion
  - Physeal arrest

- **Diaphyseal femur fractures (** Table 11.9)
  - Principles and presentation
    - Bimodal age distribution in pediatric patients, with peaks between ages 2 and 4 years and later in adolescence
    - **Child abuse should be considered with such fractures in pediatric patients not yet walking.**
  - Treatment
    - Based on fracture pattern and patient age
    - Infant younger than 6 months can be treated in a Pavlik harness.
    - Patient younger than 5–6 years can be treated with early spica casting or traction with delayed spica casting especially if minimal (<2 cm) shortening.
    - Patient between 5 and 11 years can be treated with several approaches:
      - Flexible intramedullary nailing is appropriate for more stable simple fracture patterns without significant shortening but is associated with poorer results in children older than 11 years and in heavier or obese children.

Table 11.9

Pediatric Femoral Shaft Trauma

Injury	AGE	Treatment	Complications
Femur fracture (including subtrochanteric fractures)	≤6 yr	Spica cast; may need short period of traction if shortened >2 cm, followed by spica casting	LLD: Angular deformity (>10 degrees frontal and >10 degrees sagittal malalignment must be avoided)
	6–13 yr	Current trend to use flexible titanium nails, with possible additional immobilization, but may also use external fixation (higher refracture rate), plate (need to remove, causes large scar formation), or traction (rare)	Rotational deformity (>10 degrees); 0.9 cm overgrowth expected in children <10 yr
	≥14 yr	IM nail (trochanteric entry)	AVN reported with IM nails in children with growth remaining

- Submuscular plate fixation is appropriate for more unstable fracture patterns, especially with shortening and comminution.
- External fixation is appropriate for the polytrauma patient, open fractures, or fractures with soft tissue management concerns and is usually placed laterally to avoid the quadriceps.

- Patients older than 11 years and those approaching skeletal maturity can usually be treated with antegrade intramedullary nailing.
    - Trochanteric or lateral entry nailing required
    - Piriformis entry nailing must be avoided because it risks the vascularity to the femoral head.
    - External fixation is always an option in the emergency setting in which the patient may be

hemodynamically unstable, is multiply injured, or has open fractures.

- Complications
    - Malunion—rotational deformities do not remodel so need to be controlled at the time of reduction and fixation. Greater sagittal angulation is acceptable secondary to better remodeling capability than varus/valgus angulation.
- LLD
- Overgrowth
    - Overgrowth of 0.7– 2.0 cm is common in younger children (<10 years). It is most common during the 2 years after injury.
- Shortening
    - **Up to 2.0 cm of shortening is acceptable in young children with the potential for overgrowth. Thus older children and those with more than 2.0 cm of shortening need to have either traction applied to restore length or appropriate ORIF to address shortening.**

- **Distal femur fractures**
    - Principles and presentation
        - Most distal femoral physeal fractures occur in adolescence (two-thirds).
        - Often the result of direct trauma with some degree of rotation or angulation
            - Physis often fails on the tension side, whereas metaphysis often fails on the compression side, resulting in the Thurston-Holland fragment (in SH II physeal fractures) (Fig. 11.28).
        - Must be considered in adolescent patients possibly misdiagnosed with collateral ligament injuries
        - Stress views may help delineate subtle physeal injuries (Fig. 11.29).

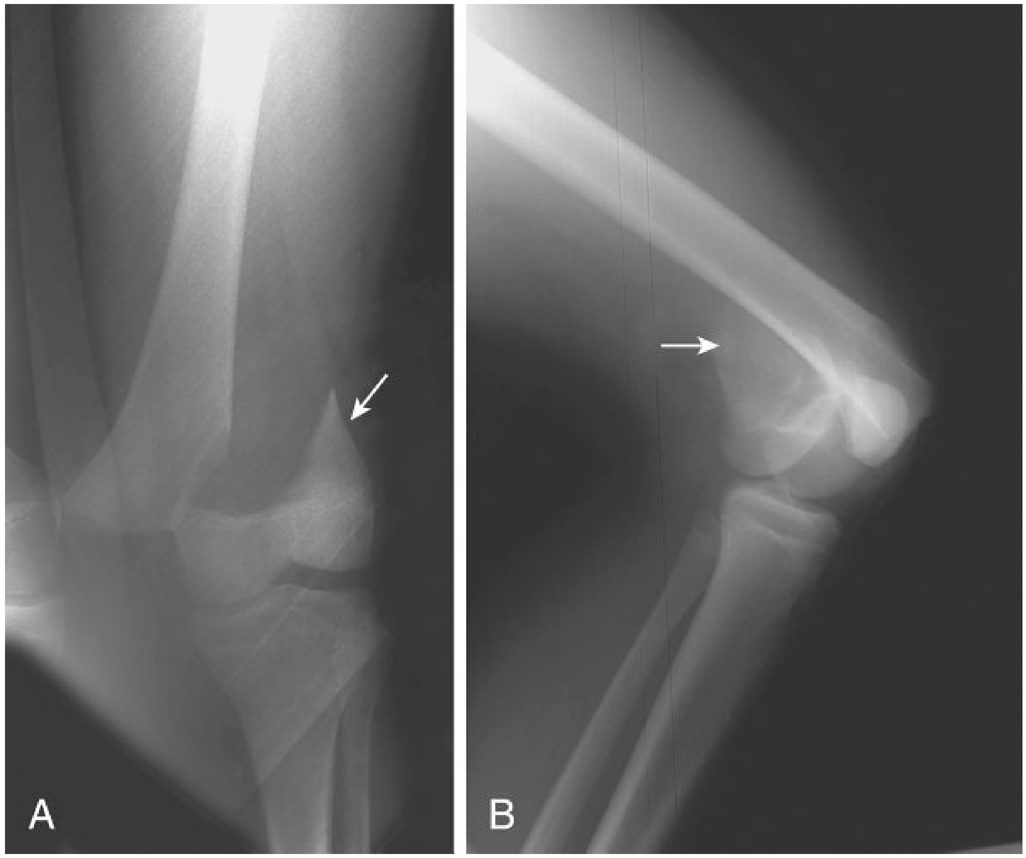


FIG. 11.28 Anteroposterior (A) and lateral (B) images of a typical Salter-Harris type II fracture of the distal femur in a 15-year-old boy who sustained a valgus force to the knee while playing football. Note the significant displacement iof the lateral Thurston-Holland fragment *(arrows).*
From Herring J: *Tachdjian's pediatric orthopaedics,* ed 4, Philadelphia, 2007, Saunders.

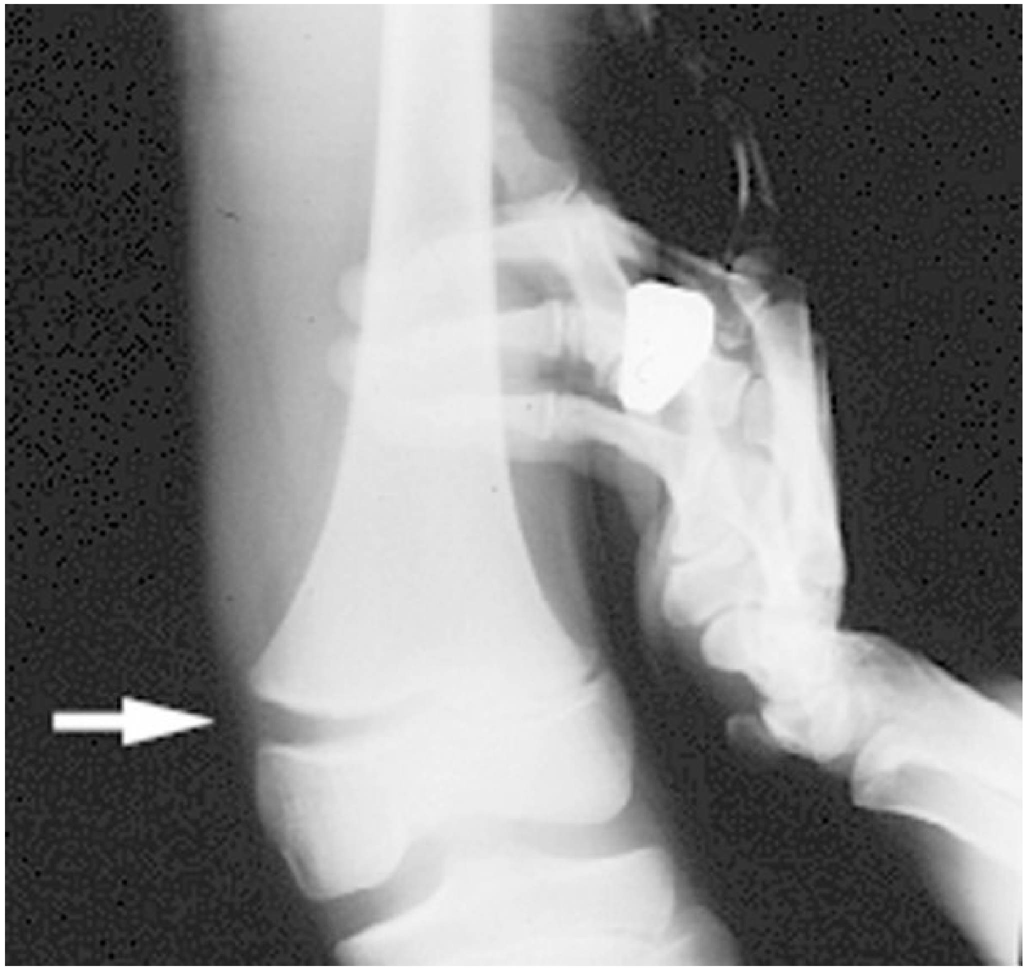


FIG. 11.29 Stress radiograph of a physeal injury of the distal femur. An AP radiograph with valgus stress applied reveals unstable physeal disruption *(arrow)*.
From Townsend C et al: *Sabiston textbook of surgery,* ed 18, Philadelphia, 2007, Saunders.

FIG. 11.30 (A) Schematic representation of a sleeve fracture of the patella. (B) Lateral radiograph showing patella alta (note that the large articular cartilage segment attached to the bony distal fragment is not visualized). (C) Lateral radiograph following operative repair.
From Scott WM, editor: *Insall & Scott surgery of the knee,* ed 4, Philadelphia, 2005, Elsevier.

- Angiograph is occasionally necessary to evaluate for a vascular injury, especially in a physeal fracture with wide displacement and posterior spiked fragments and a clinical presentation that warrants evaluation.

□ Treatment

- Nonoperative treatment with cast immobilization appropriate for nondisplaced fractures
- Operative treatment indicated for open fractures, intraarticular fractures, or displacement through the physis
- Smooth wires can be placed across the physis temporarily to hold the physeal reduction.
- Fixation across the Thurston-Holland fragment to the rest of the metaphysis may help the reduction but generally cannot by itself hold the reduction of the physis.

□ Complications

- Growth arrest—very common (30%–50%); patients and families should be counseled about issue at the time of initial evaluation; can also result in LLD and angular deformities, depending on the amount of physis arrested and the age of the patient.
- Vascular injury (<2%)—especially with hyperextension injury that has a posterior spike
- Peroneal nerve palsy (3%)—especially with varus injuries
- Knee instability (possibly up to 40%)—some stretch of the cruciate ligaments is thought to occur during these injuries. Whether this stretch and instability cause functional deficits is unclear.

▪ **Patellar fractures**

□ Principles and presentation

- Manifests like adult patellar fractures
- Examiner should be aware of bipartite patella (5%)
- Can be missed secondary to difficulty of radiographic visualization of cartilaginous avulsion injury—**patellar sleeve fracture**
- Radiographs must be examined for patella alta and defect (Fig. 11.30)

□ Treatment

- Similar to that for adult patellar fractures
- **Indications for surgical reduction and internal fixation include extensor lag, patient's inability to do a straight-leg raise, and intraarticular displacement.**
- Tension band constructs are often used if bone stock is sufficient.

- Soft tissue repair techniques with careful attention to repair of the retinacular structures if repair of a cartilaginous sleeve fracture is needed
- Complications
  - Loss of ROM; fixation technique should allow for early motion.

- **Proximal tibia**
  - Tibial spine fractures
    - Principles and presentation
      - Similar to ACL ruptures in terms of mechanism of injury; often occurs during landing with a rotational component; hyperextension and valgus forces predominant
      - Manifest with hemarthrosis
      - Often the Lachman or pivot shift test shows instability.
      - SH III fracture
      - Occurs most commonly in children ages 8–14 years
      - 40% rate of associated injuries, including meniscal tears, collateral ligament injury, capsular injury, and osteochondral fractures
      - An AP view taken perpendicular to the tibial plateau to account for the 5–10 degrees of posterior tibial slope can help visualize the often small osseous fragment.
    - Classification—Meyers and McKeever
      - Type I—nondisplaced spine fragment
      - Type II—anterior angulation and displacement of the spine fragment hinging on the posterior cortex
      - Type III—completely displaced fragment
    - Treatment
      - Type I and type II fractures that reduce with extension can be treated nonoperatively with initial immobilization in extension; ROM can be progressed once bony union is achieved, usually at 4–6 weeks.
      - Type II fractures that do not reduce and type III fractures are treated with operative fixation (both open and arthroscopic techniques can be used).
        - Failure of closed reduction may be due to the entrapped medial

meniscus, entrapped intermeniscal ligament, or the pull of the lateral meniscus attachment
            - Fixation can be achieved with screw fixation if the fragment is big enough; otherwise, suture fixation is suggested.
    - Complications
        - Knee stiffness and loss of extension—very common; loss of extension found in up to 60%
        - Late anterior instability—up to 60%; possibly secondary to ligamentous stretch; unclear whether clinically significant
        - Malunion can lead to impingement (similar to a Cyclops lesion after ACL reconstruction).
- □ Tibial tuberosity fractures
    - Principles and presentation
        - Most common between ages 14 and 16 years; often occurs in athletes
        - Tibial tubercle and tibial plateau physis closes from posterior to anterior and from medial to lateral.
        - Predisposing factors include patella baja, tight hamstrings, and history of Osgood-Schlatter disease.
    - Classification—Ogden modification of Watson-Jones
        - Type I—small fragment displaced proximally
        - Type II—secondary ossification completely displaced proximally
        - Type III—fracture extends intraarticularly
        - A and B versions of each type denote increasing comminution and displacement.
    - Treatment
        - Nondisplaced fractures can be treated with long-leg immobilization in a manner similar to tibial spine fractures.
        - Displaced fractures should be treated with ORIF.
            - Screws can be used in most patients with this fracture because they are approaching skeletal maturity.
            - Intraarticular reduction must be confirmed (arthroscopically or through an arthrotomy) for type III

fractures.

- Complications
  - **Compartment syndrome**—anterior tibial recurrent artery can be tethered and torn as it enters anterior compartment from the trifurcation posteriorly; increased risk of swelling.
  - Growth arrest—most patients are approaching skeletal maturity; however, young patients may suffer from a recurvatum deformity if a growth arrest occurs.

□ Proximal tibial physeal fractures

- Principles and presentation
  - More uncommon but often unstable
  - Vascular injury is the most serious sequela, given that the popliteal artery is tethered behind the knee.
- Treatment
  - Nondisplaced fractures can be treated with immobilization but need to be followed closely because these injuries can be unstable.
  - Displaced fractures can be treated with reduction, d smooth pin fixation that crosses the physis can be used when necessary.
  - Intraarticular fractures (SH III and IV) should be visualized by arthroscopy or arthrotomy to confirm reduction.
- Complications
  - Neurovascular injury—popliteal injury possible during initial trauma; peroneal nerve susceptible to stretch injuries from varus displacement
  - Growth arrest—can result in LLD; partial arrests or bars can be associated with angular deformities.

□ Proximal tibia metaphyseal fractures

- Principles and presentation
  - Common in 3- to 6-year-old children
  - Heal rapidly but often manifest with late genu valgum (Cozen phenomenon) (Fig. 11.31)
  - Unknown cause but resolve spontaneously over time
- Diagnosis and radiographs
  - Standard AP, lateral views of the knee and/or tibia
- Treatment

- Closed reduction and long-leg cast immobilization
- Complications
  - Cozen phenomenon; resolves spontaneously

FIG. 11.31 Posttraumatic tibial valgus with subsequent resolution. *Arrows* indicate metaphyseal fracture location.
Reprinted with permission from Macnicol MF: Paediatric knee problems, *Orthop Trauma* 24:369–380, 2010.

- **Tibial shaft fractures**
  - Principles and presentation
    - Common; account for 15% of all pediatric fractures
    - Average age: 8 years
    - 30% associated with fibular fracture
    - Most commonly secondary to pedestrian versus motor vehicle accidents (50%)
    - Toddler's fracture is a nondisplaced oblique or spiral tibial shaft fracture with intact fibula.
      - Typically occurs in child younger than 6 years who sustained a twisting injury
      - Occasionally mistaken for infection, because radiographic findings are often normal
  - Treatment
    - Closed reduction and casting can be used for nondisplaced fractures and adequately reduced fractures.
    - Toddler's fracture should be placed into a long-leg cast for 2 weeks, and repeat radiographs obtained to demonstrate presence of callus, thus confirming diagnosis.
    - Indications for surgery include open fractures, neurovascular

compromise, more than 5 degrees of valgus angulation, more than 5 degrees of posterior angulation, and more than 5 to 10 degrees of varus or anterior angulation.
    - Operative fixation techniques include percutaneous pinning (younger patients), screw and plate fixation, external fixation (especially in open fractures), and intramedullary nail fixation (either flexible nails or rigid nails in older patients).
  - Complications
    - Compartment syndrome
    - LLD
    - Angular deformity
    - Unrecognized proximal or distal physeal injury
- **Distal tibia/ankle fracture**
  - Principles and presentation
    - 25%–38% of all physeal injuries
    - Second most common physeal injury (distal radius is most common)
    - Physeal injuries in the distal tibia and fibula are typically seen between ages 8 and 15 years.
    - Mechanism of injury is similar to that for adult ankle fractures; occasional direct trauma, usually rotation around a fixed foot and ankle
    - The distal tibial physis closes in a predictable pattern from central to medial, and the anterolateral portion closes last; this gives rise to unique "transitional" type physeal fractures.
    - Tillaux fractures are SH III fractures of the distal tibia (Fig. 11.32).
      - External rotation force fractures off the anterolateral portion of the distal tibia.
      - Usually in patients between 12 and 14 years old
      - Evaluated with CT scan
    - Triplane fractures are usually SH IV fractures of the distal tibia that occur in three planes (Fig. 11.33):
      - Sagittal plane fracture occurs through the epiphysis (seen on AP or mortise view).
      - Axial plane fracture occurs through the physis.
      - Coronal plane fracture occurs through the metaphysis (seen on lateral view and **looks like an SH II fracture).**

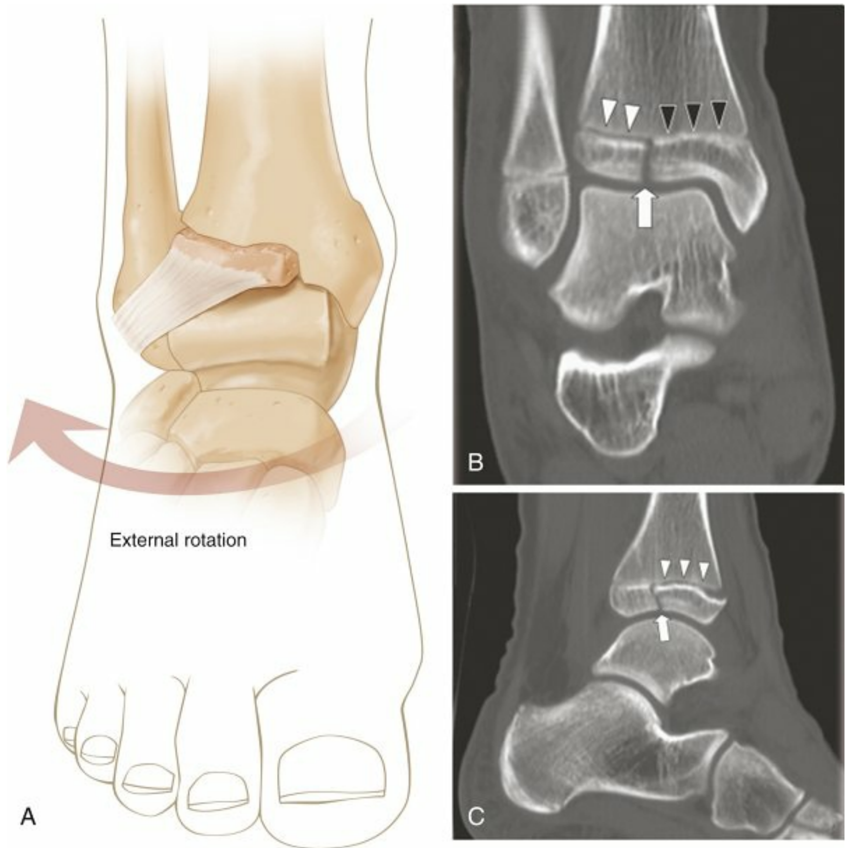


FIG. 11.32 (A) Tillaux fracture. (B) Coronal CT scan shows the Salter-Harris type III fracture with a longitudinal component through the epiphysis *(arrow)* and a transverse component through the unfused lateral physis *(white arrowheads).* The fused medial physis is indicated by the *black arrowheads*. (C) Sagittal CT scan shows the Salter-Harris type III fracture with a longitudinal component through the epiphysis *(arrow)* and a transverse component through the unfused physis *(arrowheads).*

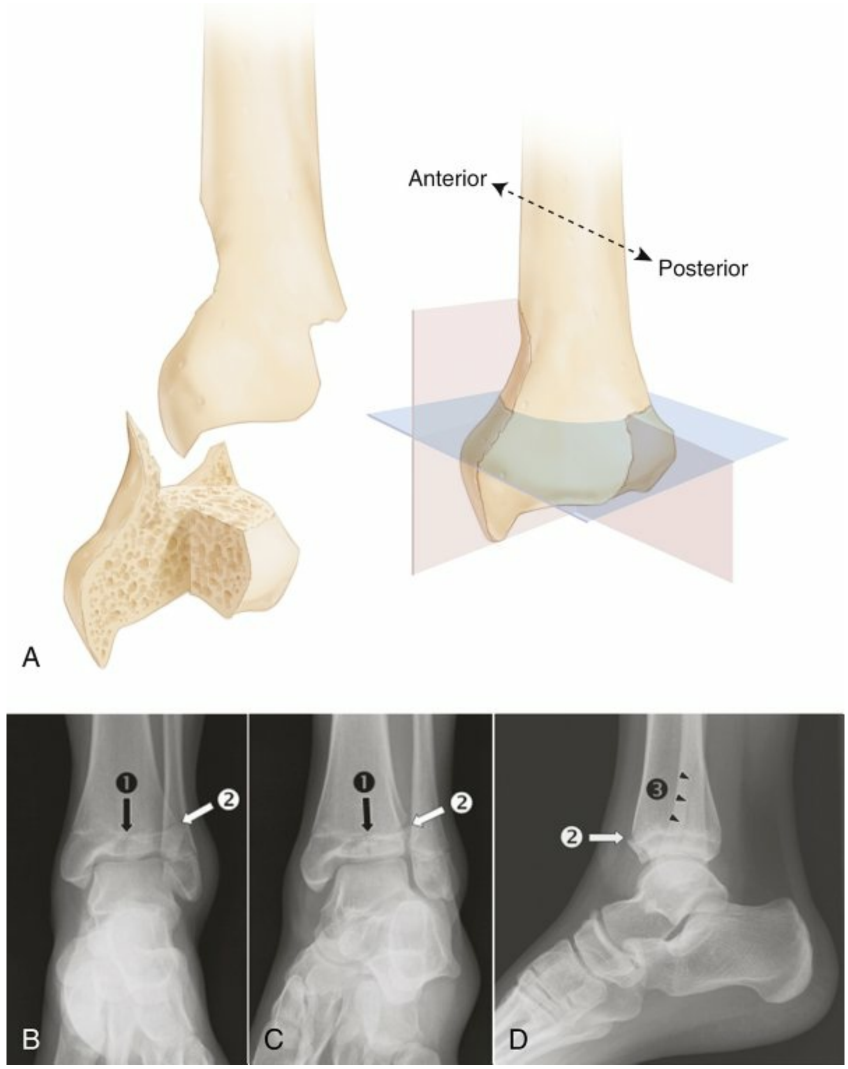


FIG. 11.33 Triplane fractures are usually Salter-Harris type IV fractures. (A) Schematic depiction showing the orientation of the three fracture planes. Anteroposterior (B) and mortise (C) radiographs. When minimally displaced, the fracture margins can be difficult to see on radiographs. The *black arrow* points to the epiphysis fracture, running vertically in the sagittal plane *(plane 1)*. The *white arrow* points to the physis fracture, running horizontally in the axial plane *(plane 2)*. (D) Lateral non–weight-bearing radiograph. The *arrow* points to the physis fracture, running horizontally in the axial plane. The *arrowheads* point to the metaphysis fracture, running obliquely vertically in the coronal plane *(plane 3)*.

- On the AP view the fracture **appears to be an SH III injury** with the fracture line exiting in the ankle joint.
- Thurston-Holland metaphyseal fragment is generally posterolateral.
- Occurs most commonly in children ages 12 to 15 years who have partial distal tibial physis closure
- Distal tibial physis closure begins centrally, then medially, then laterally

    - Similar mechanism of external rotation through a partial closed physis
  - CT scan may be needed to evaluate the displacement of intraarticular extension of triplane or Tillaux fractures.
- ▫ Treatment
  - Nondisplaced fractures of the distal tibial and fibular physes can often be treated with immobilization and non–weight-bearing status.
  - Less than 2 mm of intraarticular displacement is generally considered the appropriate amount that can be tolerated; more displacement should be treated with ORIF or closed reduction and percutaneous pin or screw fixation.
- ▫ Complications
  - Growth arrest
    - Partial arrests can result in angular deformity; distal fibular arrests result in valgus deformity; medial tibial physeal arrests are associated with varus deformities.
    - Complete arrests can result in LLD; contralateral epiphysiodesis can address these issues if prompt diagnosis and remaining skeletal growth allow.
  - Posttraumatic arthrosis
    - Unrecognized intraarticular displacement or inadequate reduction can result in premature arthritic changes.

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Testable Concepts

Section 1 Care of the Multiply Injured Patient

I. Principles of Trauma Care

- Failure to respond to a 2-L crystalloid bolus in a trauma patient should be considered to indicate an estimated blood loss greater than 30% of blood volume and requires early blood product transfusion.
- Massive transfusion should be a 1:1:1 ratio of packed red blood cells, fresh frozen plasma, and platelets.
- The end points of adequate resuscitation are not clear. Use of hemodynamic parameters is inadequate. Base deficit, as measured by lactate value, is a proxy for the amount of anaerobic metabolism by the body.
  - Lactate value and base deficit are used to guide the adequacy of resuscitation.
- Hemorrhagic shock manifests as increased heart rate and systemic vascular resistance. Central venous pressure and pulmonary capillary wedge pressure are low.
- Neurogenic shock manifests as a low heart rate, low blood pressure, and failure to respond to crystalloids. Treatment is with dobutamine and dopamine.
- Damage control orthopaedics should be employed in severely injured patients with elevated lactate values. Acute stabilization is achieved primarily via external fixation.
- A pregnant patient should be placed into the left lateral decubitus position to alleviate potential vena cava compression by the uterus.

II. Care of Injuries to Specific Tissues

- Compartment syndrome is a clinical diagnosis with pain out of proportion to the injury and pain with passive stretch.
  - Intracompartmental pressure measurement is abnormal if pressure is within 30 mm Hg of the diastolic pressure (ΔP)
  - Anesthesia may lower the diastolic blood pressure and give abnormally low ΔP values.
- Motor recovery potential after repair is poorest for the peroneal nerve. The best results are seen in the radial, musculocutaneous, and femoral nerves.
- Traumatic arthrotomies may be detected via a saline load test or reverse arthrocentesis. The knee may require at least 175 mL for correct diagnosis. However, small puncture wounds may be missed.
- Open segmental fractures and farm injuries are automatically Gustilo type III.
  - Types I and II → first-generation cephalosporin

    - Type III → cephalosporin and aminoglycoside
    - Farm → cephalosporin, aminoglycoside, and penicillin
- Osteoporotic fractures
    - World Health Organization Fracture Risk Adjustment Tool (FRAX) calculates the 10-year risk of hip fracture
    - Low-energy stress fracture associated with bisphosphonate use in patients treated for osteoporosis; fracture characterized by cortical thickening, mostly transverse pattern, minimal comminution.
    - Fracture of the proximal humerus consistently predicts patient's risk for a subsequent low-energy hip fracture.

III. Biomechanics of Fracture Healing

- Stability determines strain. Strain determines the type of healing. Strain less than 2% results in primary bone healing, whereas strain 2%–10% results in secondary bone healing.
    - Examples of fixation devices with absolute stability include oblique fractures fixed with lag screws and transverse fractures fixed with compression plating technique.

IV. Biomechanics of ORIF

- For compression plating, the order in which screws are inserted is neutral position, then compression on opposite side of fracture, then lag screw (if placing through plate).
    - May need to be prebent to eliminate gapping opposite the plate.
    - Tight contact of plate to bone when initially applied decreased periosteal blood flow and temporary osteopenia.
- Bridge plating spans an area of comminution with fixation above and below the fracture. It allows some elastic deformation.
- Advantages of submuscular plating include retained medullary and periosteal bone perfusion.
- Locking plates are most useful in unstable short-segment metaphyseal fractures and in osteoporotic bone.
    - Other indications: periprosthetic fractures, proximal humerus fractures, intraarticular distal femur and proximal tibia fractures, and humeral shaft nonunions in the elderly
    - Multiaxial locking screws increase options for fixation in working around periprosthetic fractures but do not offer strength or pullout advantages.
    - Locking plates with unicortical locked screws are weaker in torsion compared with bicortical screws.
    - Locked plating screws typically fail simultaneously rather than sequentially.

- IM nail stiffness depends on material, size, and wall thickness.
  - Increased diameter results in increased stiffness at a ratio of radius to the power of 3 in bending and to the power of 4 in torsion.
  - The working length is the portion of the nail that is unsupported by bone when loaded.
  - Increased working length produces increased interfragmentary motion and may delay union.

Section 2 Upper Extremity

I. Shoulder Injuries

- Sternoclavicular dislocation is most commonly anterior. The majority of dislocations remain unstable, but they are typically asymptomatic.
  - The medial clavicular epiphysis is the last to close at a mean age of 25 years. In younger patients, sternoclavicular dislocation is often a Salter-Harris type I or II fracture.
- Clavicle fractures are most commonly middle third. Open clavicle fractures are associated with high rates of pulmonary and closed-head injuries.
  - Treatment is controversial. Traditionally midthird fracture is treated nonoperatively in a sling. There is no difference in outcomes between sling and figure-eight bandage.
  - Risk of nonunion after midshaft fractures is higher in females, elderly patients, and those fractures that are displaced, shortened more than 2 cm, or comminuted.
  - Operative treatment is recommended for displaced and shortened clavicle fractures, owing to higher rates of nonunion and decreased shoulder strength and endurance.
- Scapula fractures are associated with pulmonary contusion, pneumothorax, clavicle fracture (i.e., floating shoulder), rib fracture, head injury, brachial plexus injury, upper extremity vascular injury, pelvic or acetabular fracture, and spine fracture. These fractures are generally treated nonoperatively.
- Glenoid neck fractures are almost always treated nonoperatively.
  - Operative treatment is indicated when the glenoid neck and humeral head are translocated anterior to the proximal fragment or are medially displaced. Preferred surgical approach is posterior between infraspinatus and teres minor.
- Scapulothoracic dissociation should be suspected when there is a neurologic and/or vascular deficit. More than 1 cm of lateral displacement of the scapula on a chest radiograph is also suggestive. Functional outcome is based on the severity of the associated neurologic injury.
- Proximal humerus fracture treatment can be differentiated according to the Neer classification. Two-part fractures treated nonoperatively should have immediate

physical therapy to facilitate faster recovery.

    - Three- and four-part fractures may be treated ORIF for young patients and hemiarthroplasty for elderly patients. During hemiarthroplasty, attention must be paid to humeral height, humeral version, and tuberosity reconstruction. The insertion of the pectoralis major is a reliable landmark for determining height.
    - AVN can be predicted by Hertel's criteria: disruption of the medial periosteal hinge, medial metadiaphyseal extension less than 8 mm, and increasing fracture complexity.
    - Locking plate constructs are associated with significant rates of screw cutout.
    - Nonunion of the greater tuberosity after arthroplasty results in a loss of active shoulder elevation.
- Shoulder dislocation must be evaluated with an axillary radiograph. The most common associated injury at arthroscopy is an anteroinferior labral tear. There is a high incidence of rotator cuff injury after a shoulder dislocation in patients older than 45 years.
    - Inferior dislocation (luxation erecta) commonly manifests with the arm abducted between 110 and 160 degrees.
    - Fixed posterior dislocation—physical examination shows a lack of external rotation.

II. Humeral Injuries

- Humeral shaft fractures may be treated nonoperatively if there is less than 20 degrees of anterior angulation, less than 30 degrees of valgus/varus angulation, or less than 3 cm of shortening.
- Indications for fixation include open fracture, floating elbow, polytrauma, pathologic fracture, and associated brachial plexus injury.
    - ORIF (with plate/screws) has high union rates and low rates of secondary operations. Weight bearing to tolerance is safe after plate fixation.
    - IM nails may be used for segmental or pathologic fractures. Complications include a higher rate of reoperation and shoulder pain. Distal locking options vary by nail design. Lateral-to-medial screws put radial nerve at risk, whereas anterior-to-posterior screws put musculocutaneous nerve at risk.
- Radial nerve palsy occurs in 5%–10% of cases.
    - When to observe:
    - Vast majority (up to 92%) resolve with 3–4 months observation.
    - Brachioradialis followed by extensor carpi radialis longus are the first to return, whereas the extensor pollicis longus and extensor indicis proprius are last to return.
    - When to explore:

    - Open fracture: there is a higher likelihood of transection; ORIF of fracture should be performed at time of exploration.
    - Controversial whether to observe or explore:
    - Secondary nerve palsy (i.e., after fracture manipulation)
    - Spiral or oblique fracture of distal third (Holstein-Lewis fracture)
- Humeral shaft nonunion should be treated with compression plate and bone grafting if atrophic. Locking plates may be used in elderly patients.
- Distal humerus fractures involving both columns should be treated with ORIF using a posterior approach with two plates applied to either column.
    - Total elbow arthroplasty is a treatment option in severely comminuted fractures in patients older than 65 years, particularly if they have rheumatoid arthritis.
    - The most frequent complication is stiffness, which is treated with static-progressive splinting.
    - No benefit from ulnar nerve transposition during ORIF
    - Elbow muscle strength typically decreases 25%.
- Coronal shear fractures should be treated with ORIF via a lateral approach.

III. Elbow Injuries

- In olecranon fracture treated with a tension band construct, the wire loop should be dorsal to the midaxis of the ulna, thus transforming tensile forces at the fracture site into compressive forces at the articular surface.
    - Kirschner wires should be buried in the anterior cortex of the ulna for increased stability. Wire protrusion through the anterior cortex, however, is associated with reduced forearm rotation.
    - Plate fixation is the preferred technique for oblique fractures that extend distal to the coronoid process, because this is more stable than tension band wiring.
    - Excision with triceps advancement is reserved for nonreconstructible proximal olecranon fractures in elderly patients with low functional demands.
- Radial head fracture that is nondisplaced may be treated in a splint for no more than 7 days, followed by early motion.
    - Comminuted fractures with less than three pieces may be treated with ORIF. Otherwise treated with metallic radial head replacement.
    - The safe zone for ORIF of a head fracture is a 110-degree arc between the radial styloid and the Lister tubercle.
    - The PIN is at risk, and the arm must be pronated to avoid injury.
- Simple elbow dislocations may be treated with brief immobilization.
- The terrible triad of the elbow is a complex dislocation with lateral collateral ligament injury, radial head fracture, and coronoid fracture. The lateral collateral ligament injury is most commonly a ligamentous avulsion from the origin on the

distal humerus. This injury is always unstable and requires treatment.
    - Requires coronoid ORIF, radial head ORIF or replacement, lateral collateral ligament repair (typically to distal humerus), and possibly medial collateral ligament repair, depending on stability.

IV. Forearm Fractures

- Monteggia fractures are ulnar fractures with associated radial head dislocation.
    - Treated with ORIF. The radial head normally reduces and is stable.
    - Nonanatomic reduction of the ulna followed by interposition of the annular ligament is the most common cause for failure of radial head reduction.
    - Posterior radial head dislocation (Bado type II) or radial head fractures (Monteggia equivalent) are associated with higher complication rates. PIN injury is most frequent, typically resolves spontaneously, and should be observed for 3 months.
- Both-bone forearm fractures are almost universally treated with ORIF.
    - Restoration of the radial bow is directly related to functional outcome.
    - Refracture risk is elevated with removal of hardware in less than 12–18 months.
    - Synostosis is associated with single-incision approach to ORIF and treated with early excision, irradiation, and indomethacin.
- Galeazzi fractures are radius fractures with distal radioulnar joint instability.
    - ORIF of the radius should be performed, followed by intraoperative assessment of the distal radioulnar joint.
    - Irreducible distal radioulnar joint is most commonly due to interposition of the extensor carpi ulnaris tendon. Recommended approach is dorsal to remove the block.

Section 3 Lower extremity and Pelvis

I. Pelvic and Acetabular Injuries

A. Pelvic Fractures

- Pelvic ring injuries are commonly classified using the Young-Burgess system.
    - APC I—stretching of anterior sacroiliac ligaments
    - APC II—rupture of the anterior sacroiliac sacrotuberous and sacrospinous ligaments
    - APC III—rupture of sacrotuberous, sacrospinous, and anterior and posterior sacroiliac ligaments
- Emergent treatment of a hemodynamically unstable patient with a pelvic ring injury:

- Volume resuscitation
    - Pelvic binder
    - Angiographic embolization
    - External fixation—placed before emergent laparotomy
    - Skeletal traction—for vertically unstable patterns
    - Pelvic C clamp (rarely used)
- Nonoperative treatment is indicated for stable fracture patterns
- Weight bearing as tolerated for isolated anterior injuries
- Anterior injuries are generally treated with plate fixation. External fixation with pins in the anterior inferior iliac spine region is stronger than iliac wing pins but not stronger than internal fixation. The lateral femoral cutaneous nerve is most at risk during external fixation pin placement.
- Posterior injuries with a vertically oriented sacral fracture are at higher risk for loss of fixation.
- Vertically unstable patterns with anterior and posterior dislocations can be treated with anterior ring internal fixation and percutaneous sacroiliac screw fixation, the most stable fixation construct.
- The risk of severe, life-threatening hemorrhage is highest in APC II and III and LC III patterns and in vertical shear.
- Urogenital injury is common.
    - Men: urethral stricture
    - Women: dyspareunia and need for cesarean section childbirth
- The most common complication of pelvic ring injury is DVT if thromboprophylaxis is not employed.
- Risk factors for death during initial treatment:
    - Blood transfusion requirement in first 24 hours
    - Unstable fracture type (APC II and III, LC II and III, vertical shear, combined mechanism)
- Percutaneous sacroiliac screw insertion requires appropriate fluoroscopic visualization of anatomic landmarks. The pelvic outlet radiograph is used to visualize the S1 neural foramina. The lateral sacral view identifies the sacral alar slope and minimizes risk to the L5 nerve root.
- Anterior subcutaneous internal fixator can result in both femoral nerve injury (impairing quad function) and lateral femoral cutaneous nerve (may occur in third of cases).
- Heterotopic ossification is the most common complication after use of an anterior subcutaneous internal fixator.

B. Acetabular Fractures

- The obturator oblique view profiles the anterior column and posterior wall. The iliac oblique view profiles the posterior column and anterior wall.
- The Letournel classification divides acetabular fractures into five simple and five

associated types.

- The associated both-column fracture represents a dissociation of the acetabular dome from the intact ilium. A spur sign, seen on the obturator oblique view, represents the intact portion of the iliac wing.
- Cardinal radiographic features of fracture types:
    - Posterior wall—iliopectineal and ilioischial lines intact
    - Posterior column or posterior column/posterior wall—ilioischial line disrupted
    - Anterior wall or anterior column—iliopectineal line disrupted
    - Transverse or transverse/posterior wall—iliopectineal, ilioischial lines disrupted, obturator ring intact
    - Both-column or anterior column posterior hemitransverse—T-type—iliopectineal, ilioischial, iliac wing, and obturator foramen disrupted
- General guidelines for surgical approach based on fracture type:
    - Kocher-Langenbeck (posterior): posterior wall, posterior column, transverse, transverse/posterior wall (when posterior wall requires fixation), posterior column/posterior wall, and some T types
    - Ilioinguinal (anterior): anterior wall, anterior column, anterior column posterior hemitransverse, associated both-column, and some T types (if limited posterior wall involved)—the ilioingunal nerve travels with the round ligament or spermatic cord through the superficial inguinal ring.
    - Extensile approaches: fractures more than 3 weeks old, complex associated fractures, and need for posterior column reduction
- Relative indications for treatment with ORIF and acute total hip arthroplasty are age older than 60 years with presence of superomedial dome impaction on radiograph (gull sign), associated displaced femoral neck fracture, and significant preexisting arthrosis.
- The risk of neurologic injury can be reduced with hip extension and knee flexion.
- Quality of reduction is the most important predictor of posttraumatic osteoarthritis. Malreduction is associated with a longer delay until surgery.

II. Femoral and Hip Injuries

A. Hip Dislocations

- Hip dislocation requires emergent closed reduction to attempt to ameliorate the risk of osteonecrosis.
    - Posterior dislocation is most common, and leg is short, adducted, and internally rotated.
    - In anterior dislocation leg is short, abducted, and externally rotated.
    - Posterior wall and anterior femoral head fractures are common associated injuries. There is a 30% rate of labral tear.

B. Femoral Head Fractures

- Treatment principles include restoration of articular congruity of the weight-bearing portion of the femoral head and removal of associated loose bodies.
- Smith-Petersen approach for ORIF recommended for Pipkin types I and II. Type IV fractures are typically fixed via a posterior approach.

C. Femoral Neck Fractures

- High-energy femoral neck fractures are typically vertical and associated femoral neck fractures.
- AP radiographs should be obtained with the legs in internal rotation to compensate for femoral anteversion.
- **Open anatomic reduction with internal fixation is the optimal treatment for displaced femoral neck fractures in young patients.**
- Treatment of femoral neck fractures is controversial and includes cannulated screws, sliding hip screws, hemiarthroplasty, and total hip arthroplasty.
    - Cannulated screw fixation starting points should be above the lesser trochanter to decrease risk of periimplant subtrochanteric fracture.
    - Hemiarthroplasty is associated with a lower risk of dislocation than total hip arthroplasty, especially in patients unable to comply with dislocation precautions (e.g., from dementia, Parkinson disease)
    - In “active” elderly patients, better functional results are seen with total hip arthroplasty.
- Osteonecrosis risk is increased with greater initial displacement and poor reduction.
- Nonunion risk is higher with varus malreduction. Treatment options include conversion to hip arthroplasty (worse results than those of primary arthroplasty) and valgus osteotomy.
- Preinjury cognitive function and mobility predict postoperative functional outcome.

D. Intertrochanteric Hip Fractures

- The size and location of the lesser trochanteric fragment determine stability.
- A sliding hip screw device is indicated for most fractures.
    - Exceptions: reverse oblique fractures, subtrochanteric fractures, and fractures without an intact lateral femoral wall
    - These fractures are associated with a moderate amount of collapse, resulting limb shortening, and medialization when sliding hip screw is used for unstable fractures. Collapse is more than that seen with intramedullary implants.
- Long intramedullary nails are indicated for standard and reverse oblique

fractures and for subtrochanteric fractures.

- **Long nails cost more than short nails.**
    - Risk of distal anterior perforation occurs owing to mismatch of anterior bow between femur and nail.
    - Distal anterior cortical perforation also associated with a posterior starting point
    - Sliding hip screw has higher revision rates than IM nail in transverse/reverse oblique trochanteric fractures.
- Implant failure/cutout is associated with a tip-apex distance greater than 25 mm.
- Periimplant fracture is more common with nails than with plates.
- American Society of Anesthesiologists classification predicts mortality in patients with intertrochanteric hip fractures.

E. Subtrochanteric Fractures

- Apex anterior and varus angulation are the most common deformities. The psoas and abductors lead to flexion, abduction, and external rotation of the proximal fragment.
- Lateral positioning allows easier alignment of the distal segment with the flexed proximal segment.

F. Femoral Shaft Fractures

- Piriformis and trochanteric starting points are indicated with appropriately designed nails.
    - Piriformis entry is contraindicated when fracture extends to piriformis fossa and in children with open physes (osteonecrosis).
    - Anterior starting point in piriformis fossa is associated with increased hoop stress and risk of iatrogenic comminution.
    - Anterior trochanteric starting point is associated with minimal hoop stress.
    - Trochanteric starting point risks (1) medial comminution of shaft owing to off-axis starting point and (2) varus if straight (no trochanteric bend) nail used.
- Static interlocking for most fractures
- Reamed nailing for most fractures
    - Higher union rates than unreamed nailing
- Patients with multitrauma may benefit from delayed nailing with immediate provisional external fixation (damage control principles). Benefits include reductions in blood loss, hypothermia, and inflammatory mediator release.
    - External fixation can be safely converted to intramedullary nailing in absence of pin tract infection for up to at least 3 weeks after injury with equal union and infection rates.

- Nonunion treatment is more successful with plate/screw/bone graft constructs than with exchange nailing. Dynamization is less successful than exchange nailing for treating delayed union.
- Malalignment is difficult to diagnose, but comparison must be made to the contralateral limb before the patient leaves the operating room. Use of a fracture table is associated with increased risk of malalignment.
- Ipsilateral femoral neck and shaft fractures are uncommon (<10%), but when present they are missed in up to 50% of cases.
    - Neck component is typically vertical in orientation. It has the highest priority.
    - Preferred technique is to use parallel screws or sliding hip screw for the neck, followed by retrograde nail or plate fixation for the shaft.

G. Supracondylar Femur Fractures

- Intracondylar extension warrants CT evaluation for a coronal fracture (Hoffa fracture).
    - 40% incidence, with 80% affecting lateral femoral condyle
- Plate fixation is indicated for most fractures. Non–fixed-angle plates are prone to varus collapse, especially in metaphyseal comminution. Prominent medial screws should be avoided.

III. Knee Injuries

- Vascular injury is present in 5%–15% of knee dislocations. Selective arteriography with the use of a physical examination (including ankle brachial index <0.9) rather than an immediate arteriogram is now the standard of care.
- Patella fractures may be treated nonoperatively or with tension band wiring, cerclage and tension band wiring, or partial patellectomy.
    - Bending Kirschner wires both proximally and distally may prevent wire migration.
    - Age is a significant predictor of patellar fixation failure.
    - Partial patellectomy is useful for extraarticular distal pole fractures, but preserve the patella whenever possible.
    - ORIF, when possible, is associated with better outcomes than partial patellectomy in comminuted and displaced fracture of the inferior pole of the patella.
    - Quadriceps tendon rupture repair with suture anchor fixation was shown to have less gap formation during cadaveric cyclic loading and higher strength than transosseous suture fixation.

IV. Tibial Injuries

A. Tibial Plateau Fractures

- Meniscus tears occur in more than 50% of tibial plateau fractures. Lateral is more common than medial; peripheral tears are the most common type.
- **Lateral meniscus tears most common in split depression (Schatzker type II) fractures**
- Medial fractures are uncommon. Think *knee dislocation* with spontaneous reduction.
- The goal of treatment is restoration of normal alignment. Posttraumatic arthrosis development does *not* correlate with articular step-off.
- Spanning external fixators are used temporarily with selected high-energy injuries to allow for a reduction in soft tissue swelling before definitive fixation.
- Percutaneous locked plating used for poor-quality bone in bicondylar fractures. Stripping should be avoided.
- Posteromedial fragments may not be captured via a lateral pate. A separate posteromedial incision should be used if a second plate is needed.
- Use of bone void fillers
    - Calcium phosphate cement has highest compressive strength.
    - Calcium phosphate cement has a lower rate of subsidence than autograft and allograft.

B. Tibial Shaft Fractures

- Indications for nonoperative management:
    - Shortening less than 1–2 cm
    - Cortical apposition more than 50%
    - Varus-valgus less than 5 degrees
    - Flexion-extension less than 10 degrees
    - Shortening is the most difficult deformity to correct. Shortening and cortical apposition seen on injury radiograph are equivalent to shortening at union.
- Operative management in intramedullary nailing is associated with shorter immobilization and earlier weight bearing than achieved with a cast.
- Avoidance of malreduction of proximal-third fractures associated with valgus and apex anterior angulation is achieved by the following:
    - Ensuring a laterally based starting point and anterior insertion angle
    - Starting point should be in line with the medial border of the lateral tibial eminence.
    - Blocking screws, placed posteriorly and laterally to the central axes of the proximal fragment
- For type III open tibia fractures, significantly longer time to union and poorer functional outcomes seen after definitive fixation with external fixation than after intramedullary nailing.

- Plate fixation for extreme proximal and distal shaft fractures is associated with a higher infection risk than that for intramedullary nailing in open fractures.
    - Use of a 13-hole percutaneous plate places the superficial peroneal nerve at risk during percutaneous screw insertion for holes 11, 12, and 13. A larger incision with blunt dissection should be used for insertion of screws in this region.
- Nonunion should be treated with reamed-exchange nailing after infection has been ruled out.
- Malunion is most common with proximal-third fractures, resulting in valgus and apex anterior angulation.
    - This may increase long-term risk of arthrosis, particularly in the ankle (more common with varus deformity).
    - Rotational malalignment is common with distal-third fractures.
- Risk factors for reoperation to achieve bony union within the first year:
    - Transverse fracture pattern, open fracture, cortical contact less than 50%
- Infection risk increases with severity of soft tissue injury and time to soft tissue coverage. Use of vacuum-assisted wound closure does not alter the risk of infection.
- Anterior knee pain occurs in more than 30% of intramedullary nail cases and resolves with removal of the nail in 50% of cases.

Section 4 Pediatric Trauma

A. Child Abuse/Physeal Fractures/Polytrauma

- Suspected child abuse must be reported. Suspicion should be high in children younger than 3 years who have inconsistent or developmentally incorrect histories.
- Skin injuries are most common, followed by fractures and head injuries.
    - Skeletal surveys are most helpful in children younger than 5 years. In older children a bone scan should be considered as alternative or adjunct.
    - The most common locations of fractures, in order of frequency, are the humerus, tibia, and femur.
    - Spiral femur fractures in nonambulatory children, as well as distal humeral physeal separations, are highly suggestive of abuse.
    - Corner fracture (at the junction of metaphysis and physis) is said to be pathognomonic for abuse. They are four times less common than diaphyseal fractures, however.
- Salter-Harris type I fractures involve the zone of hypertrophy in the physis.
- Polytrauma outcomes are most closely linked with the severity of traumatic brain injury.

B. Upper Extremity Fractures

- Clavicle fractures represent 90% of obstetric fractures, are frequently associated with brachial plexus palsies, and are almost universally treated nonoperatively.
- Proximal humerus fractures have increased remodeling potential, because 80%–90% of humeral growth occurs at the proximal physis.
    - In children younger than 12 years, 70-degree angulation and 100% displacement may be accepted.
    - The distal fragment is shortened and adducted by the deltoid and pectoralis major. Gravity can be a useful reduction aid.
    - All pediatric elbow fractures should undergo a systematic evaluation of radiographic anatomy.
    - Distal humeral physeal separation in the young child should raise suspicion of child abuse. This injury is often confused with an elbow dislocation.
    - Radiographs demonstrate an intact relationship between the radius and capitellum with loss of relationship between the radius/ulna and distal humerus.
    - Treatment is with CRPP.
- Supracondylar humerus fractures are 98% extension type and 2% flexion type.
    - Most common nerve injury:
    - Extension-type—anterior interosseous nerve
    - Flexion-type—ulnar nerve
    - Gartland classification guides treatment
    - I—nondisplaced: long-arm cast
    - II—displaced with intact posterior cortex: long-arm cast if no swelling, anterior humeral line intersects capitellum, and no medial distal humeral cortical impaction; otherwise, CRPP
    - III—displaced: CRPP; crossed pins more biomechanically stable
    - Vascular abnormalities should be first treated with reduction, not angiography.
    - Complications of treatment include iatrogenic ulnar nerve injury and cubitus varus from malunion/malreduction.
- Lateral condyle fractures are historically classified using the Milch system, with a type I representing an SH IV fracture and a type II representing an SH II fracture. The Jakob classification, however, is more clinically useful:
    - Amount of displacement guides treatment
    - Less than 2 mm: Cast and closely observe.
    - 2–4 mm: CRPP

- More than 4 mm: CRPP if arthrogram shows perfect reduction; otherwise, ORIF to ensure articular reduction
    - During ORIF, the blood supply arises posteriorly and should be protected.
    - This is one of the rare pediatric fractures that may proceed to nonunion.
- Medial epicondyle fracture that occurs in an adolescent represents an apophyseal avulsion injury of the flexor mass and medial collateral ligament.
    - Associated with elbow dislocation 50% of the time (most common fracture associated with an elbow dislocation in children); can result in an incarcerated fragment in 15% of cases.
    - Close attention must be given to identifying the apophysis on the AP radiographic view. If it is missing, an incarcerated fragment should be sought on a lateral or oblique view.
    - Most injuries are treated nonoperatively, but this issue is controversial.
    - Treatment of an incarcerated fragment is ORIF.
    - There are multiple techniques for closed reduction.
- Radial head subluxation (nursemaid's elbow) occurs when the annular ligament subluxates over the radial head. Closed reduction is achieved by supination and flexion with orthopaedist's thumb placed over the radial head.
- Monteggia fractures can be classified as in adults. Plastic deformations and incomplete injuries may be treated with closed reduction and casting.
    - The key feature in treatment is based on ulnar length restoration, which generally results in radial head reduction.
- Diaphyseal both-bone forearm fractures are generally treated nonoperatively with closed reduction and long-arm casting.
    - Apex dorsal angulation—supination
    - Apex volar angulation—pronation
- Distal radius fractures can be treated nonoperatively in the majority of cases.
    - Acceptable sagittal angulation is up to 30 degrees in patients with more than 5 years of growth remaining, with 5 degrees less accepted for each year less than 5 years of growth remaining.

C. Lower Extremity Fractures

- Avulsion fractures of the pelvis are relatively common in the pediatric population and generally treated nonoperatively.
- Femoral neck fractures resulting in avascular necrosis can be identified through the Delbet classification, with type I transphyseal fractures approaching 100% AVN risk.
    - Transphyseal, transcervical, and basicervical fractures represent surgical emergencies.

- Diaphyseal femur fracture management is based on fracture pattern and age of the patient.
    - Birth to 6 months: Pavlik harness
    - 6 months to 6 years: spica casting
    - 6 to 11 years: flexible nails for stable fractures, submuscular plating for unstable fractures, and external fixation for such fractures in polytrauma
    - Older than 11 years: trochanteric-starting intramedullary nail
- Distal femur physeal fractures should be suspected in adolescent patients with "knee sprains" and can be diagnosed with stress views.
    - Nonoperative treatment is reserved for nondisplaced fractures.
    - Displaced fractures are treated with CRPP and casting versus ORIF.
    - Growth arrest occurs in approximately 50% of cases, resulting in either LLD (1 cm/yr) or angular deformity.
    - Up to 40% of patients with distal femur physeal fractures sustain injury to the cruciate ligaments.
- Patellar sleeve fractures should be suspected when radiographs demonstrate patella alta. Indications for surgery include extensor lag, inability to perform a straight-leg raise, and intraarticular displacement. A tension band construct can be used if bone stock permits it.
- Tibial spine fractures are similar to anterior cruciate ligament ruptures in terms of mechanism.
    - Meyers and McKeever classification guides treatment:
    - I—nondisplaced: casting
    - II—anterior hinge: reduction in extension and casting
    - III—displaced: operative fixation
    - Both stiffness (arthrofibrosis) and late anterior instability are common complications, occurring in up to 60% of cases. It is unclear whether late anterior instability is clinically significant.
- Tibial tuberosity fracture that is not displaced can be treated nonoperatively. The anterior tibial recurrent artery may be injured in such a fracture, increasing the risk for compartment syndrome.
- Proximal tibial metaphyseal fractures may be termed *Cozen fractures* because of the phenomenon he described. These minimally displaced fractures manifest as late genu valgum that spontaneously resolves.
- Toddler's fracture is a nondisplaced oblique or spiral tibial shaft fracture with intact fibula. It may not be apparent on radiographs and can be confused with tibial osteomyelitis. Treatment is with a long-leg cast and repeat radiographs in 2 weeks to look for evidence of callus to confirm the diagnosis.
- Tillaux fractures are an SH III fractures due to external rotational force – evaluate with CT Scan

- Triplane fracture is an SH IV fracture due to external rotational force through a partially closed physis. It appears as an SH III on AP radiographs and an SH II on lateral radiographs. CT may be particularly helpful for diagnosis.
    - A fracture with less than 2 mm of displacement may be treated nonoperatively.

Chapter 11 Review Questions

I. Principles of Trauma Care

1. Initial radiologic imaging of the trauma patient includes:
   A. Chest radiograph + anteroposterior (AP) view of pelvis
   B. Abdominal series
   C. CT of abdomen and pelvis
   D. AP cervical spine radiograph
   E. Chest radiograph, AP view of pelvis, and CT of cervical spine

Answer 1: **E.** CT of the cervical spine has replaced the lateral cervical spine radiograph in the standard trauma series for spine clearance. Radiography of the pelvis and chest remains the standard. The other examinations may be indicated by the clinical scenario.

2. Urgent actions by the orthopaedic surgeon to help with resuscitation of a trauma patient include:
   A. Placing central lines
   B. Pinning metacarpal fractures
   C. Reducing open fractures and applying splints
   D. Ordering CT for extremity injuries
   E. Performing detailed neurovascular examinations

Answer 2: **C.** Reduction and splinting of fractures allows control of bleeding as well as pain control, which assists with overall resuscitation.

3. Which of the following is *not* a principle of damage control orthopedics?
   A. Early definitive treatment of long bone fractures to prevent further injury from occurring
   B. Placement of external fixators for long bone fractures
   C. Staged management of polytrauma patients to reduce the incidence of a second hit
   D. Delaying definitive fixation during days 2 to 5 after severe traumatic event
   E. Monitoring of inflammatory parameters to try to predict safer times to

return to the operating room

Answer 3: **A.** This is referred to as *early total care.* There is significant controversy over which method is more appropriate, and further study is needed to determine the best course of action in a given situation. The other answers are all components of damage control orthopaedics.

4. When can a femoral external fixator placed for polytrauma be safely converted to intramedullary nail fixation?

   A. Within 1 week

   B. Within 3 days

   C. Within 3 weeks

   D. At any time as long as the pin sites are clean

   E. Never

Answer 4: **C.** Current studies indicate safe conversion of femoral fixators within 3 weeks and tibial fixators within 7–10 days if pin sites are clean; otherwise, staged removal with treatment of the pin sites can safely be performed.

5. A Mangled Extremity Severity Score (MESS) of 8 indicates:

   A. Amputation should be performed.

   B. Amputation should not be performed.

   C. The likelihood of successful reconstruction is zero.

   D. The limb is severely injured, but both reconstruction and amputation may be reasonable treatments.

   E. No decision on treatment may be made until the Injury Severity Score (ISS) is known.

Answer 5: **D.** The MESS provides a numerical value to a severely injured lower extremity. Although scores greater than 7 are associated with a higher likelihood of amputation, each case is unique and all scoring systems are merely tools to assist in the complex determination of limb viability.

II. Care of Injuries to Specific Tissues

6. A 45-year-old man involved in a motorcycle crash is brought to the emergency department with a displaced, closed, proximal-third tibia fracture. What is the most sensitive clinical finding of compartment syndrome?

   A. Compartment pressure reading of 40 mm Hg with Stryker monitor

   B. Severe pain on passive stretch of muscles within a compartment

C. Decreased pulse in the affected area

D. Paresthesias in the affected limb

E. Inability to dorsiflex ankle

Answer 6: **B.** Pain on passive stretch is thought to be the most sensitive finding in awake patients. Pressure of 40 mm Hg may be significant, but this is not an absolute and depends on diastolic blood pressure, with a ΔP of less than 35 being accepted as significant. The other answers are late findings of compartment syndrome.

7. You note that the patient described in question 6 has diminished pulses in his right ankle. The next step is to:

A. Obtain vascular surgery consultation

B. Obtain an urgent angiogram

C. Obtain an MR/CT angiogram

D. Check ankle-brachial index (ABI) and compare with the uninjured side

E. Use tourniquet to control suspected arterial injury

Answer 7: **D.** ABI measurements have been shown to be sensitive for the diagnosis of significant vascular injury without any morbidity. If the ABI on the injured side is less than 0.9, vascular surgery consultation and possible further diagnostic workup are indicated. Also, fracture reduction may take the stretch off a tented vessel and restore adequate pulses, but this was not given as a choice.

8. What is the most likely type of nerve injury attributed to a low-velocity gunshot wound to the extremities?

A. Laceration

B. Crush injury

C. Stretch injury

D. Contusion

E. Entrapment in fracture

Answer 8: **D.** Nerve palsies from gunshot wounds are most likely due to the concussive effect of the shock wave as the missile passes through the tissue. In general, nerve injuries associated with fractures are most likely due to stretch of the nerve.

9. A 27-year-old woman was thrown from a horse and has sustained a transverse midhumerus fracture. She is unable to actively extend her wrist or index/long fingers or thumb and notes numbness in her first dorsal web space. What is the most likely cause of her nerve dysfunction?

A. Laceration by fracture fragment

B. Direct blow from landing on the ground

C. Crush injury from impact with the ground

D. Vascular injury from interruption of the blood supply

E. Stretch injury from the fracture displacement

Answer 9: **E.** Although certain fracture patterns in the humerus (spiral distal third—the Holstein-Lewis pattern) are more likely to be associated with nerve injuries, the mechanism for most nerve palsies associated with fractures is stretch.

10. External fixation is used most often for which of the following?

A. Definitive treatment of type I open tibia fractures

B. Definitive treatment of pediatric femur fractures

C. Temporization of open fractures or fractures with soft tissue compromise

D. Treatment of unstable elbow injuries

E. Definitive treatment of polytraumatized adults

Answer 10: **C.** Although used for all the situations given, external fixation is primarily used for temporization of fractures and occasionally for definitive treatment.

11. In what percentage of midshaft clavicle fractures that are treated closed can symptomatic malunions/nonunions be expected to occur?

A. 5%

B. 30%

C. 15%

D. 2%

E. 75%

Answer 11: **C.**Whereas most clavicle fractures heal with some displacement, a prospective study has found a 15% symptomatic malunion/nonunion rate with detailed evaluation and physical testing.

12. Which risk factor is *not* associated with a symptomatic malunion/nonunion after closed treatment of a midshaft clavicle fracture?

A. Female sex

B. Shortening of 2.5 cm

C. Central comminution

D. 100% displacement

E. Smoking

Answer 12: **D.** Most midshaft clavicle fractures will displace 100%, but the other factors listed have been noted to be significant in determining the likelihood of a symptomatic malunion.

13. For proximal humerus fractures, which pattern is *not* a reason to perform ORIF?

A. Displaced three-part fracture in a 67-year-old tennis player

B. Displaced four-part fracture in a 45-year-old laborer

C. Femoral head–splitting four-part fracture in a 70-year-old retired homemaker

D. Two-part fracture with 1.5-cm greater tuberosity displacement in a 30-year-old administrator

E. Irreducible three-part fracture-dislocation in a 40-year-old female recreational athlete

Answer 13: **C.** The head-splitting fracture variant typically calls for arthroplasty because the likelihood of successful ORIF is low, especially in a lower-demand patient. The other scenarios would all be reasonable for an attempt at ORIF.

14. A 30-year-old woman presents with a closed midshaft humerus spiral fracture after she fell off her bike. The fracture is in 15 degrees of varus and 15 degrees of extension. She is comfortable but has a weakness in her wrist and finger extensors but normal sensation in her first dorsal web space. Which of the following is an appropriate management option?

A. Operative fixation to return to recreational bike riding as fast as possible

B. Operative fixation to explore her nerve and remove any compressive forces on it

C. Figure-eight strap and early range of motion

D. Sarmiento fracture brace and repeat radiography in 1 week

E. Shoulder spica cast to immobilize potential deforming forces

Answer 14: **D.** Closed fractures of the humerus can often be successfully treated with closed management in a functional (Sarmiento) brace. Operative exploration of fractures with nerve palsy has not yielded better results, and most palsies fully resolve with closed management. Options A and B would not be indicated initially, and options C and E do not involve appropriate orthoses for humeral shaft fractures.

15. For operative treatment of humeral shaft fractures, an advantage of compressive plating over intramedullary nailing is:

A. Decreased incision length and blood loss

B. Increased union rate

C. Shorter operative time

D. Decreased infection risk

E. Easier patient positioning on the operative table

Answer 15: **B.** Union rates and numbers of secondary operations are improved with plating. Nailing has the advantage of smaller incisions/blood loss and decreased operating times. Infection risk and positioning have shown significant differences with plating.

16. What three injuries make up the "terrible triad" of the elbow?

A. Olecranon, lateral collateral ligament, radial head

B. Olecranon, lateral collateral ligament, medial collateral ligament

C. Medial collateral ligament, lateral collateral ligament, radial head

D. Coronoid, lateral collateral ligament, radial head

E. Coronoid, lateral collateral ligament, capitellum

Answer 16: **D.** Although other structures may be injured as well, the presence of these three combined injuries (typically as the result of a fracture-dislocation) indicates an unstable elbow that requires surgical stabilization and is associated with worse functional outcomes.

17. Decision making for operative management of a transverse acetabular fracture with 3 mm of displacement may be aided by which factor?

A. Patient is a 24-year-old male high-level recreational athlete

B. Measurement of roof arcs to determine location of fracture line

C. Presence of associated femoral shaft fracture

D. Presence of positive spur sign on Judet views

E. Lack of protrusion on AP radiograph

Answer 17: **B.** Roof arcs are useful for determining which fractures involve the weight-bearing dome of the acetabulum and are particularly helpful if displacement is borderline for operative fixation. Although options A, C, and E contain useful information, none is as sensitive in determining need for surgery of the acetabulum. Option D is a radiologic finding in associated both-column fractures.

18. Proper technique for insertion of cannulated screws to treat valgus impacted femoral neck fractures includes which of the following?

A. Spread of at least 15 mm between pins

B. Starting point at or above the level of the lesser trochanter

C. Use of fully threaded screws to prevent backing out

D. Tips of the screws within 2.5 mm of the subchondral surface

E. Use of at least four screws for increased strength

Answer 18: **B.** For starting points below the lesser trochanter, stress risers for subsequent subtrochanteric fractures will develop. None of the other options is considered necessary or highly recommended in all cases.

19. Knee dislocations can be associated with which of the following?

A. Vascular injuries

B. Ligamentous injuries

C. Low-energy mechanisms

D. Fractures

E. All of the above

Answer 19: **E.** Knee dislocations are often the result of complex forces acting across the joint. They can occur with low-energy mechanisms, particularly in obese patients. There is an increased risk for vascular injury with an associated dislocation, and by definition a ligament must tear for the knee to dislocate. Although less common than ligamentous injury, bony injuries, especially compression and avulsion fractures, do occur.

20. Corner fractures are:
   A. The most common facture type seen in child abuse
   B. Fractures at the junction of the metaphysis and physis
   C. Pathognomonic for child abuse
   D. B and C
   E. A, B, and C

Answer 20: **D.** Long bone fractures are noted to be more common injuries with child abuse but are not pathognomonic for it and can certainly occur without willful abuse.

21. An 8-year-old boy presents to the emergency department with a Salter-Harris type IV fracture of the distal femur from a football tackle. The fracture has 3 mm of displacement and 15 degrees of angulation in the sagittal plane. Because of his young age you know the bone has excellent potential for remodeling. The *best* treatment option would include:
   A. Long-leg cast
   B. Percutaneous pinning in situ
   C. Open reduction and internal fixation with distal femoral locking plate
   D. Open reduction and internal fixation of the metaphyseal component but not the epiphyseal component to avoid potential growth arrest
   E. Open reduction and internal fixation of both components with plates and/or screw fixation

Answer 21: **E.** Intraarticular fractures in children are treated much as those in adults. Attention must be paid to the physeal region, but anatomic reduction and stability are required. Because children have thick periosteum and faster, more consistent healing, large rigid implants are not typically necessary (and would likely compromise the physis), so C is not the best answer.

22. A 10-year-old boy with a spiral midshaft femur fracture from a sledding injury presents to the emergency department for evaluation. He is 48 inches tall and weighs 120 lb. The *best* option for treatment would be:
   A. Long-leg cast
   B. Traction then long-leg cast
   C. Retrograde flexible intramedullary nails
   D. Rigid, straight antegrade intramedullary nail
   E. Submuscular plating

Answer 22: **E.** Flexible intramedullary nails are contraindicated with weight more than 100 lb and especially in spiral fracture patterns, owing to the risk of malunion with deformation of the nails. Rigid, straight antegrade nails are contraindicated because of an increased risk of femoral head avascular necrosis with a starting point in the piriformis fossa. Long-leg casts are not typically used for 10-year-olds because of high malunion rates. A rigid nail with trochanteric starting point (proximal bend) would be a reasonable option but was not given as a choice.

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CHAPTER 12

Principles of Practice

Marc M. DeHart

Introduction (Fig. 12.1)

- **Profession, ethics, and laws**
  - Key components of a **profession** include a **self-regulating** occupation in which work is **limited** to a privileged group who demonstrate mastery of a **complex body of knowledge and skills** and agree to a common **code of ethics.** Admittance to and continued participation in the profession include demonstrating sufficient understanding of information through examination, observation of peers, and adequate performance of the ethical practice of the art in the service of others.
  - Codes of ethics are the governing rules our community of professionals have agreed upon as standards of conduct that define

the essentials of honorable behavior for orthopaedic surgeons.

- The four major principles in medical ethics can be easily defined, but their application can be complex.
  - **Nonmaleficence**: a basic obligation not to inflict harm on one's patients, either intentionally or carelessly, summed up first by Hippocrates' "Do no harm."
  - **Beneficence**: obligation to intervene to benefit the well-being of an individual
  - **Autonomy**: personal rule of the self, free both from controlling interferences by others and from personal limitations that prevent meaningful choice.
  - **Justice**; there are three types:
    - Distributive justice (allocation of limited health-care resources)
    - Rights-based justice (patient rights)
    - Legal justice (upholding and obeying the law)

□ Laws are the external regulations and rules that are created and enforced through government to guide behavior and should be obeyed.

□ Morals are personally held beliefs concerning what behavior is acceptable and frequently direct an individual orthopaedic surgeon's actions.

▪ **Conflicts and focus of ethics**

□ The aspiration of our profession has changed very little over the centuries, but our understanding of the science behind our practice, the laws that govern our activities, and the business realities that face us every day constantly change. With such change comes conflict.

□ When conflicts of interest arise among medical care, business goals, and legal considerations, ethical resolutions focus on the best interest of our patients.

□ **The physician-patient relationship is the central focus of all ethical concerns.**

▪ **Documents have been developed by the American Academy of Orthopaedic Surgeons (AAOS) with the help of other organizations to outline ethical principles of medicine and orthopaedic surgery:**

□ *Medical Professionalism in the New Millennium: A Physician Charter* (2002)

□ *Principles of Medical Ethics and Professionalism in Orthopaedic Surgery* (2002)

□ *Code of Ethics and Professionalism for Orthopaedic Surgeons* (2011)

□ *Guide to Professionalism and Ethics in the Practice of Orthopaedic Surgery* (2015)

- *AAOS Standards of Professionalism*

Medical Professionalism in the New Millennium: A Physician Charter (2002)

Available at: https://www.abimfoundation.org/what-we-do/physician-charter

- **The AAOS adopted the charter crafted by physicians throughout the industrialized world who were concerned about changes in health care delivery systems that threaten professional values.**
  - Three fundamental principles of professionalism define the basis of the contract between the field of medicine and society:
    - Primacy of patient welfare: serve the patient's interest.
      - Altruism—selflessness—builds trust, which is key to patient-doctor relationship.
    - Autonomy: respect patient's informed choices, which depends on knowledge.
      - Honest information on treatment's benefits and risks needed for choice
    - Social justice: promote fair distribution of health care resources.

FIG. 12.1 Word cloud created from *AAOS Principles of Medical Ethics and Professionalism in Orthopaedic Surgery.*
Document available at
https://www.aaos.org/uploadedFiles/PreProduction/About/Opinion_Statements/ethics/Principles.pdf.

- **The charter also defines a set of 10 professional "commitments" that apply to physicians:**
  - □ Professional competence: individual commitment to lifelong learning
    - Profession must strive to ensure all members are competent.
  - □ Honesty with patients: good information must be provided before and after treatment.
    - Reporting of mistakes
      - Enhances patient and societal trust
      - Encourages prevention and improvement
  - □ Patient confidentiality: privacy reinforces trust and encourages patient disclosure.
    - Full information from patients enables the best diagnosis.
    - May need to be broken when the patient endangers others
  - □ Appropriate relations: patients must never be exploited for sexual or

financial advantage.

- Improving the quality of care: professionals and their organizations must:
  - Maintain clinical competence, reduce errors, create mechanisms to improve care
- Improving access to care
  - Health care system's objective to provide a uniform and adequate standard of care
  - Eliminating barriers based on laws, education, finances, geography, and social issues
- Just distribution of finite resources: promote the wise and cost-effective use of limited resources.
- Scientific knowledge: promote research, create new knowledge, and use it appropriately.
- Managing conflicts of interest: must recognize and disclose them to patients and to public
  - Private gain from drug, equipment, and insurance companies
  - When reporting results of clinical trials or guidelines
- Professional responsibilities
  - Work collaboratively to maximize patient care
  - Be respectful of one another
  - Participate in self-regulation and in disciplining others
  - Define educational and standard-setting process
  - Engage in self-assessment and accept scrutiny

Aspirational Documents

- **These documents can be found online at AAOS:**
  - *Principles of Medical Ethics and Professionalism in Orthopaedic Surgery* (2002)
  - *Code of Ethics and Professionalism for Orthopaedic Surgeons* (2011)
  - *Guide to Professionalism and Ethics in the Practice of Orthopaedic Surgery* (2015)
- The documents
  - Take legal requirements into account but may call for a standard behavior that is often higher than the law
  - Define the "essentials of honorable behavior" as briefly summarized here
    - The physician–patient relationship is the "central focus of all ethical concerns."
      - This relationship is based on trust, confidentiality, and honesty.
        - Facts must be presented in

understandable terms

- Also has a contractual basis
    - Patient and doctor free to enter/discontinue relationship
    - Within third party contractual constraints
    - No discontinuation without adequate notice
    - Obligation to care only for those conditions for which competent
    - Obligation to assist in transfer to appropriate care
    - No illegal discrimination
- Conduct of the orthopaedic surgeon must have the following goals:
    - Emphasize the patient's best interests
    - Provide "competent and compassionate care"
    - Obey the law and maintain professional dignity and discipline
- Conflicts of interest are common
    - They must be resolved in the best interest of the patient.
    - **Most common conflicts:**
        - **Medical facility ownership**
            - If not obvious must disclose
        - **Relationships with industry**
        - All payments should be disclosed to patients
- The other sections of the code address additional important issues.
    - Maintaining competence
    - Relationships with orthopaedic surgeons, nurses, and allied health professionals
    - Relationship to the public
    - General principles of care
    - Research and academic responsibilities
    - Responsibility to society as a whole

Standards of Professionalism

Available at: https://www.aaos.org/sop/

- **Different from prior aspirational documents**

- **AAOS Standards of Professionalism are unique mandatory levels of ethical behavior; they represent the minimal level of acceptable conduct to remain a member of our academy.**
- **Nonadherence to these principles can result in the loss of membership.**
- **Violations of these standards:**
  - Are grounds for formal complaints to AAOS
  - Are subject to review by the AAOS Professional Compliance Program
  - The Program's actions are outlined by the AAOS Bylaws:
    - Include reprimand, censuring, suspension for a time, or expulsion from AAOS *and*
      - May result in action's being outlined in **reporting** to
        - National Practitioner Data Bank
        - State medical licensing boards
        - American Board of Orthopaedic Surgery
- **Providing musculoskeletal services to patients (2008)**
  - Responsibility to the patient is paramount.
  - Provide equal treatment of patients regardless of race, color, ethnicity, gender, sexual orientation, religion, or national origin.
  - Provide needed and appropriate care or refer to a qualified alternative provider.
  - Present pertinent medical facts and obtain informed consent.
  - Advocate for the patient and provide the most appropriate care.
  - Safeguard patient confidentiality and privacy.
  - Maintain appropriate relations with patients.
  - Respect a patient's request for additional opinions.
  - Pursue lifelong scientific and medical learning.
  - Provide services and use techniques only for which one is qualified by personal education, training, or experience.
  - If impaired by substance abuse, seek professional care and limit or cease practice as directed.
  - If impaired by mental or physical disability, seek professional care and limit or cease practice as directed.
  - Disclose to the patient any conflict of interest, financial or otherwise, that may influence care.
  - Do not enter into a relationship in which the surgeon pays for the right to care for patients with musculoskeletal disorders.
  - Make a reasonable effort to ensure that the academic institution, hospital, or employer does not pay for the right to care for patients.
  - Do not couple a marketing agreement or provision services, supplies, equipment, or personnel with required patient referrals.
- **Professional relationships (2005)**

- Responsibility to the patient is paramount.
- Maintain fairness, respect, and confidentiality with colleagues and other professionals.
- Act in a professional manner with colleagues and other professionals.
- Work collaboratively to reduce medical errors, increase patient safety, and improve outcomes.
- Facilitate and cooperate in transferring patient care.

- **Orthopaedic expert witness testimony (2010)**
  - Do not testify falsely.
  - Provide fair and impartial opinions.
  - Evaluate care by standards of time, place, and context as delivered.
  - Do not condemn standard care or condone substandard care.
  - Explain the basis for any opinion that varies from standard.
  - Seek and review all pertinent records prior to giving opinion/statement.
  - Have knowledge and experience, and respond accurately to questions.
  - Have current valid, unrestricted license to practice medicine.
  - Have current board certification in orthopaedic surgery (i.e., American Board of Orthopaedic Surgery).
  - Have an active practice or familiarity with current practices to warrant expert designation.
  - Accurately represent credentials, qualifications, experience, or background.
  - Fees should not be contingent on trial outcome.
  - Expect reasonable compensation that is based on expertise, time, and effort needed to address issue.
- **Research and academic responsibilities (2006)**
  - Responsibility to patient is paramount.
  - Informed consent is required.
  - Honor withdrawal requests.
  - Seek peer review, and follow regulations.
  - Be truthful with patients and colleagues.
  - Report fraudulent or deceptive research.
  - Claim credit only if substantial contributions made.
  - Give credit when presenting others' ideas, language, data, graphics, or scientific protocols.
  - Expose fraud and deception.
  - Make significant contributions when publishing manuscripts.
  - Disclose existence of duplicate publications.
  - Include and credit or acknowledge all substantial contributors.
  - Acknowledge funding sources or consulting agreements.
- **Advertising by orthopaedic surgeons (2007)**
  - Advertising must not suggest any of the following:

        - A diagnosis can be made without consultation.
        - One treatment is appropriate for all patients.
        - A treatment is without risk.
    - □ Do not use false or misleading statements.
    - □ Use no misleading representation about ability to provide medical treatment.
    - □ Use no false or misleading images or photographs.
    - □ Use no misrepresentations that communicate a false degree of relief, safety, effectiveness, or benefits of treatment.
    - □ Surgeons will be held responsible for any violations of their office or public relations firms retained.
    - □ Surgeons will make efforts to ensure that advertisements by academic institutions, hospitals, and private practices are not false or misleading.
    - □ Advertisements shall abide by state and federal laws and regulations related to professional credentials.
    - □ Provide no false or misleading certification levels.
    - □ Provide no false or misleading representations of procedure volume or academic appointments or associations.
    - □ Provide no false or misleading statements regarding development or study of surgical procedures.
- ▪ **Orthopaedist-industry conflicts of interest (2012)**
    - □ Surgeons shall regard their responsibility to the patient as paramount.
    - □ Surgeons shall prescribe drugs, devices, and treatments on the basis of medical considerations, regardless of benefit from industry.
    - □ Surgeons shall be subject to discipline by AAOS Professional Compliance Program if convicted of federal or state conflict-of-interest laws.
    - □ Surgeons shall resolve conflicts of interest in the best interest of the patient, respecting the patient's autonomy.
    - □ Surgeons shall notify the patient when withdrawing from a patient-physician relationship if a conflict cannot be resolved in the best interest of the patient.
    - □ Surgeons shall decline subsidies or support from industry except gifts of $100 or less, medical textbooks, or educational material for patients.
    - □ Surgeons shall disclose any relationship with an industry to colleagues, institution, and other entities.
    - □ **Surgeons shall disclose to patients any financial arrangement, including royalties, stock options, and consulting arrangements with an industry.**
    - □ Surgeons shall refuse any direct financial inducement to use a particular implant, device, or drug.
    - □ Surgeons shall enter into **consulting agreements** with industry only

when agreements are made in advance in writing and have the following features:

- They include documentation of an actual need for the service.
- They include proof that the service was provided.
- They include evidence that physician pay for consulting is consistent with fair market value.
- They are not based on the volume or value of business that the physician generates.

- Surgeons shall participate only in meetings that are conducted in clinical, educational, or conference settings conducive to the effective exchange of information.
- Surgeons shall accept **no financial support to attend social functions with no educational element.**
- Surgeons shall accept **no financial support to attend continuing medical education (CME) events** except in the following situations:
    - As residents/fellows when selected by and paid by their training institution or CME sponsor
    - As faculty members of CME programs: allowed honoraria, travel/lodging/meal expenses from sponsor
- Surgeons shall accept only tuition, travel accommodations, and modest hospitality when attending industry-sponsored non-CME events, but must focus on science, education, or business.
- Surgeons shall accept no financial support for guests or other persons who have no professional interest in attending meetings.
- When reporting clinical research or experience with a product, surgeons shall disclose any financial interest in that product on the part of the surgeon or his/her institution.
- Surgeons shall truthfully report research results with no bias from funding sources, regardless of positive or negative findings.

Child, Elder, and Spousal Abuse

- **Child abuse**
    - U.S. Child Abuse Prevention and Treatment Act of 1974 requires orthopaedic surgeons to report all suspected cases of child abuse to local authorities.
        - Failure to report might result in state disciplinary actions.
        - Child protective services and social workers should be alerted, and the events and home circumstances should be investigated.
        - Legal immunity is given for reporting physicians when acting in good faith (even if the information is protected by the physician-patient privilege).

- **Elder abuse**
  - Many states have legislation to protect physician from liability for reporting elder abuse.
  - Risk factors:
    - Increasing age
    - Functional disability
    - Cognitive impairment
  - Gender is not a risk factor.
- **Spousal abuse**
  - One in four women experience domestic violence.
  - Reporting of suspected spousal abuse is not required.
  - Corresponding absence of legal protection for physicians
  - May encourage a patient to seek self-protection
  - A court order may be obtained to permit reporting
  - Risk factors:
    - Pregnancy
    - Age 19 to 29 years
    - Low socioeconomic status
    - African American race

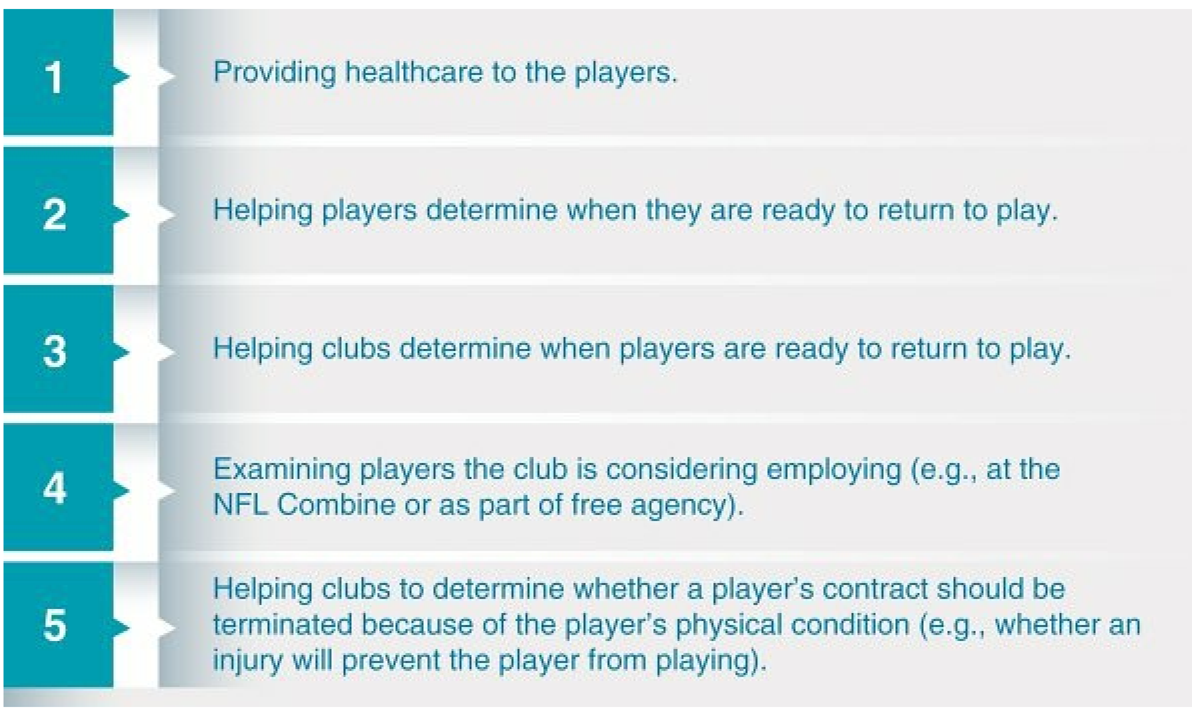

FIG. 12.2 Duties of a team physician create conflict between duties that are exclusively due to the athlete, 1 and 2, and duties that are due to the employer, 3–5.
From Deubert C et al: *Protecting and promoting the health of NFL players: legal and ethical analysis and recommendations,* ed 3, Scotts Valley, CA, 2016, CreateSpace Independent Publishing Platform.

Sexual Misconduct

- Even situations of consensual sexual relationships may create potential for sexual exploitation and loss of objectivity
    - Professional supervisor–trainee relationship
    - Boss-employee
    - Physician-patient
- Sexual harassment in employment can lead to claims under the Civil Rights Act.
    - Quid pro quo: harassment is directly linked to employment or advancement.
    - Hostile environment harassment:
    - Verbal or physical conduct (e.g., gestures, innuendo, humor, pictures) of a sexual nature
    - General gender-based hostility
- **"Reasonable woman test" is the adopted standard for offensive behavior.**
    - If a "reasonable woman" would have found the behavior objectionable, then harassment may have occurred.
- Sexual misconduct with patients is a form of exploitation.
    - Unethical and may represent malpractice or even criminal acts of assault.
    - Courts say **a patient is unable to give meaningful consent to a physician's sexual/romantic advances.**

The Impaired Physician

- ***Impairment* can include chemical impairment, dependence, misconduct, or incompetence.**
- **Resident, fellow, or attending physician who discovers impairment should report it.**
    - Can report to state or local agencies
    - Must act in good faith and have reasonable evidence
    - If patient is at risk for harm, must assert authority to relieve the impaired physician of the patient's care.
    - Should address the problem with the senior hospital staff as soon as possible

Sports Medicine Issues

- **Team physicians have a dual-loyalty issue that creates conflicts as follows**
    - Goals of pursuit of victory and maintaining health
    - Duties as team employee and athlete's physician
    - Team and athlete's financial goals and patient's well-being

- Fleeting glory of participation versus long-term functional abilities (Fig. 12.2)

- **Most courts recognize that physicians performing medical examinations for employment-related, nontreatment purposes have a limited patient-physician relationship.**
    - Patient confidentiality, which promotes honest communication and trust, may be threatened.
    - Private physicians caring for athletes are bound by strictest code of confidentiality.
        - Health Insurance Portability and Accountability Act of 1996 (HIPAA) formally legislates this relationship
    - Surgeons must not share patient information without consent unless:
        - Patient is a minor or incompetent
        - Athlete is a significant risk to others (e.g., performance gymnast, racecar driver)
    - Professional team physicians and pro athletes often sign contractual agreements.
        - Health information becomes part of the athlete's employment records.
- **Return to play issues**
    - Team physicians in college have final responsibility for clearance and return to play.
    - Professional team physicians often serve more as medical advisors to mature patients.
        - Ethical obligations are to educate the athlete on short- and long-term risks to health.
- **Doping and nontherapeutic drug use are considered unethical by most organizations.**
- **Experimental and unproven treatments demand disclosure and ideally should be used in a study.**

Research

- **Characteristics of "ethical" research**
    - Primary goal is to improve methods of detection or treatment of illness.
    - **Designed to produce useful, reproducible information**
    - Is not redundant
    - Is not intended primarily to further the interests of individuals or institutions, financially or professionally
    - Results are reported honestly, accurately, and in a timely manner.
    - **Both positive and negative results are reported.**

- **Sponsorship by industry is not tied to results.**
- **Requirements for human research subjects**
  - Volunteers only
  - Informed consent before participating in any research protocol
  - Medical care not contingent on their participation.
  - Allowed to withdraw from the study at any time
  - Demonstrate understanding of the information
  - Are able to make a responsible decision
- **Requirements for animal use in research**
  - Humane use of animals in research is justified
  - Use of animals is ethical when
    - No suitable alternatives are available.
    - The number of animals used is minimized.
    - Standards of animal care are maintained.
    - It is approved by local Animal Care and Use Committee.
- **Responsibilities of the principal investigator**
  - All aspects of the research even when duties delegated to others
  - Accurately represents the efforts of individuals/agencies involved
  - Cites contributions from other researchers or publications
- **Coauthors must**
  - Make a significant contribution: study design, data collection, project assistance
  - Sign an affidavit of manuscript review agreement before publication
  - Resident research
    - Conducted under the supervision of an attending surgeon
    - Attending surgeon must contribute to the work in actual fact or in a consultative capacity

Medical Liability

- **Malpractice: negligence by a health care provider that results in injury to a patient**
- **Negligence: failure to be as diligent and to select care that a reasonable/prudent person would exercise under the same or similar conditions.**
- **Medical negligence comprises four elements: duty, breach of duty, causation, and damages**
  - Duty: Begins when surgeon offers and patient accepts offer of care
    - To provide care that meets “standard of care”
      - Equal to the same care ordinarily executed by same medical specialty
      - Established by “expert testimony”
      - Res ipsa loquitur (“the thing speaks for itself”): does not need expert testimony (wrong site

surgery, retained instrument/sponge)

- □ **Breach of duty**: when action or inaction deviates from the standard of care
  - • Act of **commission** (doing what should not have been done)
  - • Act of **omission** (failing to do what should have been done)
- □ **Causation: when breach was the direct cause of injuries**
- □ Damages: financial loss awarded as compensation for injuries
  - • Compensatory damages: dollars to restore plaintiff's loss from injury
  - • Nominal damages: smaller sums paid for invasion of rights
  - • Punitive damages: sums to penalize defendant for egregious conduct

▪ **Physician-patient communication is frequently cited as the most common factor.**

- □ Errors in treatment should be disclosed to the patient.
- □ The law requires proof of the allegation by a preponderance of the evidence.

▪ **Statute of limitations: time limit for plaintiff to file a malpractice suit**

- □ Often ≈2 years (varies by state)
- □ For minors, generally 2 years from incident or until 18th birthday
- □ If error not disclosed, the duration of statute may be extended.

▪ **Liability status of residents and fellows**

- □ Residents and fellows are licensed physicians
  - • Function as employees
  - • Responsible for their own actions
  - • Act as agents for their supervisors
- □ **Supervisors are responsible for their trainees (vicarious liability).**
- □ **Residents/fellows held to same standard as board-certified surgeons.**
  - • Should function at the level of their training
  - • Should consult their supervisors to **avoid the risk of acting independently**
  - • **Must disclose residency or fellow status to patients**
    - • Failure to inform a patient may result in claims: fraud, deceit, misrepresentation, assault, battery, and lack of informed consent

□ **Medical record**

- □ Tells the story of patient care and allows continuity between providers
- □ Is a **legal document** and **best defense in malpractice suit**
- □ Should not be altered (may be amended)
  - • **Errors should be "lined out."**
- □ Is a business document justifying appropriate reimbursement when allowed by contract
- □ Must be **maintained for 7 years after last treatmen**t
- □ Data in records belong to patient and are confidential.

- Patient must provide written authorization to release
- May require patient to pay costs of copies
- HIPAA Privacy Rule regulates use and disclosure of protected health information.

Testable Concepts

- Four major principles in medical ethics:
  - Nonmaleficence: “do no harm”
  - Beneficence: do good
  - Autonomy: personal rule of the self
  - Justice: equal treatment
- Conflicts of interest are common and must be resolved in the best interest of the patient.
- Most common conflicts: facility ownership and relationships with industry in which physician should disclose payment to patients
- AAOS Standards of Professionalism represent the minimal level of acceptable conduct to remain a member of our academy.
  - Violations can be reported to: National Practitioner Data Bank, state medical licensing boards, and American Board of Orthopaedic Surgery
- Child abuse laws require reporting all suspected cases of child abuse to local authorities.
- Medical negligence comprises four elements
  - Duty—physician accepts care
  - Breach of duty—acts of omission or commission
  - Causation—breach was responsible for injury
  - Damages—financial payments paid by defendant to plaintiff
- Physician-patient communication the most common factor cited in malpractice cases.
- Supervisors are responsible for their trainees (vicarious liability).
- Residents/fellows held to same standard as board-certified surgeons.

CHAPTER 13

Biostatistics and Research Design

Joe M. Hart

Introduction

Critical review of published medical research is essential for orthopaedic surgeons who practice evidence-based medicine. Experiments are conducted in both the clinical and basic sciences with the intention of promoting innovation in treating patients and advancing health care. Oftentimes, conclusions from published medical research papers, which are largely based on the design and statistical approach, influence the decisions made in medical practice. Physicians are responsible to be astute appraisers of the most current evidence that supports or refutes clinical decisions that affect their patients' care.

High-quality research starts with developing a question that is important to a particular area of investigation or clinical practice. Questions often arise from anecdotal observations during clinical practice or from prior research or other clinical experiences. Developing an interdisciplinary research team with complementary knowledge bases and skill sets is essential for success. As a research study develops, the most appropriate design is selected to match the primary research question and associated study aims. A study population is defined, and the most appropriate outcome measures and variables are selected. It is important that the research team collaborate so that their combined expertise can contribute to achieving the study aims.

This chapter describes some important fundamental concepts to consider in designing a research study and analyzing and interpreting results.

Selecting A Research Study Design (Fig. 13.1)

- **Research starts with asking a clinically relevant question, determining an appropriate outcome measure (data), and deciding on the most rigorous and feasible design.**
  - **Research designs are selected to test a specific theoretical hypothesis in a way that provides the highest level of evidence.**
  - **Research designs should be rigorous and controlled to provide the highest-quality outcomes.**

Evidence-Based Medicine

- **Aims to apply evidence from the highest-quality research studies to the practice of medicine**
  - Also known as *evidence-based practice*
  - **Findings from the best-designed and most rigorous studies have the greatest influence on clinical decision making.**
  - **The *levels of evidence* in medical research (see Fig. 13.1): a hierarchy for various research applications and questions based on several factors affecting the quality of a research design**
  - Diagnostic, prognostic, or therapeutic research designs with higher levels of evidence have a greater influence on clinical recommendations. Many factors may affect the quality of a research design (see later discussion of flaws in research designs); the levels of evidence of various study designs are as follows:
    - Level I: high-quality clinical trials (randomized, controlled, blinded, etc.)
    - Level II: cohort studies or lesser-quality clinical trials
    - Level III: case-control studies
    - Level IV: case series studies
    - Level V: expert opinions

Clinical Research Designs

▪ **Clinical study design is an essential element of research that the study team must determine in advance of initiating the study.**

Confidence that study conclusions and recommendations are valid

TYPE OF STUDY				
Level	**Therapeutic Studies** (Investigating the results of treatment)	**Prognostic Studies** (Investigating the outcome of disease)	**Diagnostic Studies** (Investigating a diagnostic test)	**Economic and Decision Analyses** (Developing an economic or decision model)
Level I	1. Randomized controlled trial a. Significant difference b. No significant difference but narrow confidence intervals 2. Systematic review[2] of level I randomized controlled trials (studies were homogeneous)	1. Prospective study[1] 2. Systematic review[2] of level I studies	1. Testing of previously developed diagnostic criteria in series of consecutive patients (with universally applied reference gold standard) 2. Systematic review[2] of level I studies	1. Clinically sensible costs and alternatives; values obtained from many studies; multiway sensitivity analyses 2. Systematic review[2] of level I studies
Level II	1. Prospective cohort study[3] 2. Poor-quality randomized controlled trial (e.g., <80% follow-up) 3. Systematic review[2] of level II studies or nonhomogeneous level I studies	1. Retrospective study[4] 2. Study of untreated controls from a previous randomized controlled trial 3. Systematic review[2] of level II studies	1. Development of diagnostic criteria on basis of consecutive patients (with universally applied reference gold standard) 2. Systematic review[2] of level II studies	1. Clinically sensible costs and alternatives; values obtained from limited studies; multiway sensitivity analyses 2. Systematic review[2] of level II studies
Level III	1. Case-control study[5] 2. Retrospective cohort study[4] 3. Systematic review[2] of level III studies	Case-control study[5]	1. Study of nonconsecutive patients (no consistently applied reference gold standard) 2. Systematic review[2] of level III studies	1. Limited alternatives and costs; poor estimates 2. Systematic review[2] of level III studies
Level IV	Case series	Case series	1. Case-control study 2. Poor reference standard	No sensitivity analysis
Level V	Expert opinion	Expert opinion	Expert opinion	Expert opinion

[1]All patients were enrolled at the same point in their disease course (inception cohort) with ≥80% follow-up of enrolled patients.
[2]A study of results from two or more previous studies.
[3]Patients were compared with a control group of patients treated at the same time and institution.
[4]The study was initiated after treatment was performed.
[5]Patients with a particular outcome ("cases" with, for example, a failed arthroplasty) were compared with those who did not have the outcome ("controls" with, for example, a total hip arthroplasty that did not fail).

FIG. 13.1 Study design characteristics that are considered when various types of studies are assigned a "level of evidence."
Adapted from Wright JG et al: Introducing levels of evidence to the journal, *J Bone Joint Surg Am* 85:1–3, 2003.

▪ **Prospective studies are designed to start in the present and collect data forward in time. For example, an exposure or potential risk factor has occurred and patients are followed forward in time to determine the occurrence of an outcome of interest.**
▪ **Retrospective studies are designed to assess outcomes that have already occurred or data that have been collected in the past. Chart review of medical records is a typical application of retrospective research designs in orthopaedic research.**
▪ **Longitudinal studies involve repeated assessments over a long period. A longitudinal study can also be performed on historical (retrospective) data.**
▪ **Observational research designs can be prospective, retrospective, or longitudinal. Common observational designs are as follows (Fig. 13.2):**

□ Case reports:
- Descriptions of unique injures, disease occurrences, or outcomes in a single patient
- No attempts at advanced data analysis are made.
- Cause-and-effect relationships and generalizability are not determined.

□ Case series:
- Outcomes are measured in patients with a similar

disease/injury to determine outcomes retrospectively.
- No attempts are made to estimate frequencies or distributions.

□ Case-control studies:
- Outcomes measured in patients with similar disease/injury are compared with a control group (see later discussion of flaws in research designs for more information about control groups).
- Odds ratios (not relative risks) are appropriate measures of association from data collected in these study designs (see later Concepts in Epidemiologic Research Studies).

□ Cohort study:
- Groups of patients with a similar characteristic or exposure/risk factor are studied forward in time (prospective) or from existing data (retrospective).
- Cohort studies are appropriate for estimating incidence of disease/injury and relative risks.

□ Cross-sectional study:
- A specific patient population is studied at a given point in time.
- All measurements are made at once with no follow-up period.
- Considered "snapshot" that is useful for describing the prevalence of a particular injury/disease of interest at a particular point in time.

▪ **Experimental research designs**

□ **A clinical trial is designed to allocate treatments and track outcomes prospectively to test a specific hypothesis.** Clinical trials are costly, take a great deal of time, money, and resources and a comprehensive research team (often at multiple patient enrollment sites) to accomplish their aims.
- **The gold standard, and the type of clinical trial that produces the highest level of evidence, is the randomized controlled trial (RCT).**

□ Clinical trials with parallel design: treatments are allocated to different subjects/patients in random or nonrandom manner.

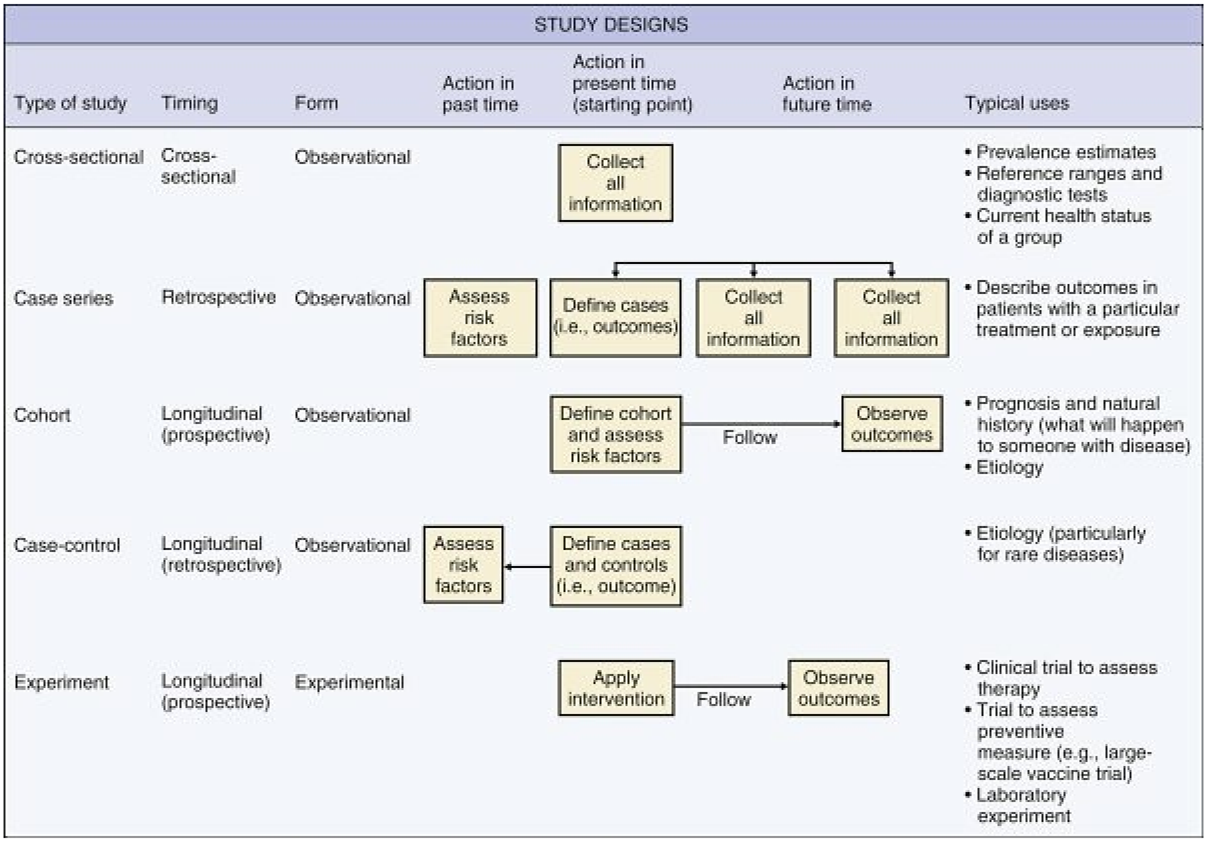

FIG. 13.2 Characteristics and typical uses of various research designs common in orthopaedic research.
Modified from Petrie A, Sabin C: *Medical statistics at a glance,* Oxford, UK, 2000, Blackwell Science.

  - Example: patients are randomly assigned to receive one of the study interventions only. This allocation is typically randomized and blinded (see discussion of prior blinding and randomization).
- □ Clinical trials with crossover designs: each subject receives two or more interventions in a predetermined or random order.
  - Patients are followed prospectively for a period while receiving treatment A, then start receiving treatment B and are followed for an additional period. One of the "treatment conditions" can be a control condition.
- □ Clinical studies can be designed to determine superiority of one treatment over another or to determine whether one treatment is no worse than another (noninferiority) or just as effective (equivalency).

Common Flaws in Research Designs

- *Confounding variables* **are factors extraneous to a research design that potentially influence the outcome.** Conclusions regarding cause-and-effect relationships may be explained by confounding variables instead of by the treatment/intervention being studied and must therefore be controlled for in the research design (via matching, randomization, etc.) or accounted for in statistical analyses (see later discussion of ANCOVA).

- ***Bias* is unintentional systematic error that will threaten the internal validity of a study. Kinds of bias include selection (sampling) bias, nonresponder (loss to follow-up) bias, observer/interviewer bias, and recall bias.**
- **Protection against these threats can be achieved through randomization (i.e., random allocation of treatment) to ensure that bias and confounding factors are equally distributed among the study groups. Single blinding (examiner or patient) or double blinding (examiner and patient) is important for minimizing bias.**
- **Control groups can help account for potential placebo effect of interventions.**
  - Control groups may receive a standard-of-care intervention, no intervention, a placebo (i.e., inactive substance), or sham intervention.
  - Control data may have been collected in the past (historical controls) or may occur in sequence with other study interventions (crossover design).
  - Control subjects are often matched on the basis of specific characteristics (e.g., gender, age), a process that helps account for potential confounding sources that may influence the impact of research findings.
- **The strongest clinical trial design uses randomly allocated, blinded and concurrent, matched controls.**
  - Descriptive and controlled laboratory studies are common in basic science research and may include similar designs and statistical methods to protect against sources of bias and confounding.
  - Design flaws may challenge the internal or external validity of a research study. *Internal validity* describes the quality of a research design and how well the study is controlled and can be reproduced. *External validity* is the ability of a study's results to be generalized or applied to a whole population of interest.
- **Study populations in clinical research studies are delimited by inclusion and exclusion criteria. During a screening process, clinical researchers carefully review all inclusion and exclusion criteria to determine eligibility for participation in a clinical research study or clinical trial.**
  - Inclusion and exclusion criteria are written to target a specific patient population for a clinical research study. The narrower a patient population becomes, the less confounded or biased, but also the less generalizable, study findings will be.
  - *Inclusion criteria* are specific characteristics that are identified to best describe a target population. Sex, age, race, primary diagnosis, and procedure are all examples of inclusion criteria. In clinical research, to be included in a study, the response to all inclusion criteria must be affirmative (i.e., "yes").
  - *Exclusion criteria* are specific characteristic that, when present, would

disqualify a potential participant from the study. For the participant to be included in a clinical research study, all exclusion criteria must be negative or ruled out.

How Many Subjects are Needed to Complete a Research Study?

- **Research studies should have enough subjects/samples to get valid results that can be generalized to a population while minimizing unnecessary work or risk to subjects.**
- **Sample size estimates are based on the desired statistical power (often termed** *power analyses*).
  - □ ***Statistical power* is the probability of finding differences among groups when differences actually exist (i.e., avoiding type II error).**
  - □ **We want to be able to find these differences with our statistical tests 80% of the time or more.**
- **Sample sizes are justified as the number of subjects needed to find a statistically significant difference or association (i.e.,** $P < 0.05$) while maintaining statistical power greater than 80%.
- **Higher sample sizes and/or highly precise measurements (lower variability) are necessary to find small differences between study groups.**
- **Power analyses can be done before the study starts (a priori) or after the study has been completed (post hoc).**
  - **Studies with low power have higher likelihood of missing statistical differences (or relationships) when they actually exist (i.e., type II error).**
- **Sample sizes are calculated to determine the number of subjects needed to study a specific outcome measure. It is important to identify a primary outcome measure in order to determine sample size for a research study.**
- **Studies that have multiple outcome measures may need multiple sample size estimates to ensure all outcomes are appropriately "powered."**

What Outcomes Should be Included in a Research Study?

- **Selecting the most appropriate outcome for a study is an important decision made in advance by the research team.**
  - □ **Primary outcome measures match the primary purpose of the study.**
  - □ **Secondary and tertiary outcomes may be included as additional (sometimes exploratory) measures that are important to achieve the goals of the study.**
    - Typically, sample size estimates for a study are based on the primary outcome measure.

- **Subjective data are opinions, judgments, or feelings (e.g., in clinical research, patient-reported outcomes are subjective). Objective data are measured by a valid or reliable instrument (see discussion Validity and Reliability).**
- **Primer on sampling and data distributions**
  - *Population*: all individuals who share a specific characteristic of clinical or scientific interest.
    - *Parameters* describe the characteristics of a population.
  - *Random sampling* affords all members of a specific population equal chance of being studied/enrolled in a clinical study.
  - *Sample populations* are representative subsets of the whole population. Statistics describe the characteristics of a sample and are intended to be generalized to the whole population.
  - Populations are delimited on the basis of inclusion and exclusion criteria that are set before a study starts.
  - Types of data collected from samples:
    - *Discrete data* have an infinite number of possible values (e.g., age, height, distance, percentages, time, etc.).
    - *Categorical data* have a limited/finite number of possible values or categories (e.g., excellent/good/fair/poor, male/female, satisfied/unsatisfied, etc.).
      - *Binary* categorical data only have two options (i.e., yes/no).
      - Categorical data can be ordered (e.g., severity: mild, moderate, severe) or unordered (e.g., gender, race).
  - Data can be plotted in frequency distributions (histograms) to summarize basic characteristics of the study sample (Fig. 13.3).
    - Continuous data are often converted into categorical or binary data through the use of cutoff points. Cutoff points can be arbitrary or evidence based.
    - Evidence-based establishment of cutoff points uses receiver operating characteristic (ROC) curves and identifies a point that maximizes sensitivity and/or specificity of a particular test.
      - Example: a numerical value can be established as a cutoff point for white blood cell count to identify whether or not an infection exists.
    - Arrays of continuous data can be separated into percentiles to identify upper/lower halves, thirds, quartiles, and so forth.

Describing Your Data with Simple Statistics

- *Data distribution* is a histogram describing the frequency of occurrence of each data value. Distributions can be described using descriptive statistics such as the following:
    - **Mean** is calculated as the sum of all scores divided by the number of samples *(n)*.
    - **Median** is the value that separates a dataset into equal halves, so that half of the values are higher and half are lower than the median.
    - **Mode** is the most frequently occurring data point.
    - **Range** is the difference between the highest value and the lowest value in a dataset.
    - **Standard deviation** (SD) is a value that describes the dispersion or variability of the data.

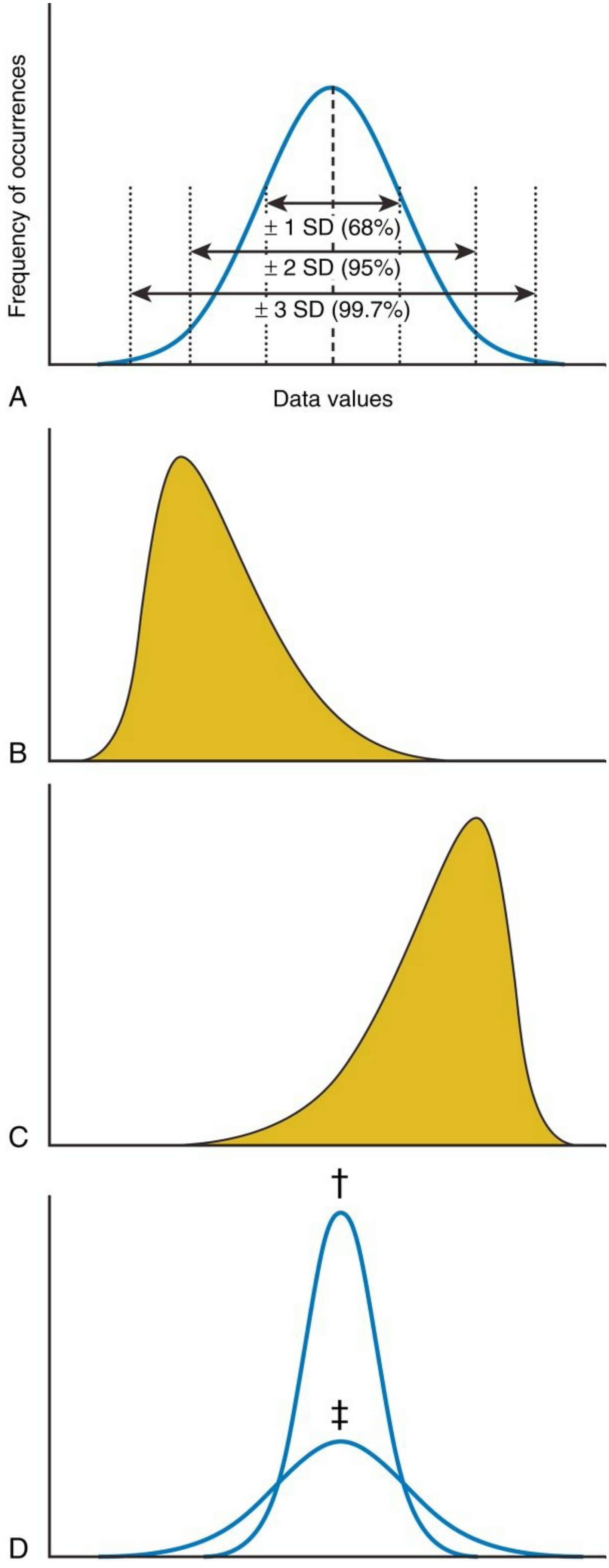
Frequency of occurrences
± 1 SD (68%)
± 2 SD (95%)
± 3 SD (99.7%)
A
Data values
B
C
†
‡
D

FIG. 13.3 Data histograms. (A) Dispersion of normally distributed data with regard to standard deviation (SD). (B) Data that are skewed to the right (positive skew). (C) Data that are skewed to the left (negative skew). (D) Data exhibiting excessively high (†) and low (‡) kurtosis.

    - SD is higher when data are more "spread out."

- □ The **confidence interval** (CI) quantifies the precision of the mean or other statistic, such as an odds ratio (OR) or relative risk (RR).
    - Datasets that are highly variable (large SDs) have larger CIs and hence are less accurate estimates of the characteristics of a population.
    - A 95% CI consists of a range of values within which we are 95% certain that the actual population parameter [mean/OR/RR] lies.
        - Example: mean = 40.5 [95% CI, 35.5–45.5] indicates that we are 95% confident that the population mean lies somewhere between 35.5 and 45.5.
- □ How to determine whether a data distribution is normal (see Fig. 13.3):
    - Because many statistical tests rely on a normal data distribution, the following factors are important to consider in the analysis of your research results:
        - Normally distributed datasets resemble a bell-shaped curve. The mean, median, and mode are the same value in a Gaussian (normally distributed) distribution.
        - Skewed data distributions are asymmetric and may be due to outliers (see later). Data distributions can be skewed to the left (negative skew) or skewed to the right (positive skew). This distribution can be calculated as a numeric value to determine the skewness of a data distribution.
        - *Kurtosis* is a measure of the relative concentration of data points within a distribution. If data values cluster closely, the dataset is more kurtotic. This concentration can be calculated as a numeric value to determine the extent of kurtosis in a data distribution.
        - **Outliers** are data points that are considerably different from the rest of the dataset. Outliers can cause data distributions to be skewed.

Concepts in Epidemiologic Research Studies

- *Epidemiology* is the study of the distribution and determinants of disease. The following measures are commonly used in this type of research:

- □ **Prevalence** is the proportion of existing injuries/disease cases conditions within a particular population.
- □ **Incidence** (absolute risk) is the proportion of new injuries/disease cases within a specified time interval (requires a follow-up period).
  - Can be reported with respect to the number of exposures.
    - Example: if 12 of 100 athletes on a sports team experience a sports injury over a 10-game season, the incidence rate would be 12 injures per 1000 athlete exposures.
- □ **RR** is a ratio between the incidences of an outcome in two cohorts. Typically a treated/exposed cohort (in the numerator of the ratio) is compared with an untreated (control) group/unexposed group (in the denominator of the ratio). Values can range from 0 to infinity and are interpreted as follows:
  - RR = 1.0: indicates the incidences of an outcome are equal in the two groups.
  - RR >1.0: indicates the incidence of an outcome is greater in the treated/exposed group (higher incidence value in the numerator).
  - RR <1.0: indicates the incidence of an outcome is greater in the untreated/unexposed group (higher incidence value in the denominator).
- □ **OR** is calculated as a ratio between the probabilities of an outcome in two cohorts.

	Disease present (+)	Disease absent (–)	
Diagnostic test (+)	True positives	False positives	Positive predictive value = True positives / Total patients with positive test result*
Diagnostic test (–)	False negatives	True negatives	Negative predictive value = True negatives / Total patients with negative test result†
	Sensitivity = True positives / Total patients with disease‡	Specificity = True negatives / Total patients without disease§	

*Total patients with positive diagnostic test results = Number of patients with true-positive results + Number of those with false-negative results

†Total patients with negative diagnostic test results = Number of patients with false-negative results + Number of those with true-negative results

‡Total patients with disease = Number of patients with true-positive results + Number of those with false-negative results

§Total patients without disease = Number of patients with false-positive results + Number of those with true-negative results

FIG. 13.4 Calculations of specificity, sensitivity, and positive and negative predictive values are presented in relation to a 2 × 2 contingency table. Data from all patients *(N)* can be calculated by summing the four boxes in the contingency table.

- ORs are well suited for binary data or studies in which only prevalence can be calculated.

□ **Interpreting RR and OR**

- OR and RR values are interpreted similarly.
- In the comparison of outcomes between two groups, an RR or OR value of 0.5 would indicate that treated/exposed patients have half the likelihood of experiencing a particular outcome than that for the untreated/control group.
- A value of 2.5 would indicate that a treated/exposed group would have a 2.5 times greater likelihood of experiencing the outcome than the untreated/control group.
- An RR or OR whose CI crosses 1 is not considered to be "significant."

▪ **Clinical usefulness of diagnostic tests (** Fig. 13.4)

□ A 2 × 2 contingency table can be used to plot occurrences of a disease/outcome of interest in those who had a positive or negative diagnostic test result.

- True positives: the number of individuals who had positive diagnostic results and actually DO have the disease/outcome of interest
- True negatives: the number of individuals who had negative diagnostic results and actually DO NOT have the disease/outcome of interest
- False positives: the number of individuals who had positive diagnostic results but DO NOT actually have the disease/outcome of interest
- False negatives: the number of individuals who had negative diagnostic results but actually DO have the disease/outcome of interest

□ Analysis of diagnostic ability

- **Sensitivity:**
  - The likelihood of positive test results in patients who actually DO have the disease/condition of interest (i.e., ability to detect true positives among those with a disease)
  - Calculated as the proportion of patients with a disease/condition of interest who have a positive diagnostic test result:

$$\text{Sensitivity} = \frac{\text{True positives}}{\text{Total patients with disease}}$$

    - Total patients with the disease of interest = true positives + false negatives
  - Sensitive tests are used for screening because they have few false-negative results. They are unlikely to miss an affected individual.
  - When the result of a highly sensitive (Sn) test is negative, the condition can be ruled OUT (mnemonic: SnOUT).
- **Specificity:**
  - The likelihood of negative test results in patients who actually DO NOT have the disease/condition of interest (i.e., ability to detect true negatives among those without a disease)
  - Calculated as the proportion of patients without a disease/condition of interest who have a negative

test result:

$$\text{Specificity} = \frac{\text{True negatives}}{\text{Total patients without disease}}$$

- Total patients without the disease or condition of interest = true negatives + false positives
- Specific tests are used for confirmation because they are tests that have few false-positive results and are therefore unlikely to result in false treatment of a healthy individual.
- When the result of a highly specific (Sp) test is positive, the condition can be ruled IN (mnemonic: SpIN).

- **Positive predictive value**: the likelihood that patients with positive test results actually DO have the disease/condition of interest
  - Calculated as the proportion of patients who have a positive test result and actually have the disease of interest (i.e., correctly diagnosed with a positive test result):

$$\text{Positive predictive value} = \frac{\text{True positives}}{\text{Total patients who tested positive}}$$

- Total number of patients who tested positive = true positives + false positives

- **Negative predictive value**: the likelihood that patients with a negative test result actually DO NOT have the disease/condition of interest
  - Calculated as the proportion of patients with a negative test result who do not have the disease of interest (i.e., correctly diagnosed with a negative test):

$$\text{Negative predictive value} = \frac{\text{True negatives}}{\text{Total patients who test negative}}$$

- Total number of patients who tested negative = true negatives + false negatives

- **Likelihood ratio**
  - Probability that a disease exists, given a test result; likelihood ratios consider both specificity and sensitivity of a given test.
  - Likelihood ratios close to 1.0 provide little confidence regarding presence/absence of a disease.
  - Positive likelihood ratios greater than 1.0 indicate higher probability of disease when diagnostic test result is positive.
    - Calculated as the ratio between the true-positive rate (sensitivity) and the false-positive rate (1 − specificity):

$$(+)\ \text{Likelihood ratio} = \frac{\text{Sensitivity}}{(1 - \text{Specificity})}$$

  - Negative likelihood ratios less than 1.0 indicate higher probability that the disease is absent given a negative test result.
    - Calculated as the ratio between the false-negative rate (1 − sensitivity) and the true-negative rate (specificity):

$$(-)\ \text{Likelihood ratio} = \frac{(1 - \text{Sensitivity})}{\text{Specificity}}$$

- **Receiver operating characteristic curves** are graphical representations of the overall clinical utility of a particular diagnostic test that can be used to compare accuracy of different tests in diagnosing a particular condition (Fig. 13.5).
  - Tradeoffs between sensitivity and specificity must

be considered in the identification of the best diagnostic tests.

- ROC curves plot the true-positive rate (sensitivity) and the false-positive rate (1-specificity) on a graph.

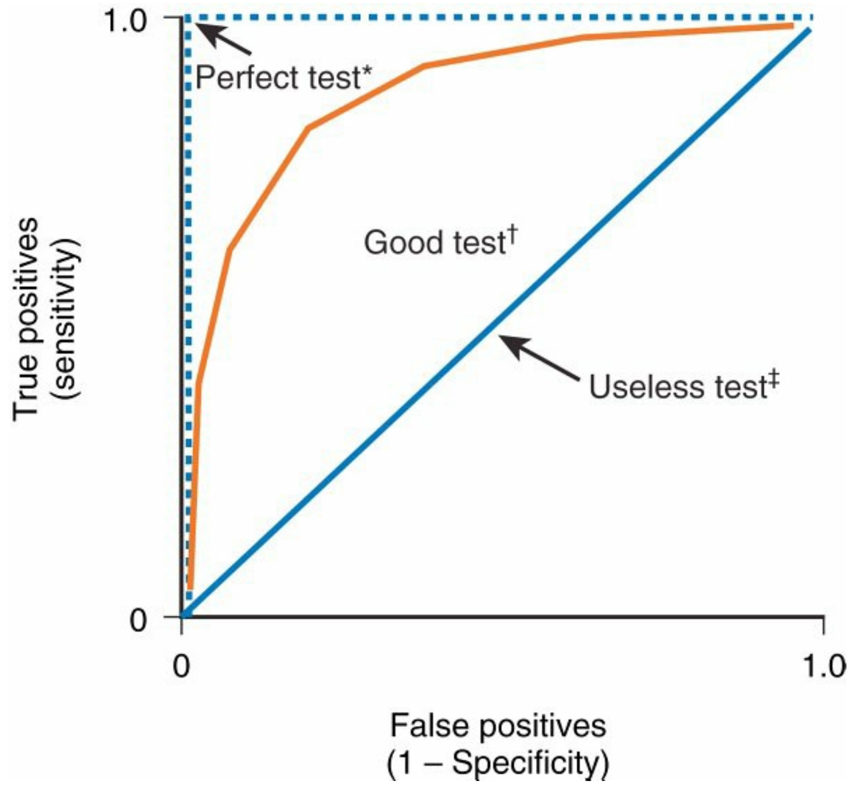

FIG. 13.5 Graphic plot showing receiver operating characteristic (ROC) curves for perfect tests (*area under the curve value = 1.0), good tests (†area under the curve is less than 1.0 but greater than 0.5), and useless tests (‡area under curve = 0.5).

- The area under the ROC curve ranges from 0.5 (useless test, no better than a random guess) to 1.0 (perfect diagnostic ability).

Testing Your Hypotheses with Statistics

- **Statistical tests are prescribed to match the purpose and design of a particular research study. Statistical tests are used to answer research questions. Statistics are merely tools to describe data and make inferences. Interpretation of statistical findings is left to expert scientists and clinicians.**
- **Statistical analyses differ according to whether a researcher wants to compare groups to identify differences, establish relationships between groups, and so on (** Table 13.1).
- **Inferential statistics are used to test specific hypotheses about associations and/or differences among groups of subject/sample data.**

- The *dependent variable* is what is being measured as the outcome. There can be multiple dependent variables depending on how many outcome measures are desired.
- The *independent variables* include the conditions or groupings of the experiment that are systematically manipulated by the investigator.
    - For example, a researcher is measuring pain and prescription medication use in patients receiving treatment A or B or C in patients with shoulder pain. The dependent variables are “pain” and “prescription medicine use.” The independent variable is “treatment condition” with three levels, “A,” “B,” and “C.”
- Inferential statistics can be generally divided into parametric tests and nonparametric tests. The goal of inferential statistics is to estimate parameters; therefore the default should be to parametric tests. Nonparametric alternatives are justified if the basic underlying assumptions for using parametric statistics are violated or if the sample sizes are very small.
    - **Parametric statistics** are appropriate for continuous data and rely on the assumption that data are normally distributed.
        - They use the mean and SD when comparing groups or identifying associations.
        - The mean of a dataset is greatly influenced by outliers, so these tests may not be as robust for skewed datasets.

Table 13.1

Decision-Making Guide for Common Parametric and Nonparametric Statistical Tests for the Desired Study Purpose

Desired Analysis	Parametric Statistics [a]	Nonparametric statistics [b]
Comparison of Two Groups		
Paired	Dependent (paired) samples *t*-test	Wilcoxon signed rank test
Unpaired	Independent samples *t*-test [a]	Mann-Whitney *U* test
Comparison of Three or More Groups		
One outcome variable	Analysis of variance (ANOVA)	Kruskal-Wallis test
Repeated observations in same patient	Repeated measures ANOVA	Friedman test
Multiple dependent variables	Multivariate analysis of variance (MANOVA)	
Analysis including a covariate	Analysis of covariance (ANCOVA)	
Establishing relationship/association	Pearson product moment correlation coefficient	Spearman rho correlation coefficient
Prediction		
From one predictor variable	Simple regression	
From more than one predictor variable	Multivariate linear regression	Logistic regression
Comparisons of Categorical Data		
Two or more variables	Chi-square	Chi-square
Better for low sample size	Fisher exact test	Fisher exact test

[a] Appropriate for normally distributed continuous data.

[b] Alternative tests appropriate for non–normally distributed data and/or small sample sizes.

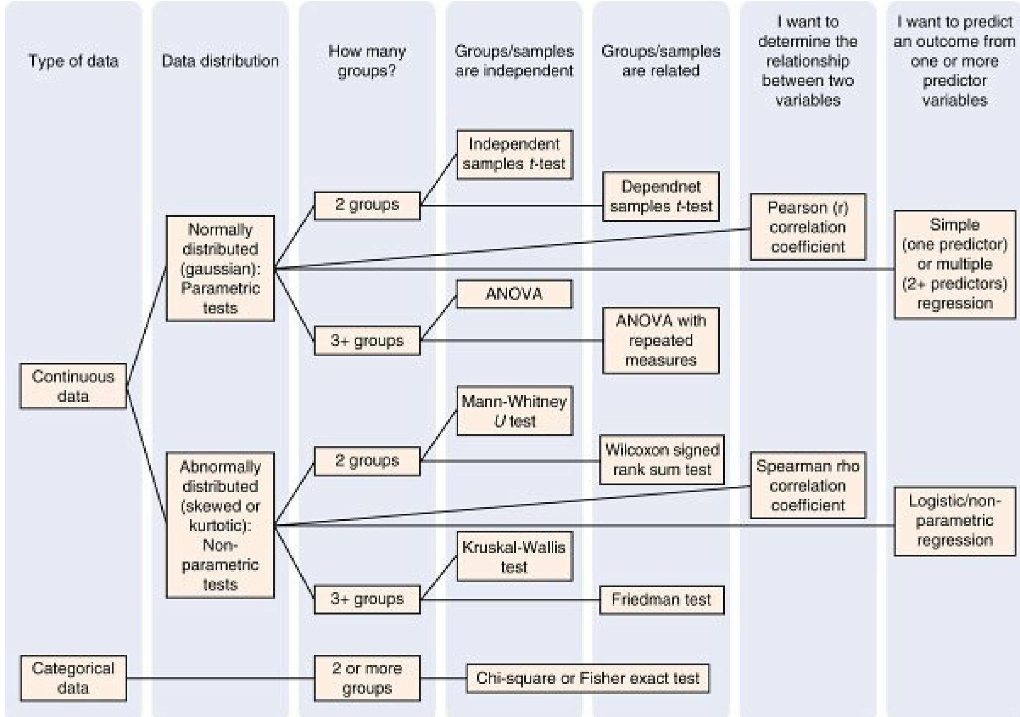

FIG. 13.6 Flow chart to guide basic decision making for statistical tests.

- **Nonparametric statistic**s are appropriate for categorical and non–normally distributed data.
    - They use the median and ranks as more robust alternatives when data are non-normally distributed.

What Statistical Test to use in Research Studies

- **The decision on which statistical test to use is based on several factors inherent to research designs. Statistical analyses should always match the purpose of the study and the primary research question asked by the researchers (** Fig. 13.6).
    - Some important considerations are:
        - How many groups are being studied?
        - Are the measures being recorded in the same or different subjects (or samples)?
        - Are the data continuous or categorical?
        - Are the data normally distributed?
    - When two groups of data are compared, the *t*-test is used; there are two variations:
        - **Dependent (paired) samples *t*-test:**
            - Appropriate for comparing continuous, normally distributed data collected two times on the same subjects
            - Example: two time points measured in the same patient (e.g., before/after intervention)

        - Also appropriate for side-by-side comparison within the same subject or in matched pairs of subjects
        - Nonparametric equivalent: Wilcoxon signed rank test.
    - **Independent samples *t*-test**
        - Appropriate for comparing continuous, normally distributed data from two separate groups
        - Example: two groups of patients who received different treatments
        - Nonparametric equivalent: Mann-Whitney *U* test
- **ANOVA** is appropriate to compare three or more groups of continuous, normally distributed data.
    - Nonparametric equivalent: Kruskal-Wallis test
- **Repeated measures ANOVA** is a variation of the ANOVA test that is appropriate for sequential measurements recorded on the same subjects.
    - For example, this test would be used to compare a dependent variable (outcome measure) recorded at three or more time points (baseline, 1 month post intervention, 2 months post intervention).
    - Nonparametric alternative: Friedman test
- **Multivariate ANOVA (MANOVA)**: variation of the ANOVA test that is used when multiple dependent variables are compared among three or more groups
- **Analysis of covariance (ANCOVA)** is an appropriate test when confounding factors must be accounted for in the statistical test.
- **Post hoc testing** is necessary after any ANOVA test to determine the exact location of differences among groups.
    - ANOVA tests describe whether or not a statistically significant difference exists somewhere among the study groups.
        - For example, in a comparison of three levels of the independent variable treatment condition (A, B, or C), post hoc testing will specifically compare A vs. B, B vs. C, and A vs. C to determine the exact locations of group differences. Post hoc testing is appropriate only if the ANOVA test is statistically significant (see later section).
    - Common post hoc tests: Tukey HSD, Šidák, Dunnett, Scheffe
- Factorial designs for multiple independent variables
    - Hypotheses regarding an interaction among three different treatment groups from pre/post intervention will have a 2 × 3 factorial design.

- "2 × 3" indicates two independent variables; for example, the first (time) has two levels, pretest and post test, and the second (treatment condition) has three levels, treatments A, B, and C.

□ Correlation and regression

- Correlation coefficients
    - Describe the strength of a relationship between two variables
    - **Pearson product correlation coefficient *(r)* used for continuous normally distributed data**
    - **Spearman rho correlation coefficient (ρ) is the nonparametric equivalent.**
    - **Values range from −1.0 to 1.0; less than ±0.33 are "weak," between ±0.33 and ±0.66 are "moderate," and more than ±0.66 are "strong."** Positive values are direct relationships; negative values are indirect relationships.
    - **Positive correlation** coefficients indicate direct relationships suggesting that patients who scored high on one scale also score high on the other.
    - **Negative correlation** coefficients indicate inverse/indirect relationships suggesting that patients who score high on one scale score low on the other.
- **Simple linear regression**
    - Describes the ability of one independent (predictor) variable to predict a dependent variable (outcome) variable
    - The coefficient of determination (R^2) is the square of r (Pearson product correlation coefficient) and indicates the proportion of variance explained in one variable by another.
    - R^2 ranges from 0 to 1.0, in which higher values indicate more variance explained.
- **Multivariate linear regression** describes the ability of several independent variables to predict a dependent variable.
    - Logistic regression is used when the outcome is categorical and the predictor variables can be either categorical or non–normally distributed continuous data.

□ Statistical tests for categorical data

- **Chi-square (χ^2) test**
    - Used for two or more groups of categorical data

- Example: to compare treatment A versus B when the outcome is either "satisfied or unsatisfied," the chi-square test can be used to identify relationships between "treatment condition" and "outcome category."
  - If the result of the test is statistically significant, frequencies of each outcome in the two treatment groups can be visually compared to describe which treatment is superior.
- **Fisher exact test**
  - Similar to the chi-square test but better for small sample sizes or when the number of occurrences in one of the categories is low (e.g., if only one patient in treatment group A had an unsatisfactory outcome, this test is preferred)

Validity and Reliability

- **Can be assessed using statistical techniques similar to correlation coefficients**
  - The intraclass correlation coefficient evaluates agreement between two measures on the same scale.
- **Accuracy/validity**
  - An instrument or test with the ability to accurately describe truth/reality is said to be valid.
  - A validation study is designed to compare measures recorded from a gold-standard method with a new or experimental method. The data should be on the same measurement scale to determine agreement between the two instruments or techniques.
- **Precision/reliability**
  - The ability to precisely describe a characteristic with repeated measurements can be tested statistically.
  - The precision of an instrument or technique can be tested for interobserver (measures taken by different examiners on the same patient) or intraobserver (reliability of measures recorded by the same examiner at consecutive times) reliability. Measures should be on the same scale to determine agreement.
- **The intraclass correlation coefficient (ICC)** is a common statistical method for statistically testing the agreement between two sets of data. Values range from 0 to 1.0 (1.0 = perfect accuracy/precision).
- **For binary or categorical data, a κ (kappa) statistic can be used to determine agreement. The κ statistic has the same scale (0 to 1.0) as the ICC.**

Interpretation of Statistical Test Results

- **In the interpretation of a statistical test result, it is important to establish whether or not your findings (e.g., a difference or relationship) were due to chance. It is also extremely important to determine whether your findings have clinical importance.**
  - **Probability values (*P* values)**
    - Inferential test statistics (*t*-statistic, *F*-statistic, *r* coefficient, etc.) are accompanied by a probability *(P)* value. These values are expressed on a 0% to 100% scale and indicate the probability that the differences/relationships among study data occurred by chance.
  - ***P* values less than 0.05 mean there is less than a 5% chance that the observed difference/relationship has occurred by chance alone and not through the study intervention.**
    - A test is identified as statistically significant if the *P* value is 0.05 or less (willing to commit type I error 5/100 times).
      - Note: decision regarding the threshold for defining statistical significance is arbitrary, but this amount of error (alpha or type I error [see later]) is generally accepted.
    - Therefore, on the basis of *P* value, we either reject the null hypothesis, which stated that there were no differences or that no association existed (i.e., $P < 0.05$) or fail to reject the null hypothesis ($P > 0.05$).
  - Bonferroni correction to the *P* value:
    - Adjusted threshold for statistical significance when performing multiple *t*-tests for each of several dependent (outcome) variables (used to protect against type I error that may occur)
    - Calculated as 0.05/k where *k* is the number of comparisons being made
      - For example, when two groups are compared using a *t*-test for each of three outcome variables, the *t*-test is statistically significant only if the *P* value is less than or equal to $0.05/3 = 0.017$.
- **Statistical significance does not imply clinical importance. Therefore, if a study result includes a statistically significant difference, it remains essential to determine whether that difference is clinically important.**
- **Minimal clinically important differences (MCIDs)** is a method to describe the importance of an observed difference during a statistical test.
  - MCIDs describe the smallest change in a patient-oriented outcome measure that would be perceived as being beneficial to the patient or

would necessitate treatment.

- Many of the more commonly used patient-oriented outcome instruments have research-established MCID values—or a change in outcome that would change the course of a disease or its treatment.
- Expert and experienced clinicians should also consider whether observed differences are important enough to change practice.

- **Effect size** (e.g., Cohen's d) is a standardized method of expressing the magnitude of differences between study groups or in subjects before and after treatment in the unit of the SD. (Effect size = 1 means that the mean difference equals the SD.) The larger the value, the greater the effect (e.g., of treatment).
  - Calculated as the mean difference (e.g., between two treatment groups or from pre- and posttreatment) divided by the SD (typically SD pooled between groups or the SD of the reference/control group):

$$\text{Effect size} = \text{Mean}_{\text{Group1}} - \text{Mean}_{\text{Group2}} / \text{Standard deviation}_{\text{pooled}}$$

    - Interpretation of effect size: effect sizes greater than 0.8 are “large”; those less than 0.2 are “small” (between these values can be interpreted as “medium”).
    - Effect sizes are similar to percentage differences, except the denominator is the SD. Therefore datasets that are highly variable may have lower effect sizes even if the mean difference is high.
- **Statistical error primer**
  - **Type I error** (alpha [α] error)
    - Probability that a statistical test is *wrong* when the null hypothesis is rejected (i.e., claiming that groups are different when they actually are not)
    - It is accepted that this may occur 5 times out of 100, so the probability value threshold for statistical significance is 0.05 or 5%.
  - **Type II error** (beta [β] error)
    - Probability that a statistical test is *wrong* when failing to reject the null hypothesis (i.e., claiming that two groups are NOT different when they actually are)
    - It is accepted that this may occur up to 20% of the time.

Testable Concepts

Selecting a Research Study Design

- Research designs are selected to test a specific theoretical hypothesis in a way that provides the highest level of evidence.
- Research designs should be rigorous and controlled to provide the highest-quality outcomes.

Evidence-Based Medicine

- Findings from the best-designed and most rigorous studies have the greatest influence on clinical decision making.
- The "levels of evidence" in medical research (see Fig. 13.1): a hierarchy for various research applications and questions based on several factors affecting the quality of a research design.

Clinical Research Designs

- Observational research designs can be prospective, retrospective, or longitudinal. Common observational designs are summarized in Fig. 13.2.
- Experimental designs
    - Clinical trials are designed to allocate treatments and track outcomes prospectively to test a specific hypothesis.
    - The gold standard and highest level of evidence clinical trial is the randomized controlled trial (RCT).

Common Flaws in Research Designs

- Confounding variables are factors extraneous to a research design that potentially influence the outcome.
- Bias is unintentional systematic error that will threaten the internal validity of a study. Sources of bias include selection (sampling) bias, nonresponder (loss to follow-up) bias, observer/interviewer bias, and recall bias.
- Control groups can help account for potential placebo effects of interventions.

How Many Subjects are Needed to Complete a Research Study?

- Statistical power is the probability of finding differences among groups when differences actually exist (i.e., avoiding type II error).
- We want to be able to find these differences with our statistical tests 80% or more of the time.
- Studies with low power have higher likelihood of missing statistical differences (or relationships) when they actually exist (i.e., type II error).

What Outcomes Should be Included in a Research Study?

- Primary outcome measures match the primary purpose of the study.
- Secondary and tertiary outcomes may be included as additional (sometimes exploratory) measures that are important to achieve the goals of the study.

Describing Your Data with Simple Statistics

- Mean is calculated as the sum of all scores divided by the number of samples *(n)*.
- Median is the value that separates a dataset into equal halves, so that half of the values are higher and half are lower than the median.
- Mode is the most frequently occurring data point.
- Range is the difference between the highest value and the lowest value in a dataset.
- Standard deviation (SD) is a value that describes the dispersion or variability of the data. SD is higher when data are more "spread out."
- The confidence interval (CI) quantifies the precision of the mean or other statistic, such as an odds ratio (OR) or relative risk (RR).
- Outliers are data points that are considerably different from the rest of the dataset. Outliers can cause data distributions to be skewed.

Concepts in Epidemiologic Research Studies

- Prevalence is the proportion of existing injuries/disease cases conditions within a particular population.
- Incidence (absolute risk) is the proportion of new injuries/disease cases within a specified time interval (requires a follow-up period).
- Odds ratios and relative risks can be calculated from clinical studies that are designed to determine associations among risk factor exposure and patient outcomes.
- Relative risk and odds ratio describe the risk and odds, respectively, of the incidences of a particular outcome of interest in two groups, typically, a group in which subjects are treated or exposed and a reference or control group. Relative risk is calculated as the ratio between the incidence rates of an outcome in two cohorts.
- Sensitivity: The likelihood of a positive test result in patients who actually DO have the disease/condition of interest (i.e., ability to detect true positives among those with a disease).
- Specificity: The likelihood of a negative test result in those patients who actually DO NOT have the disease/condition of interest (i.e., ability to detect true negatives among those without a disease).
- Receiver operating characteristic (ROC) curves are graphical representations of

the overall clinical utility of a particular diagnostic test that can be used to compare accuracy of different tests in diagnosing a particular condition (see Fig. 13.5).

Testing Your Hypotheses with Statistics

- Parametric statistics are appropriate for continuous data and rely on the assumption that data are normally distributed.
- Nonparametric statistics are appropriate for categorical and non–normally distributed data.

What Statistical Test to use for Different Analyses in Research

- For comparing two groups of normally distributed data, the independent-samples *t*-test is used (paired samples if the groups are matched or measures recorded in the same individual over time). For comparisons of three or more groups, the ANOVA is used (repeated-measures ANOVA for repeated measures, ANCOVA if there is a covariate, MANOVA if there are many dependent variables).
- Post hoc testing is necessary after any ANOVA test to determine the exact locations of differences among groups.
- Pearson product correlation coefficient *(r)* describes the strength of a relationship between two variables and is used for continuous normally distributed data; the nonparametric equivalent is the Spearman rho correlation coefficient (ϱ). Values range from −1.0 to 1.0; values closer to ±1 are stronger; positive values are direct relationships, and negative values are indirect relationships.
- Regression is used to predict an outcome from one variable (simple regression) or many (multivariate linear regression) variables. The higher the R^2 values resulting from regression equations, the better the predictive ability; that is, the variance in the outcome variable explained by the predictor(s).
- Logistic regression is used when the outcome is categorical and the predictor variables can be either categorical or non–normally distributed continuous data.
- Chi-square (χ^2) test: Used for two or more groups of categorical data. Fisher exact test is similar to the chi-square test but better for small sample sizes.

Validity and Reliability

- Accuracy/validity: an instrument or test with the ability to accurately describe truth/reality is said to be valid.
- Precision/reliability: the ability to precisely describe a characteristic with repeated measurements that can be tested statistically.

- The intraclass correlation coefficient (ICC) tests the agreement between two sets of data. Values range from 0 to 1.0 (1.0 = perfect accuracy/precision).

Interpretation of Statistical Test Results

- *P* values less than 0.05 mean there is less than 5% chance of a type I error.
- Statistical significance does not imply clinical importance.
- Minimal clinically important differences (MCIDs) is a method to describe the importance of an observed difference during a statistical test.
- Effect size (e.g., Cohen's d) is a standardized method of expressing the magnitude of differences between study groups or between the same subjects before and after treatment in the unit of the SD. (Effect size = 1 means that the mean difference equals the SD.) The larger the value, the greater the effect (e.g., of treatment).
- Type I error (alpha [α] error): probability that a statistical test is *wrong* when the null hypothesis is rejected (i.e., claiming that groups are different when they actually are not)
- Type II error (beta [β] error): probability that a statistical test is *wrong* when failing to reject the null hypothesis (i.e., claiming that two groups are NOT different when they actually are)

Chapter 13Review Questions

1. A research study that includes chart reviews of patients who underwent a partial knee arthroplasty and compares them with patients of the same age, weight, and level of arthritis who underwent osteotomy would best be described as:

A. Double-blind placebo-controlled randomized prospective trial

B. Retrospective matched case-control observational study

C. Retrospective case series observational study

D. Case series review

E. Case report

Answer 1: **B.**

2. The *validity* of a clinical instrument or test describes whether:

A. It produces measures that represent reality/the actual true measure

B. It produces consistent scores in similar situations

C. It produces a result that is statistically significant

D. It produces similar results with repeated measurements

E. It produces the proper reimbursement for the work performed

Answer 2: **A.**

3. In epidemiology studies, *incidence* describes the:

A. Proportion of individuals with a disease right now

B. Rate of new occurrences of a disease per unit of time

C. Proportion of a sample with a disease under study

D. Variability occurring between successive observations by the same surgeon

E. Variability occurring between observations by different surgeons

Answer: **B.**

4. During clinical follow-up, a subjective pain rating from two unmatched groups of patients with chronic patellofemoral joint pain is collected. One of the patient groups received a surgical intervention and the other received conservative management. The purpose of the study is to compare subjective pain ratings between the two groups. Which of the following statistical tests is most appropriate?

A. Repeated measures ANOVA

B. Spearman rho correlation coefficient

C. Independent samples *t*-test

D. Paired samples *t*-test

E. Logistic regression

Answer: **C.**

5. A statistical test is associated with a *P* value of 0.04. What is the interpretation of this value?

A. There is a 4% chance of being wrong when saying the test is statistically significant.

B. There is a 4% chance of being correct when saying the test is statistically significant.

C. The type II error is excessive.

D. The study has insufficient statistical power.

E. There is a 96% chance that the test is clinically important.

Answer: **A.**

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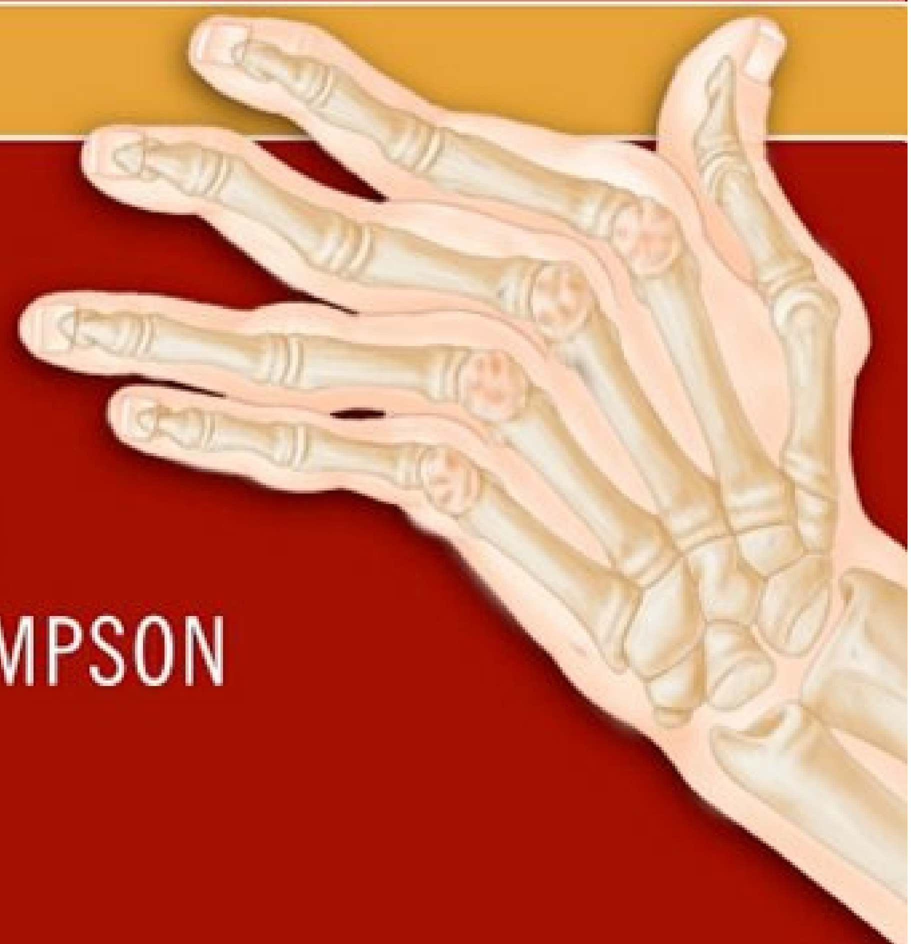
MILLER'S REVIEW OF ORTHOPAEDICS

EIGHTH EDITION



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