PLEASE CLICK ON THE FOLLOWING LINK TO WATCH THE LECTURE ONLINE:-

HTTPS://WWW.YOUTUBE.COM/WATCH?V=NMATIQM02RM&LIST=PLUBRB5B7FA_EYBVGZ4XB_AQLGCXLIEYRA

AO TRAUMA

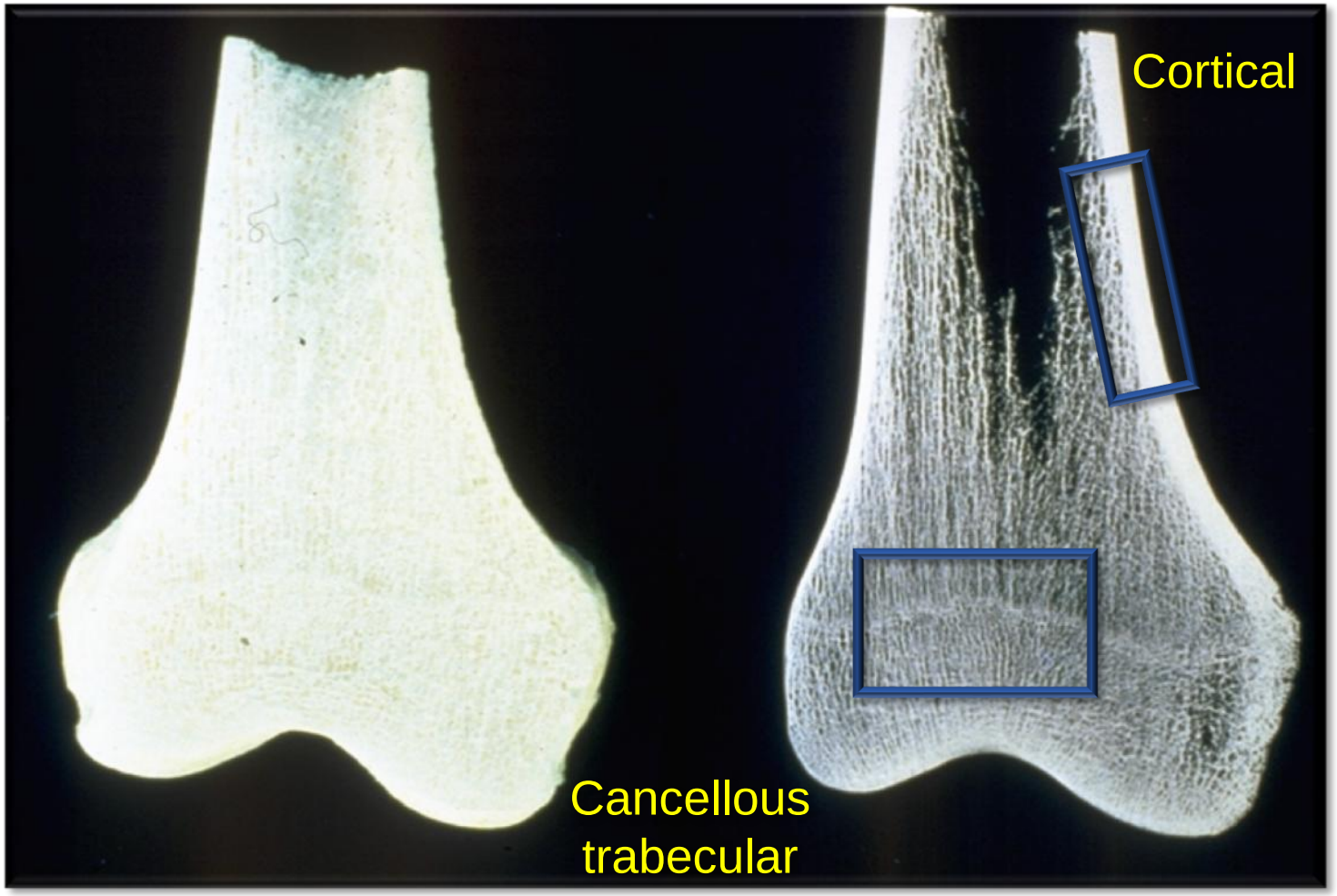
Biology of bone healing

Nizar Albrehe M.D. ,
MRCS(Ir),Tr&orth. specialist

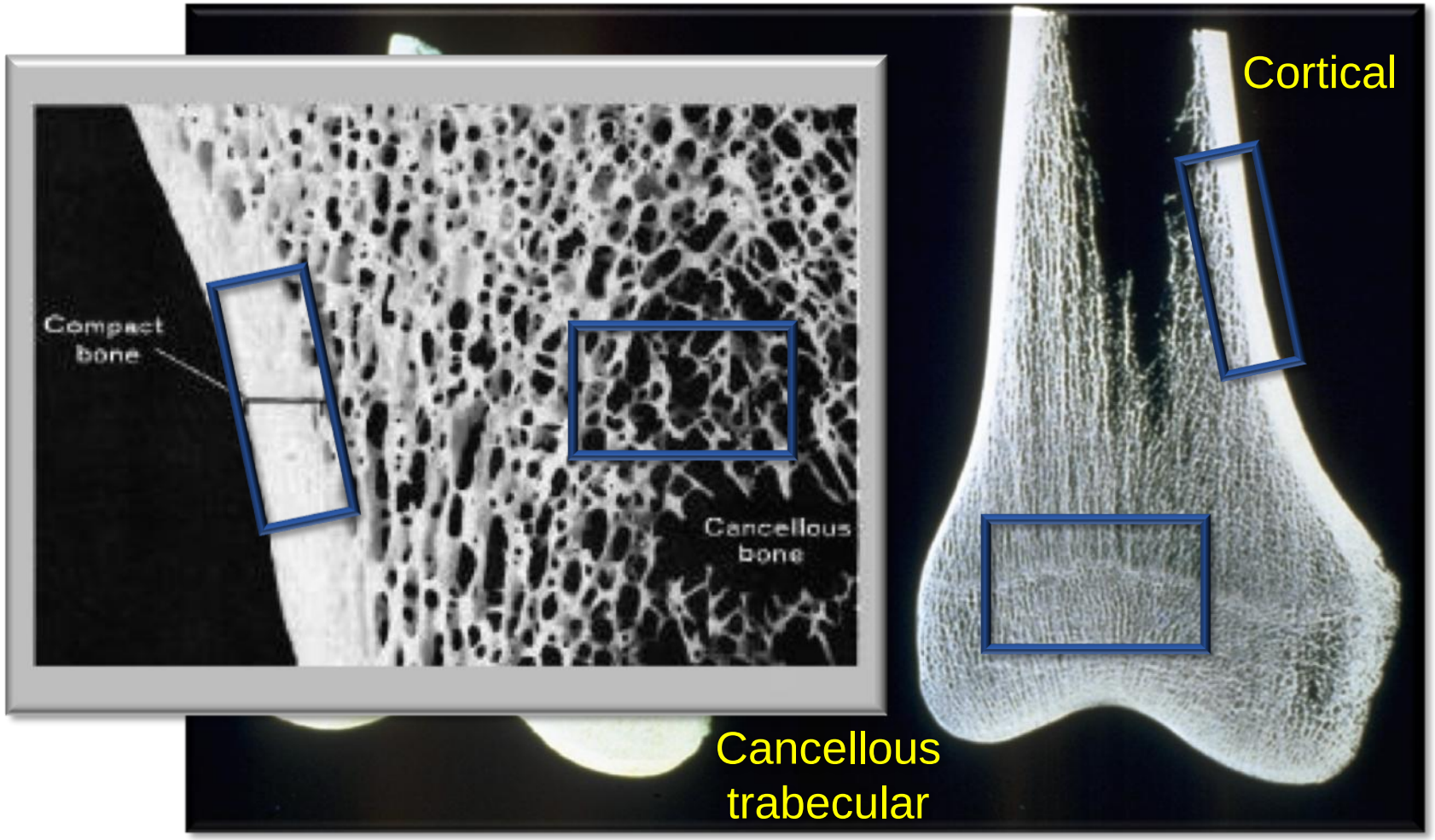
Learning objectives

- Explain the different processes of bone healing and review direct and indirect bone healing
- Describe the factors that influence the healing process and those that may lead to delayed union or nonunion
- Recognize the importance of soft tissues for bone healing
- Discuss the effects and influence of osteosynthesis on the bone and its healing process
- Nonunion definition , etiology and treatment

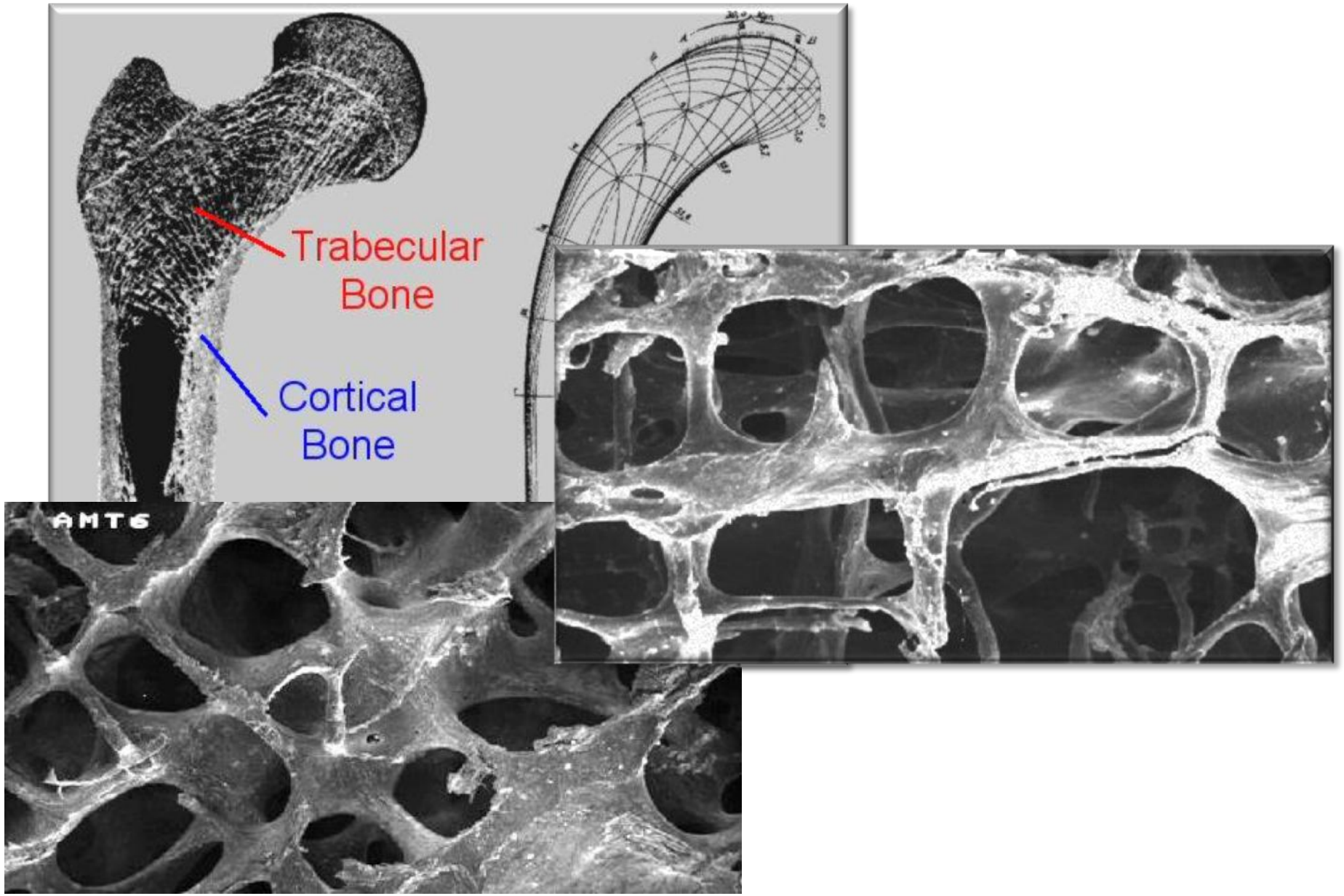
Bone structure



Bone structure

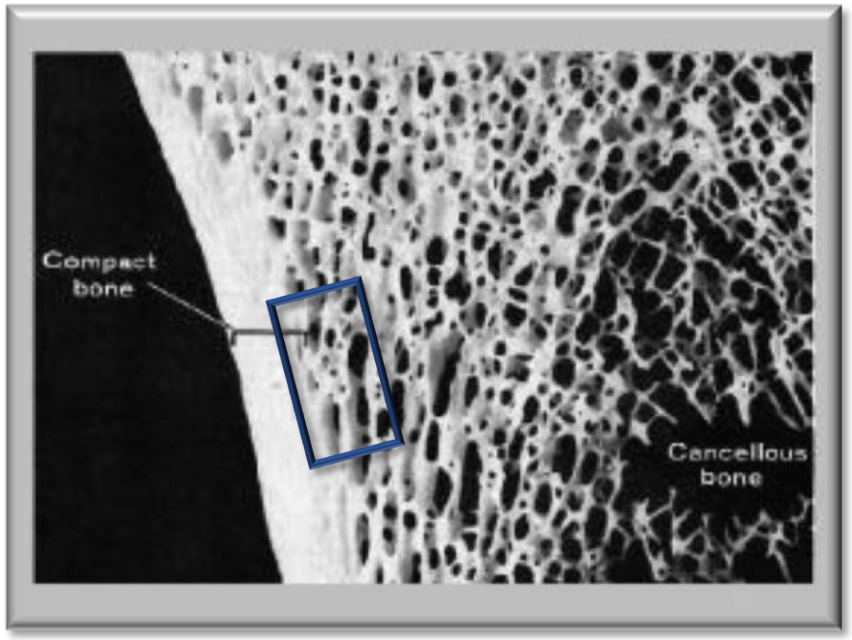


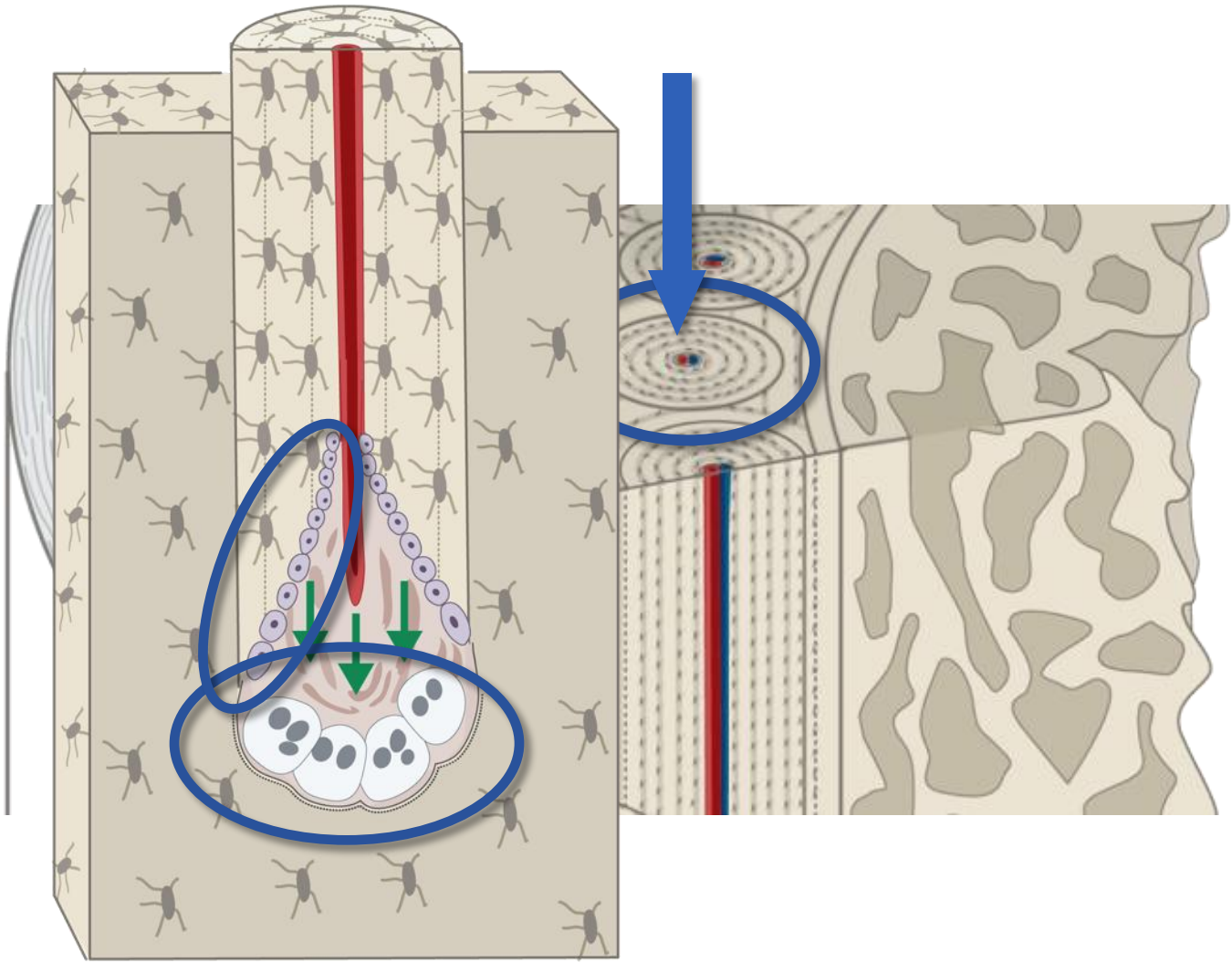
Cancellous trabecular bone



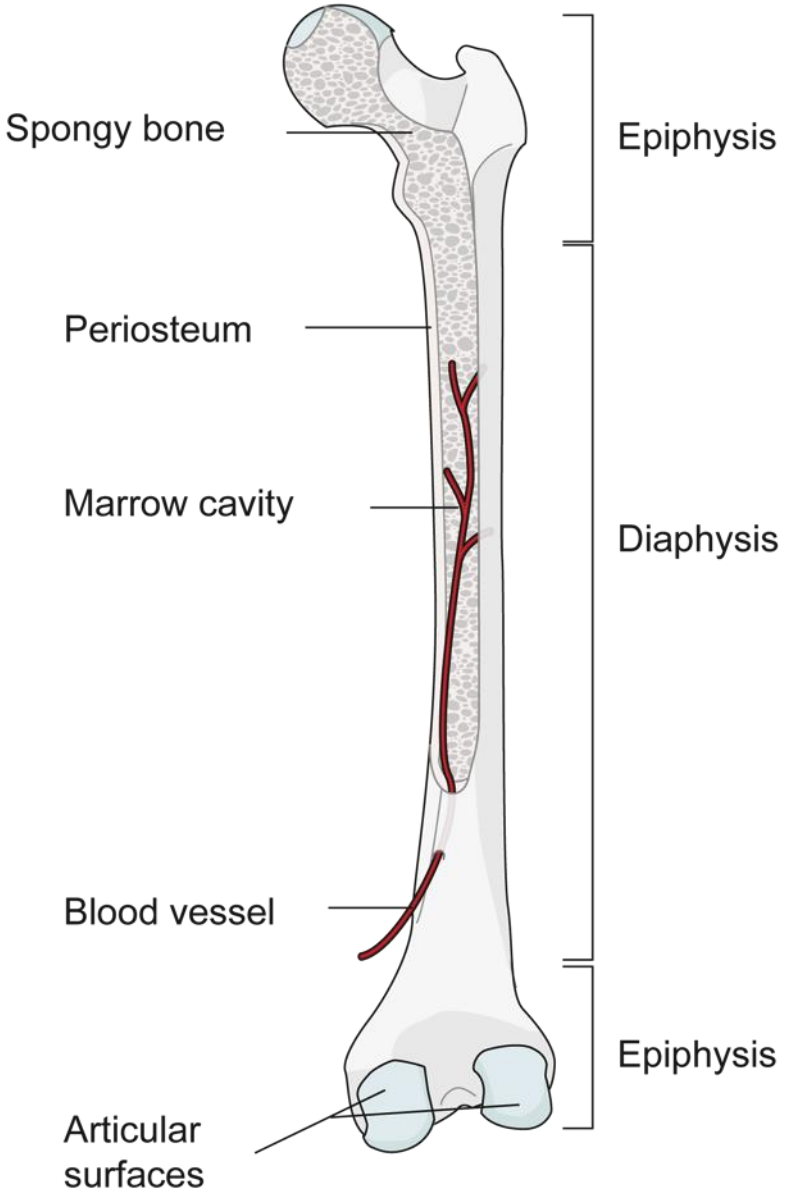
Cortical bone

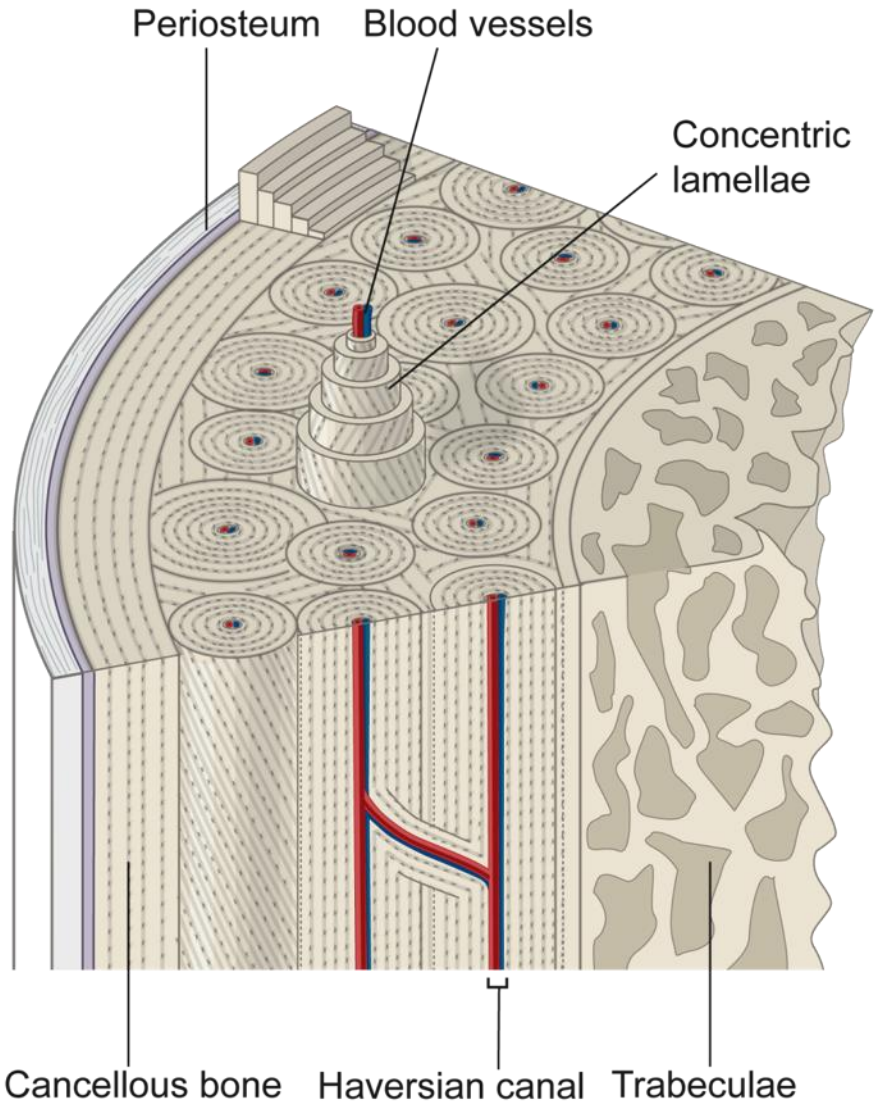
- Made up of osteons
- Continually remodelled by cutting cones



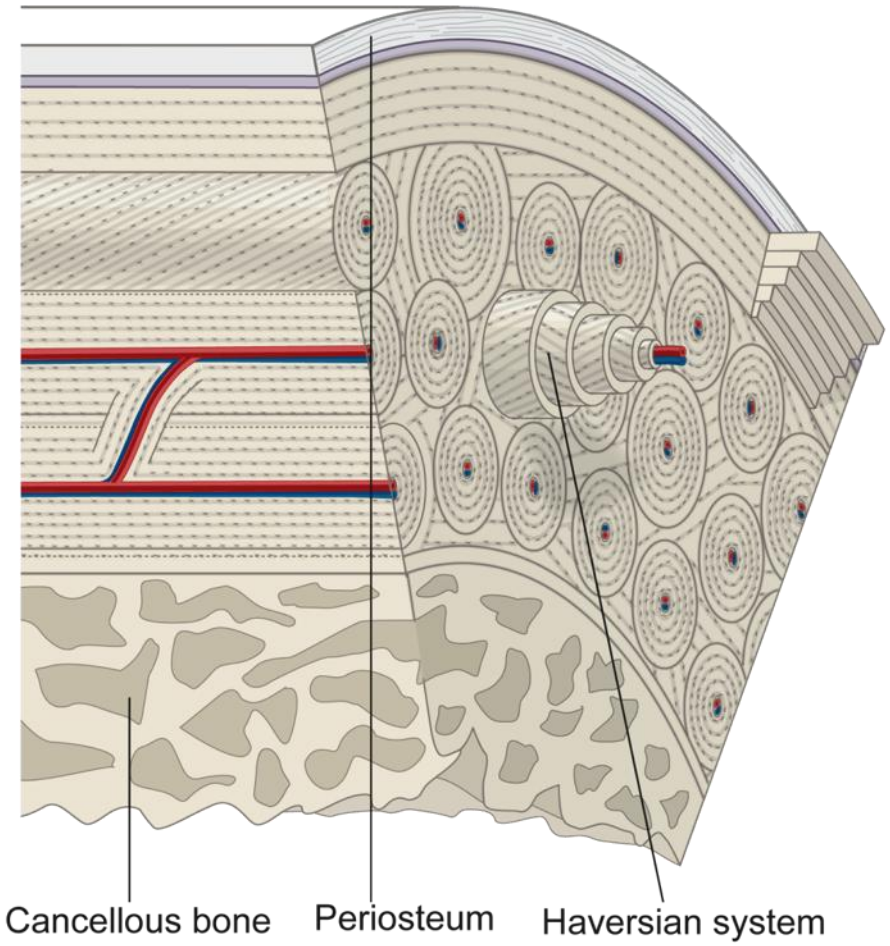


Blood supply





Bony anatomy



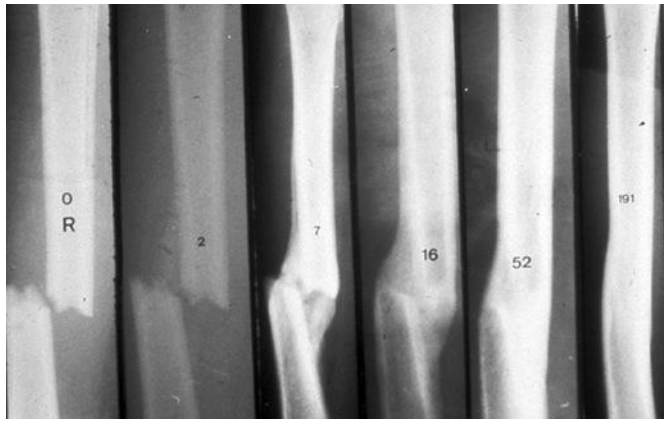
Different types of bone healing

Types Bone healing—definitions

Radiological

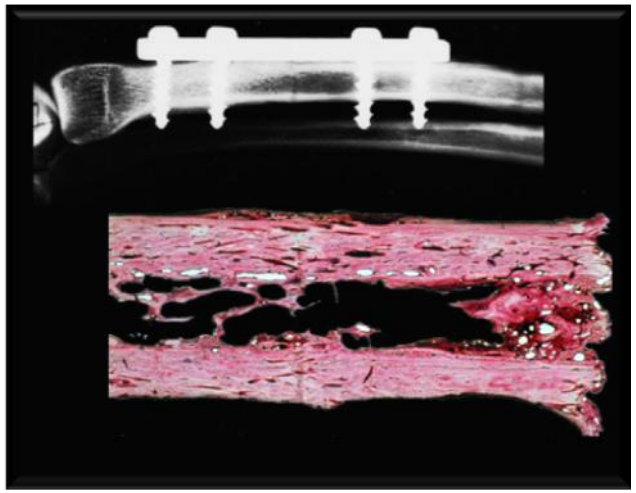
Visible callus formation

Indirect healing



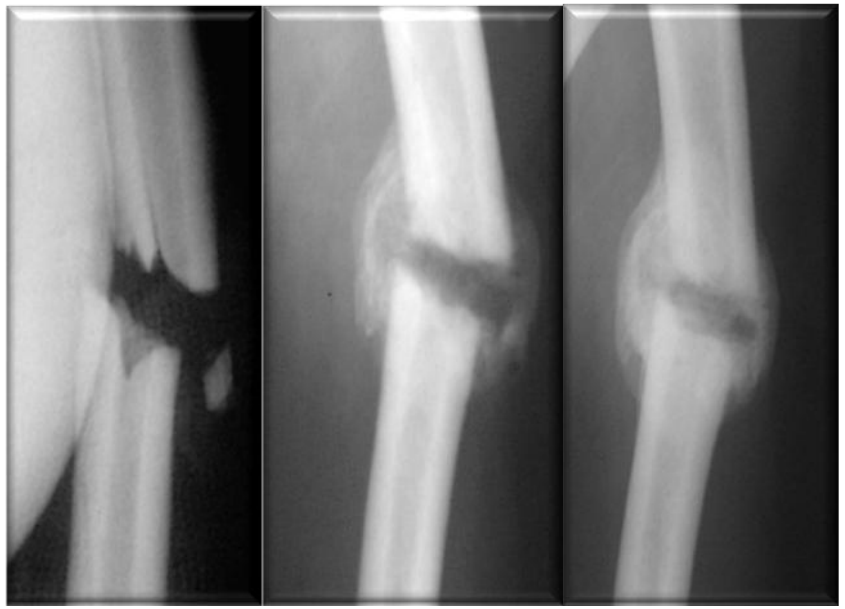
No visible callus formation

Direct healing



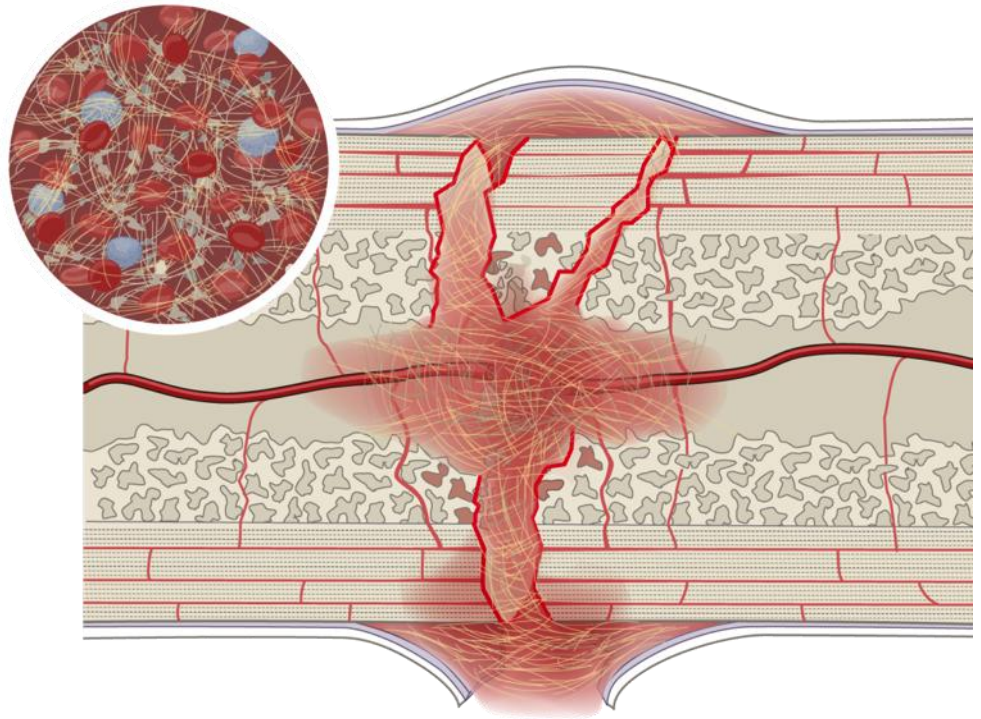
Bone healing—callus

- Left alone, a broken bone will heal by callus formation
- Callus is the natural response of living bone to interfragmentary movement



Indirect bone healing—inflammatory phase

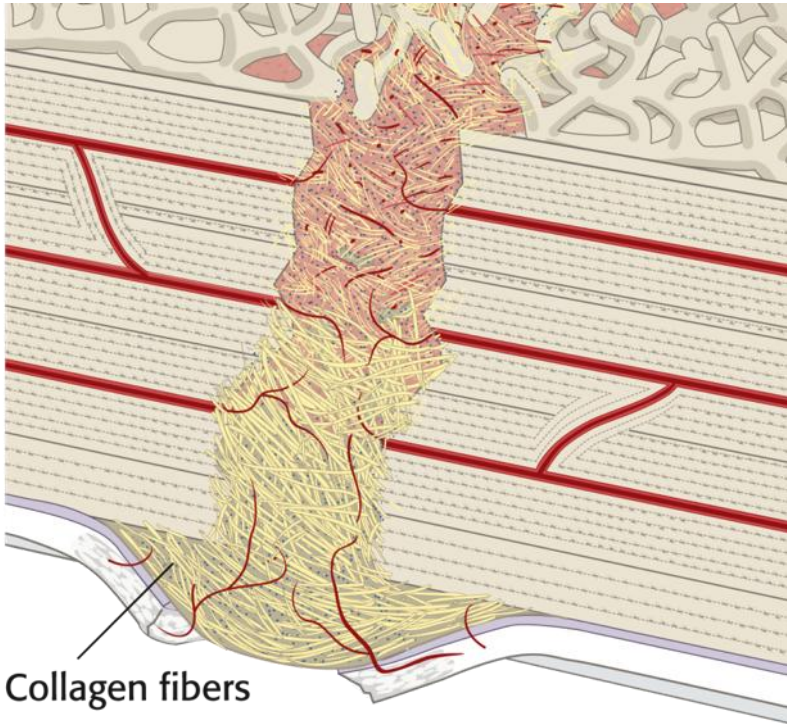
- Coagulation
- Fibrin fibers stabilize the hematoma (hematoma callus)



Indirect bone healing—granulation phase, soft callus

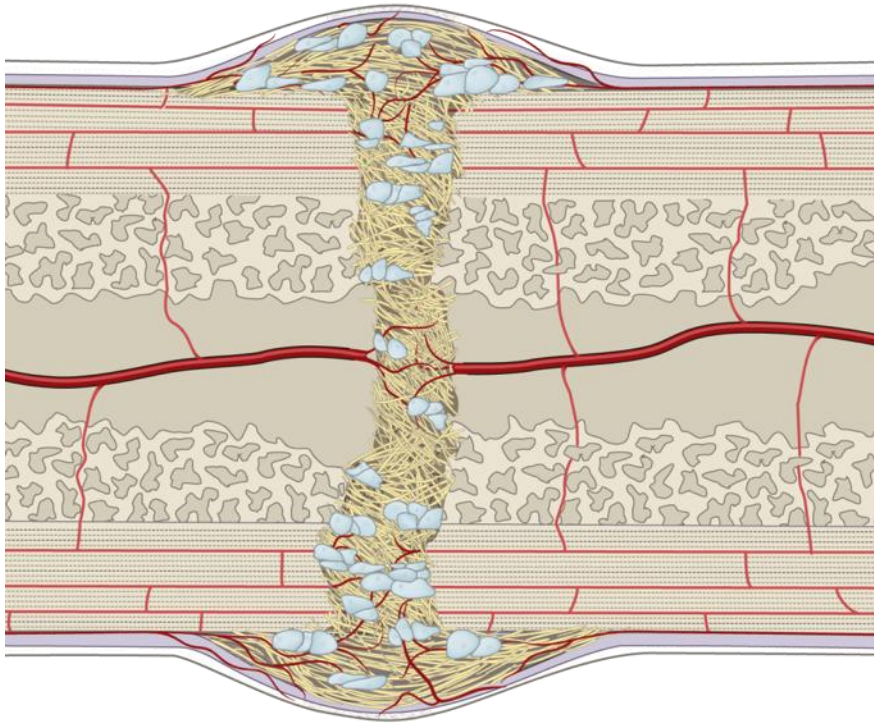
Natural bone healing process begins with soft callus:

- New blood vessels invade the hematoma
- Fibroblasts, derived from the periosteum, colonize the hematoma
- Fibroblasts produce collagen fibers (granulation tissue)
- Collagen fibers loosely link the bone fragments



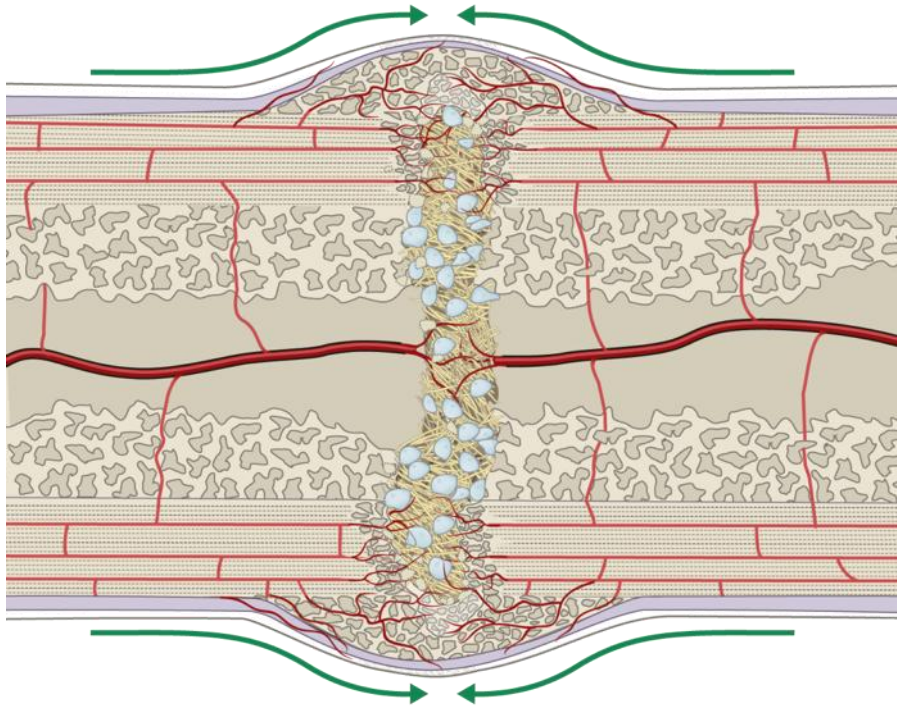
Indirect bone healing—granulation phase, soft callus

- Granulation tissue gradually differentiates into fibrous tissue, and subsequently fibrocartilage



Indirect bone healing—granulation phase, hard callus

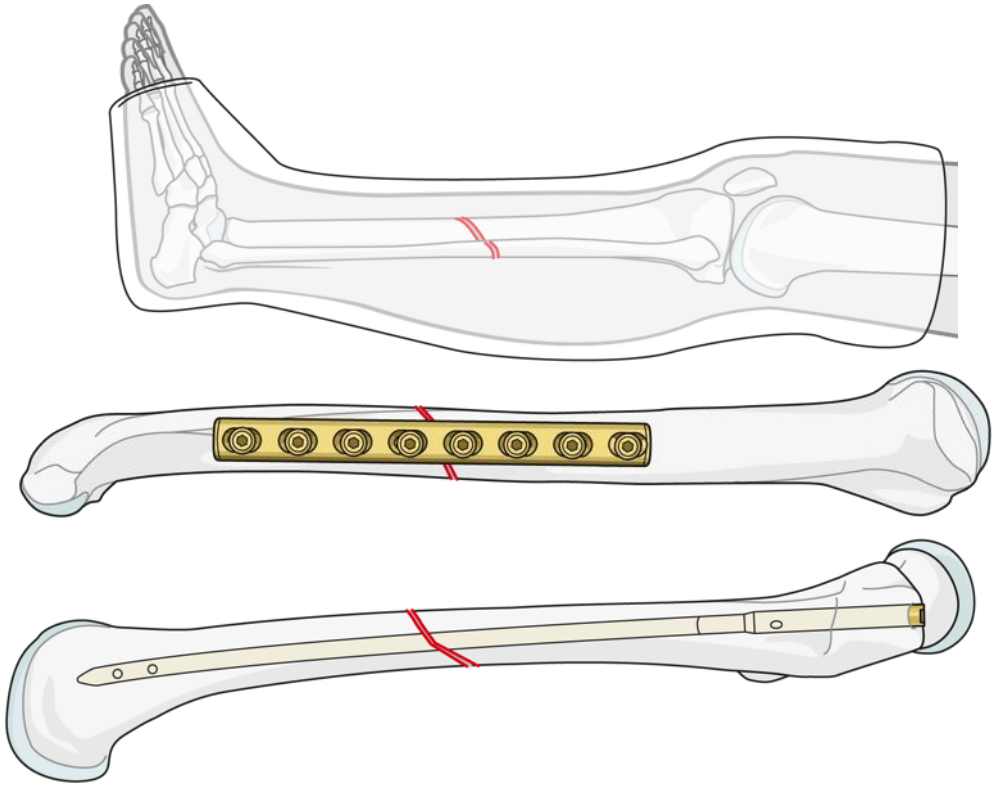
- Hard callus stage starts and lasts until the fragments are firmly united by new bone (3–4 months)
- Endochondral ossification forms spindle-shaped bone cuffs
- Starts at the periphery and moves toward the center, further stiffening the healing tissue



Micromotion—Strain theory

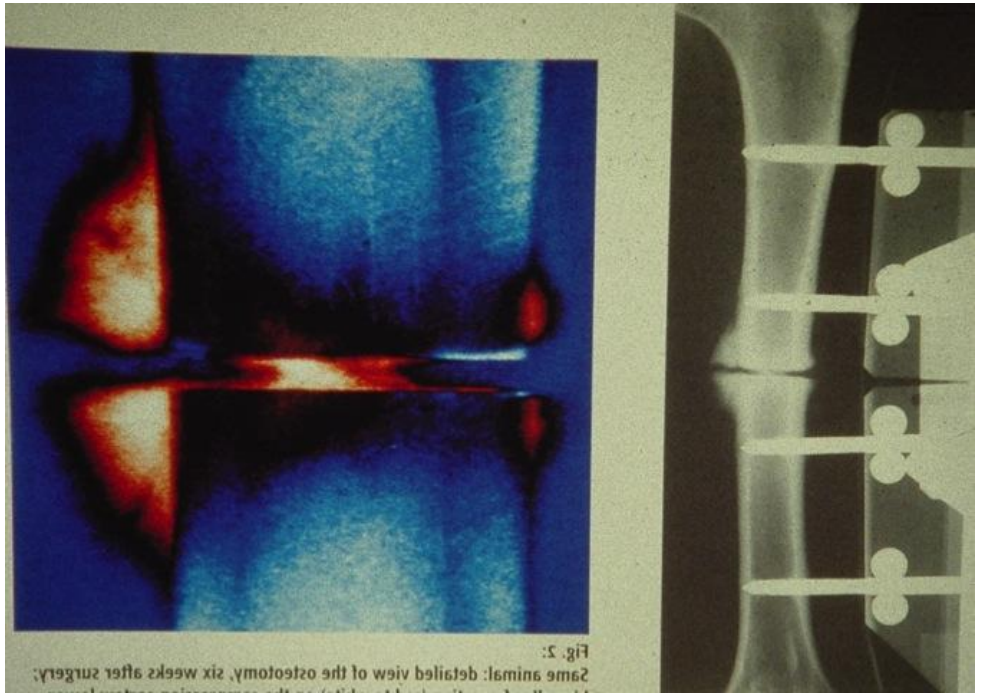
- Load applied to a material produces stress within the material and results in deformation (strain)

- Following a fracture, any motion of one main fragment relative to the other is projected to the fracture zone



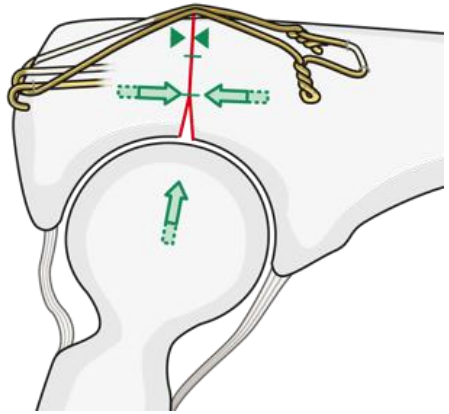
High strain in small gaps

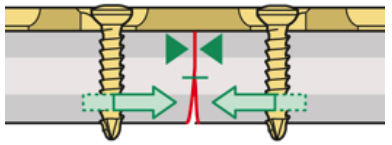
- If only two fragments are involved, the sum of all motion will be projected into the single fracture gap
- Motion amplitudes will limit the capacity of the soft repair tissue (hematoma → collagen → soft callus) to withstand shear and dislocation forces
- If the “strain” on the tissue is too great, tissue integrity is disrupted

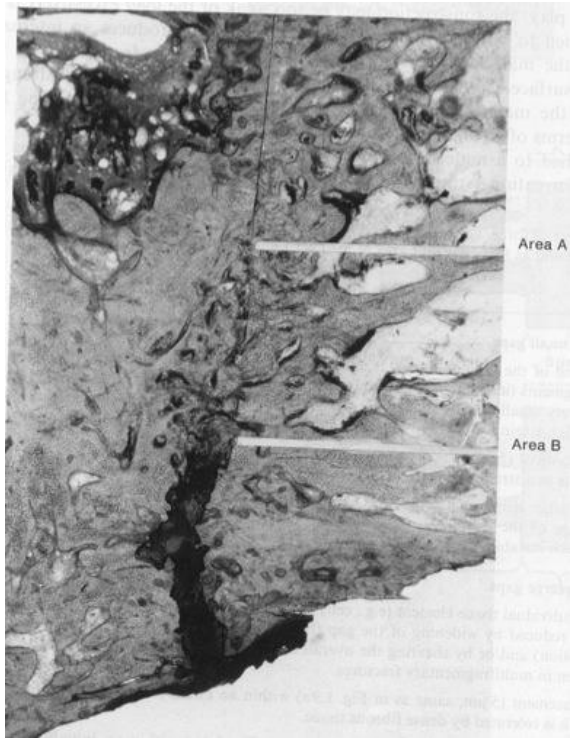


Strain

- Strain itself is considered to be an inductor of callus formation (compare embryologic tissue growth)
- With the formation of tissues of increasing stiffness, the overall stability increases
- Different healing qualities may exist simultaneously

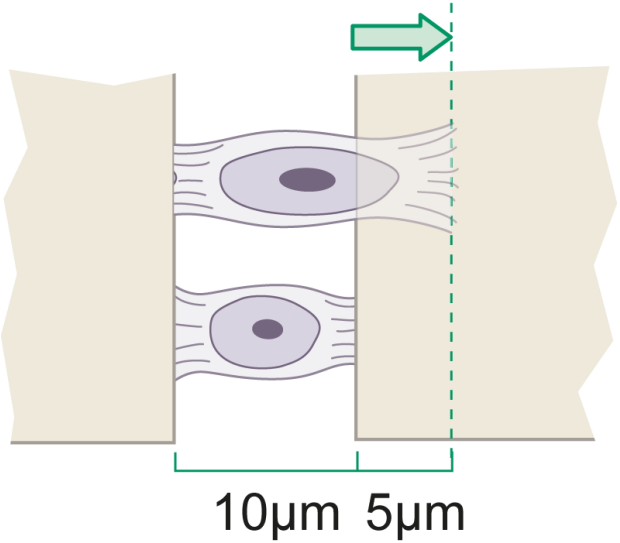




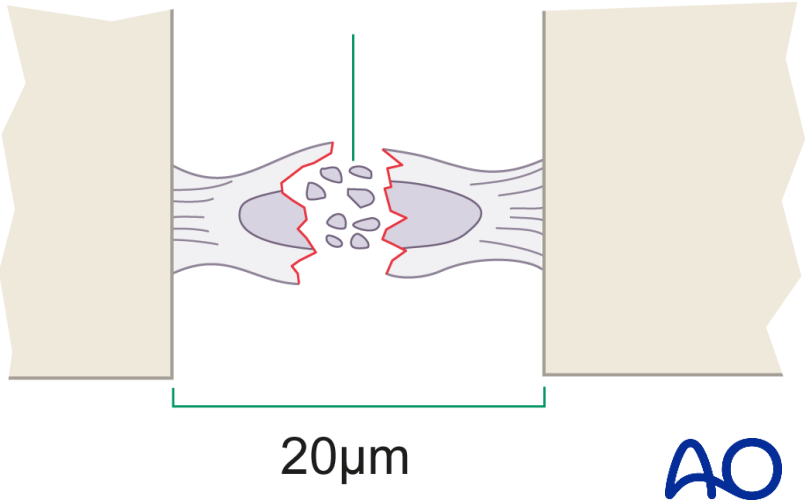


High strain in small gaps

- In a minute gap with only few bridging cells, any micromotion not contained by absolute stability will exceed strain tolerance of the tissues involved and the cell structure is destroyed



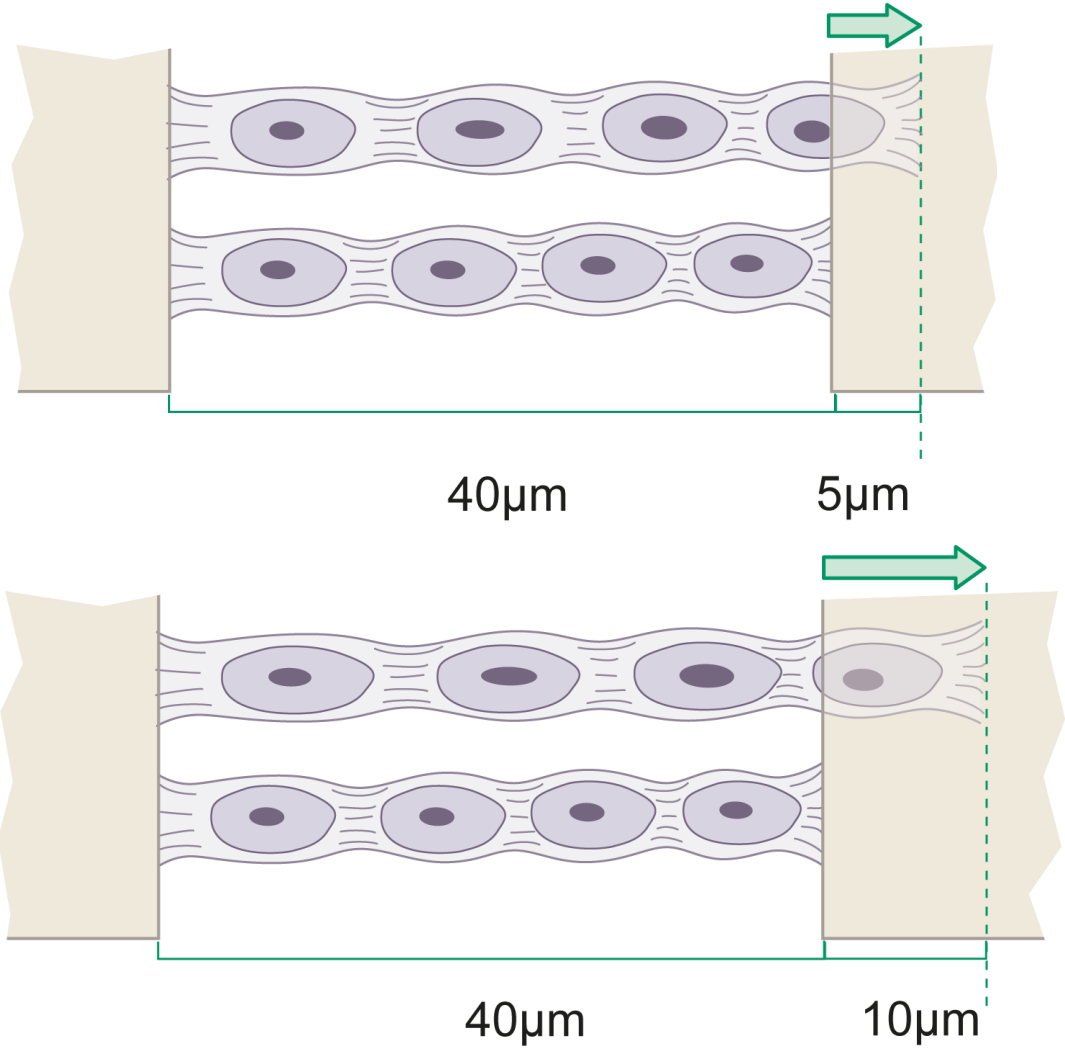
- Tissue specific strain tolerances:
  - Granulation tissue: 100%
  - Lamellar bone: 2%



Low strain in large gaps

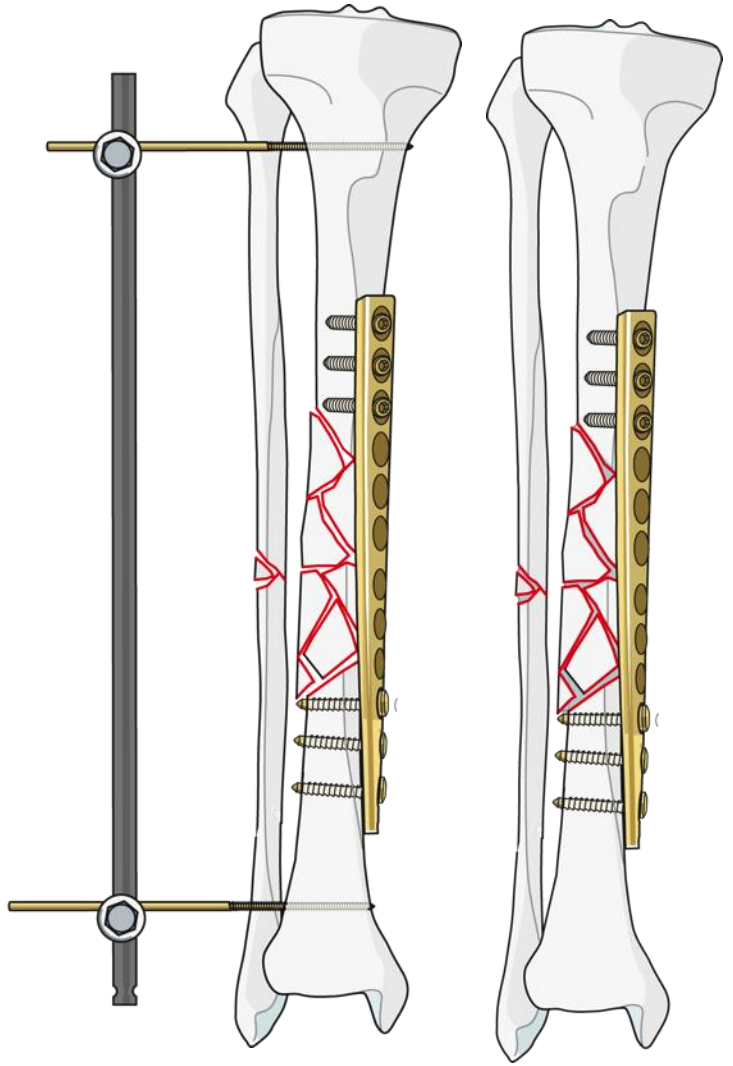
- If the gap is widened (by bone surface resorption), the strain is shared by many more bridging soft-tissue elements and fragment motion does not create an intolerable strain on individual cells

- In larger gaps, **the strain on individual cells is reduced**

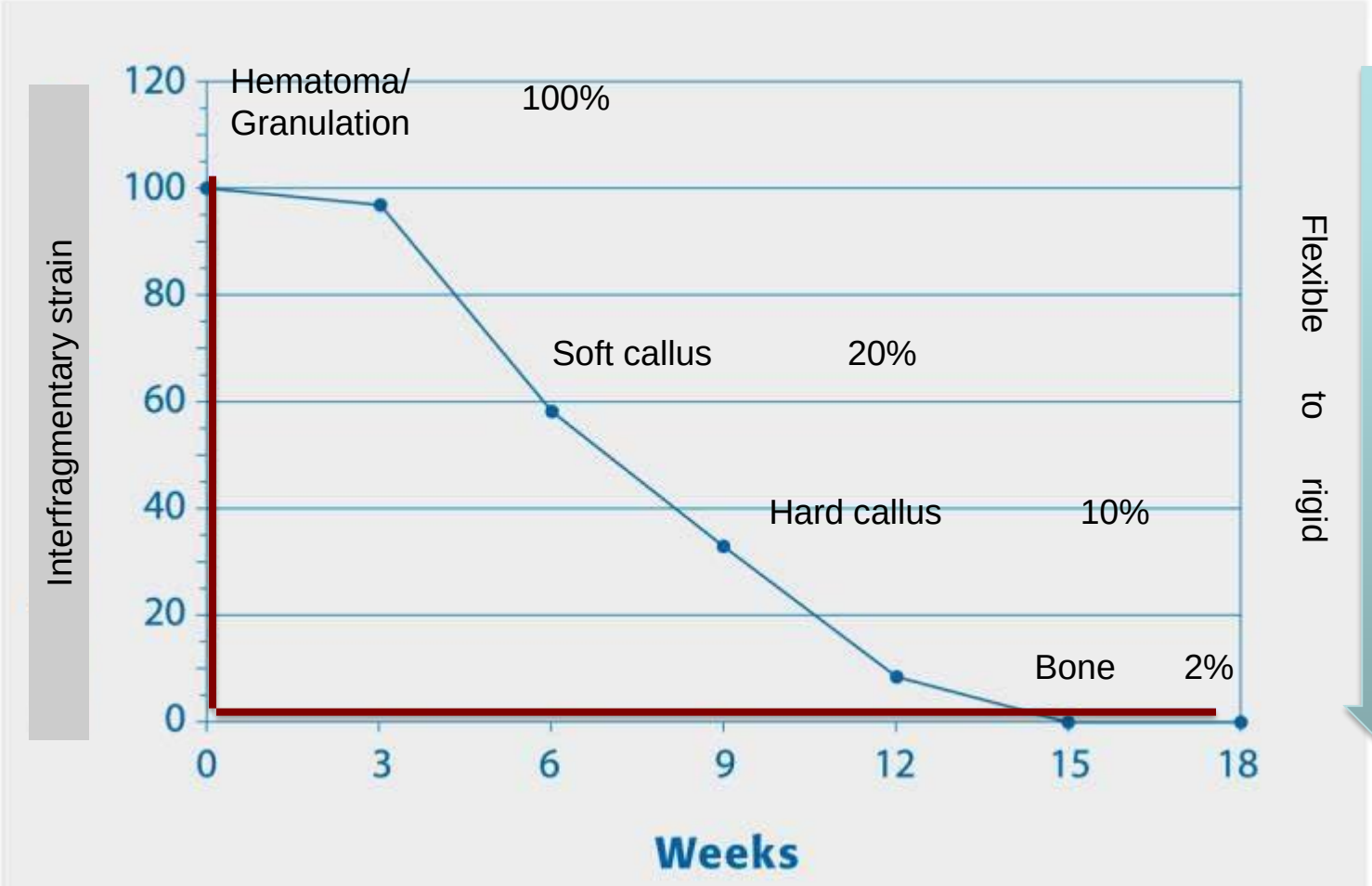


Strain

- This phenomenon explains why strain sharing permits multifragmentary fractures to heal well
- Multiple serial gaps share the overall displacement, and callus induction occurs despite relatively high total motion
- Different strains in different gap sizes also explain why various tissues, ranging from loose connective and fibrocartilage tissue, may exist simultaneously



Mechanobiology of bone healing



Indirect bone healing

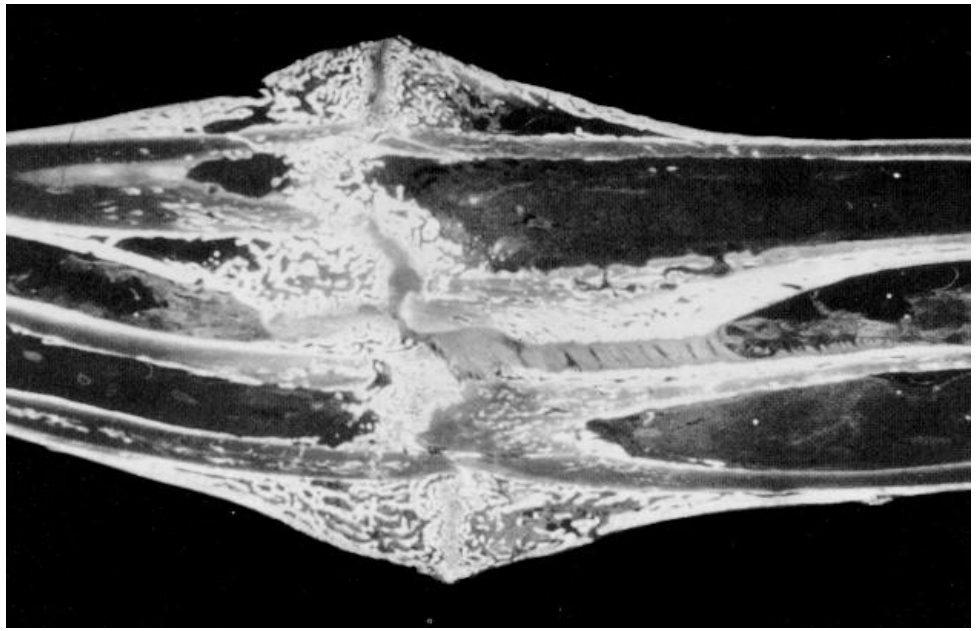
Direct bone healing

Indirect bone healing

Gap > 2 mm

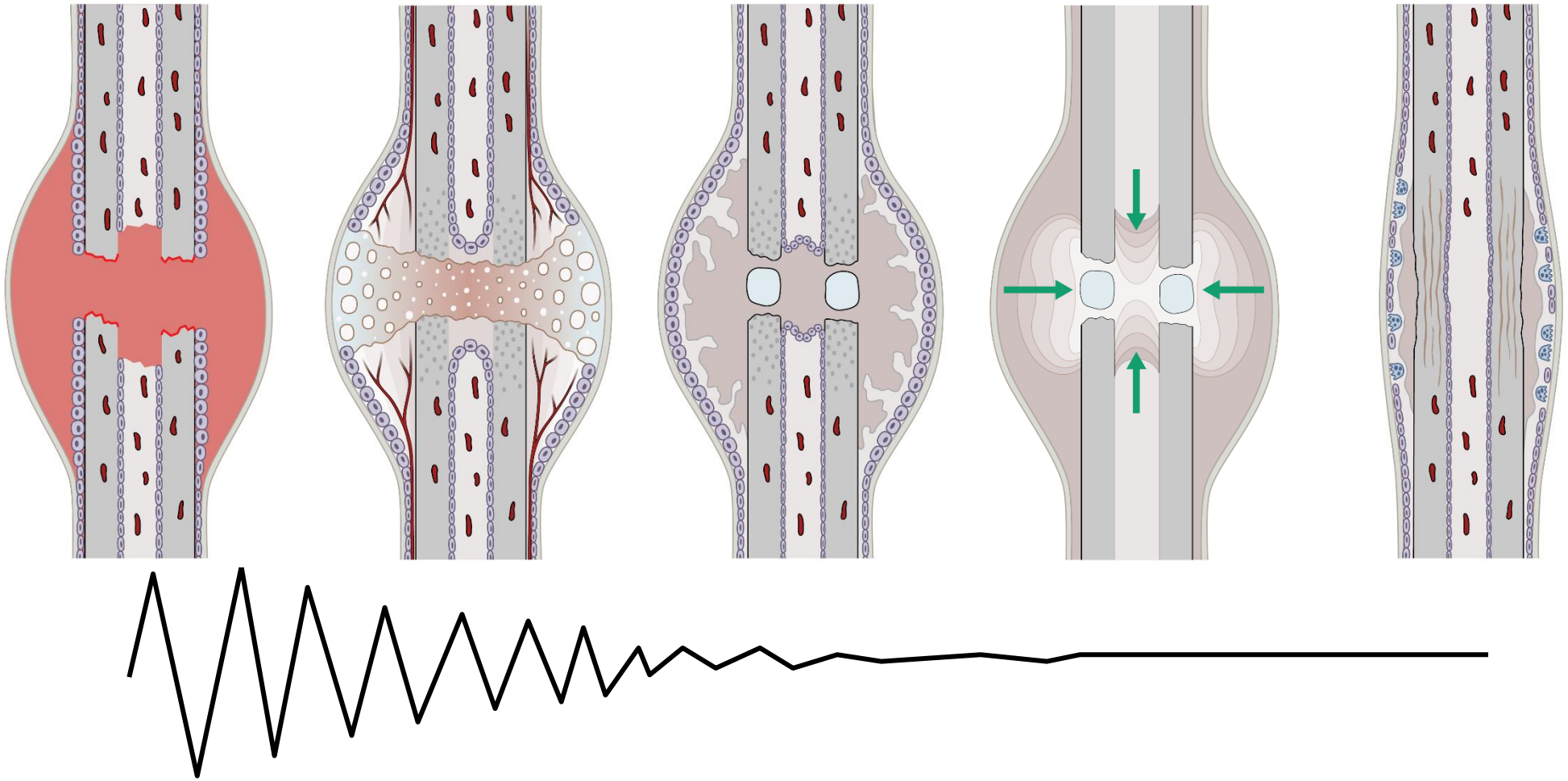
Controlled motion

Living bone



- Granulation tissue
- Ingrowth of vessels
- Fibrocartilage → calcification
- Calcified cartilage → woven bone
- Woven bone → lamellar bone
- Osteonal remodelling

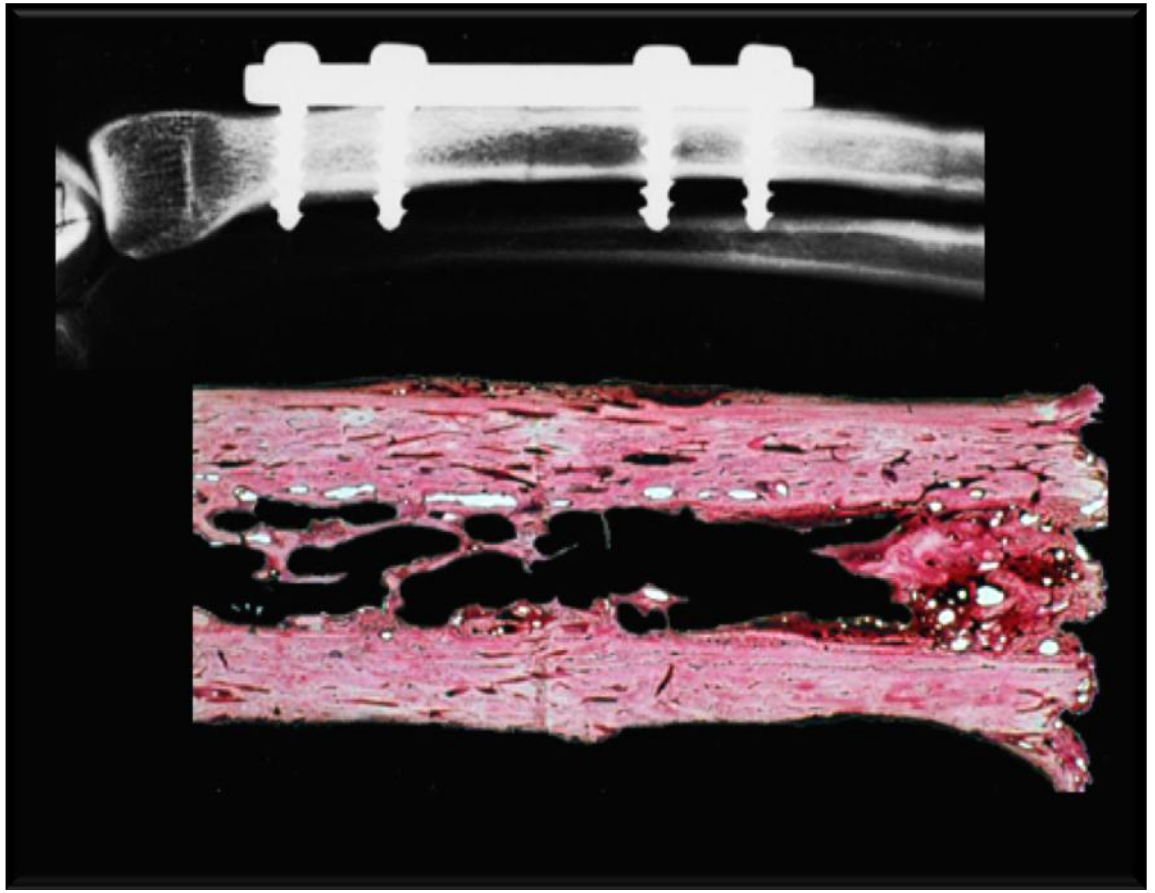
Indirect bone healing—mechanical effect



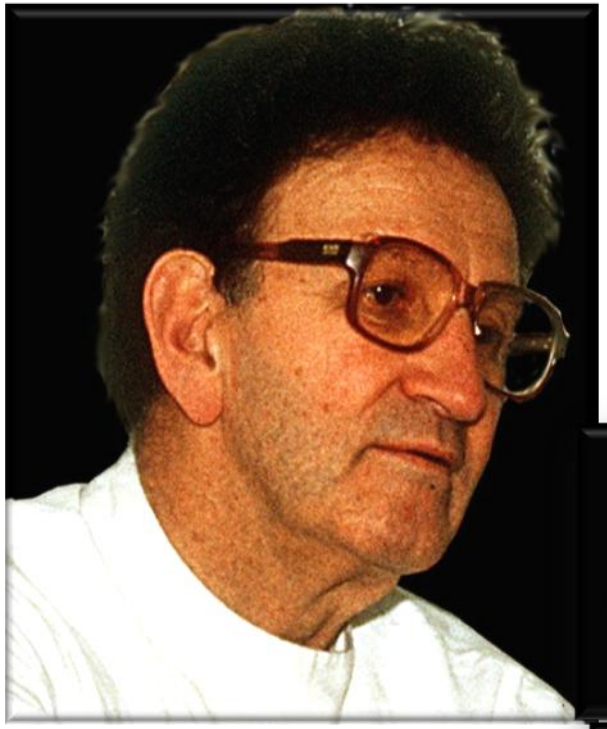
As the callus forms and stiffens, movement is abolished and normal osteonal remodeling can occur

Direct bone healing

- No visible callus formation
- Direct healing

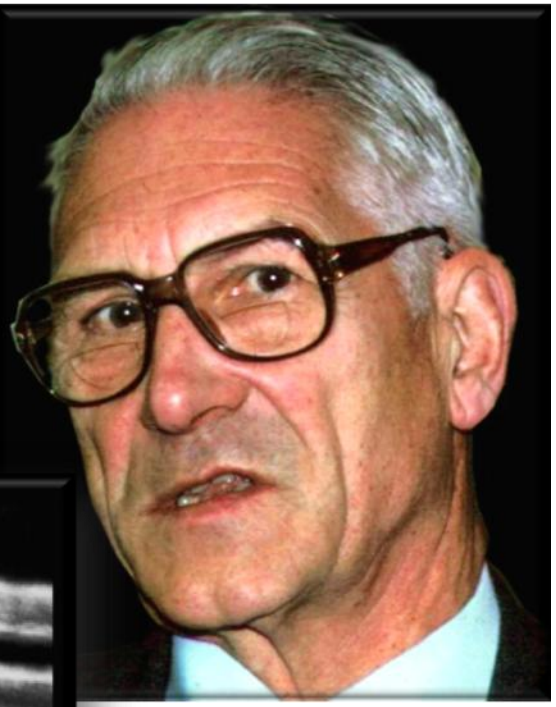


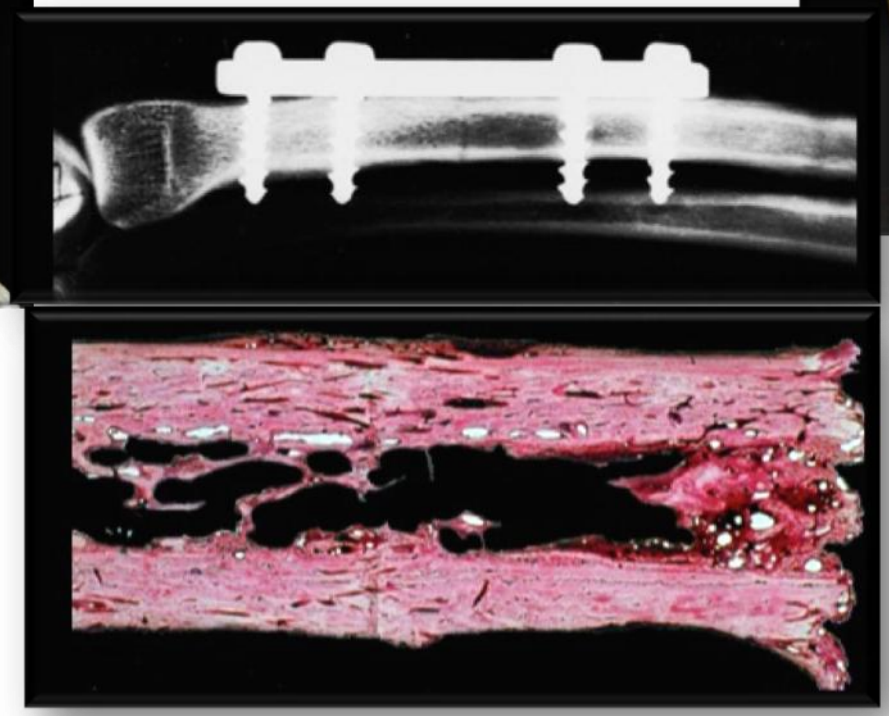
Direct bone healing



Schenk and Willenegger

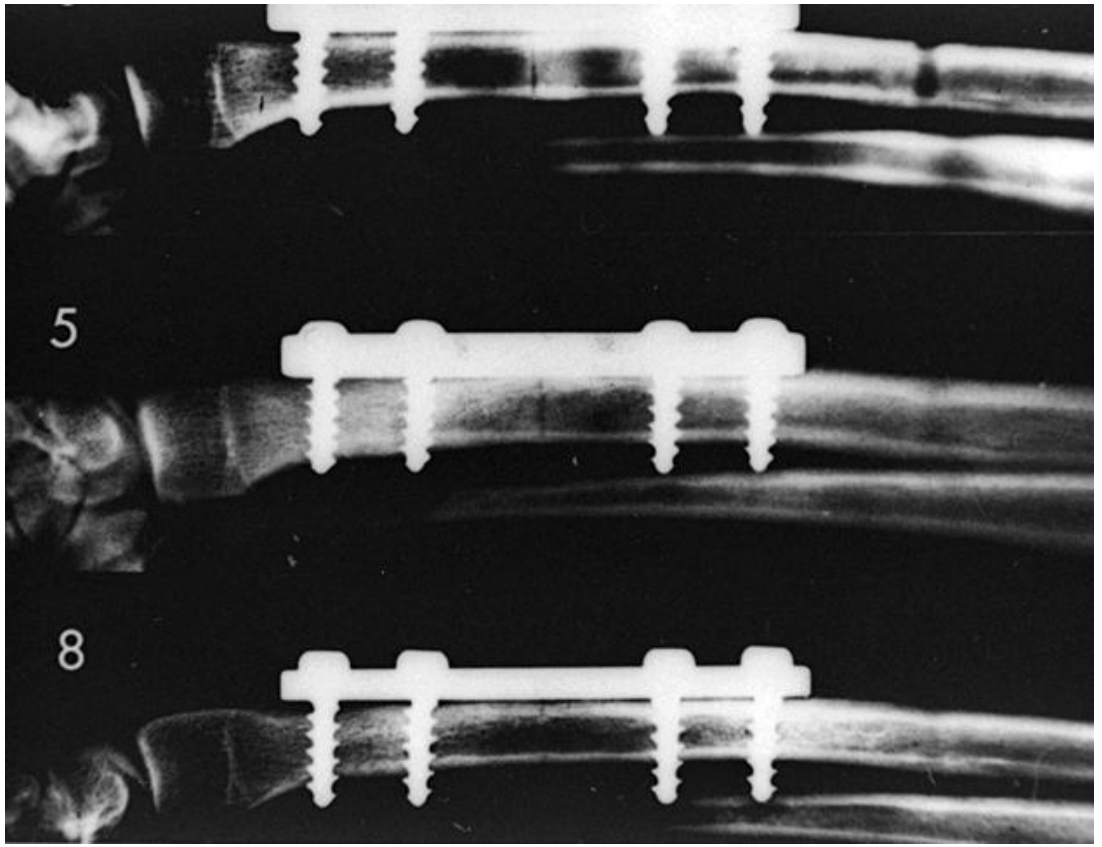
1958





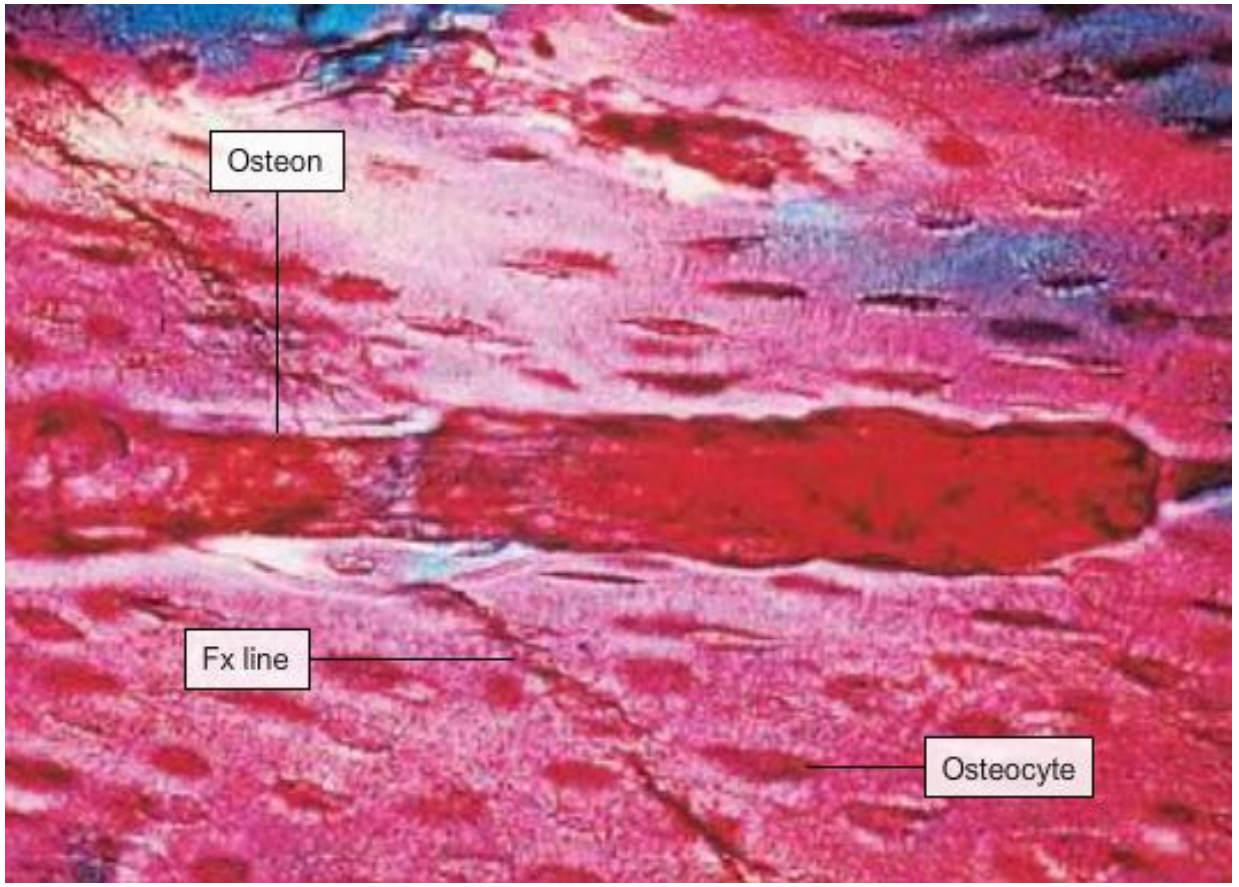
Direct bone healing

- Gap < 2 mm
- No intermediate fibrous tissue
- No movement



Direct bone healing—osteonal remodeling

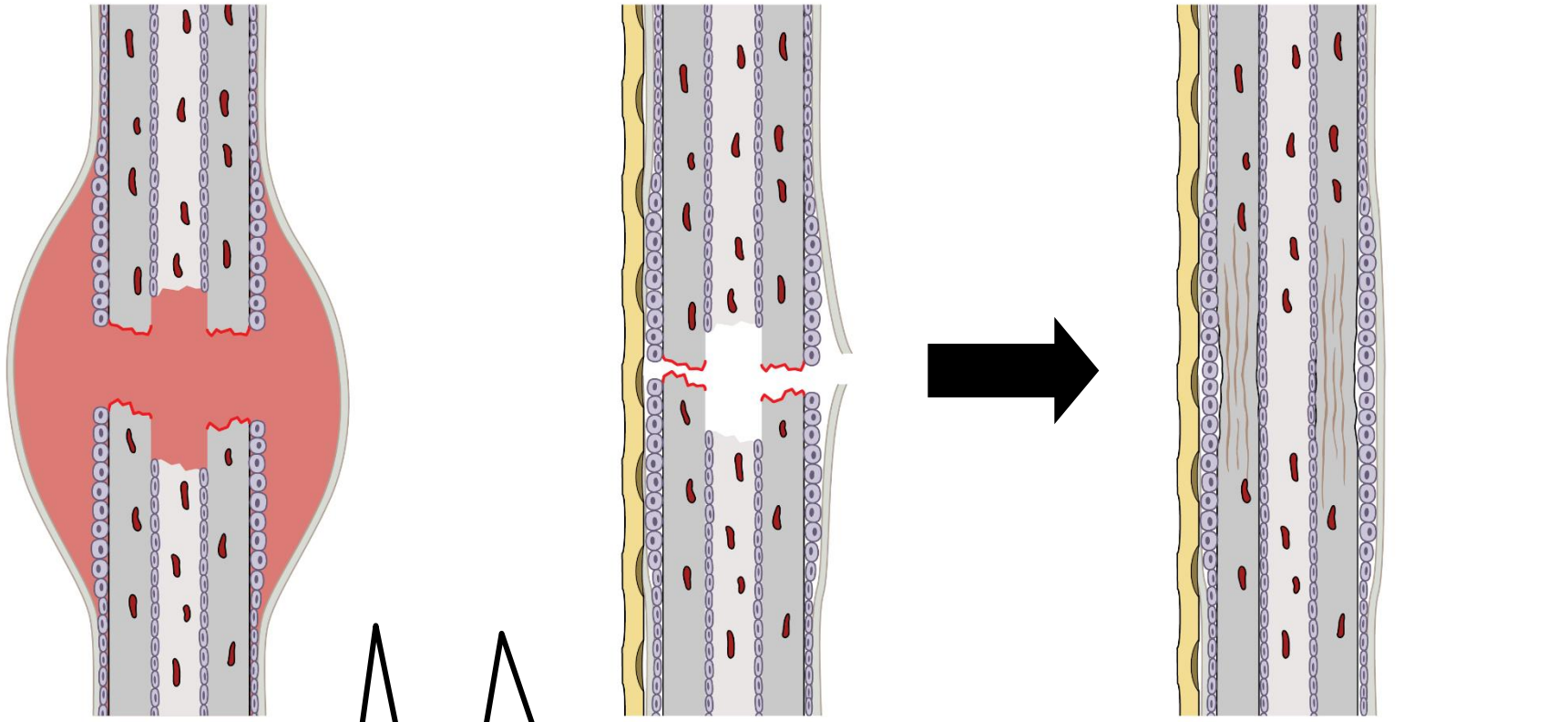
- Osteoclasts cut tunnel into cortical bone
- Behind osteoclasts, osteoblasts lay down concentric lamellae of bone, the osteon
- This process relies on absolute stability



Direct bone healing—mechanical effect of internal fixation

Stable: no gap

Osteonal remodelling



Surgical stabilization abolishes movement, so no callus forms and osteonal remodeling proceeds immediately

FRACTURE NON-UNION

- Definition
- Clinical Vs radiological union
- Delayed union

Definition

- FDA : fracture that is at least 9 months old and hasn’t shown any progressive signs of healing for 3 consecutive months

Clincal Vs radiological union

- Clinical union : no tenderness , no abnormal motion and no pain on loading
- Radiological union : bridging of bone seen in 3 out of 4 cortices
- Delayed union : fractures that shows some progression but less than anticipated for specific bone .
- Large segmental defects = functional non-unions

- Diamond concept by Giannoids (2007).,,,
- Newmann, Elliot (2016) , theory of bone healing and non union based on biological and mechanical environment and conclude that bone healing units responds to wolff’s law Perren’s strain theory and Frost’s concepts of mechanostat.

Factors affect fracture healing

- 1.Local : soft tissue involvement , bone loss , infection ,comminution ,inadequate stabilization.
- 2.Systemic : DM(decreases cellularity at fx site) , nutrition (vit D ,proteins),smoking (decreases neoangiogenisis ,nicotine increases platelets aggregation , CO displaces O2 from Hb.)
- Urine dipstick Continine testing (salandy et. al. 2016)
- 3. medications : Bisphosphonates , quinolones , steroids and NSAID
- Specific locations : scaphoid ,distal tibia , base of 5^{th} MTB,odontoid

Types

- 1. septic non-union : CRP
- 2. hypertrophic : stability Vs Biology
- 3.atrophic : stability Vs Biology
- 4. oligotrophic : inadequate reduction with fx displacement

Treatment

- Nonoperative(exogen) :

1. LIPUS accelerates healing by stimulating osteoblasts , chondroblasts and blood flow .. 20 min/day
2. Direct current increases OB activity and reduces OC activity by lowering tissue O2 and elevating pH.
3. Capacity coupled electrical fields
4. Pulsed electromagnetic fields
5. Combined magnatic fields

Treatment

- Operartive :
- r/o infection ALWAYS
- If infected : thorough debridement of non viable tissue , bony stabilization , dead space management ,soft tissue care by VAC.
- If atrophic : removal of nonviable ends , fixation +/- graft(autologous ,BMPs,osteoconductive) , maintane good soft tissue
- If hypertophic : increase stanbility , (eg : tibia→ larger nail , dynamization ,?fibula osteotomy)

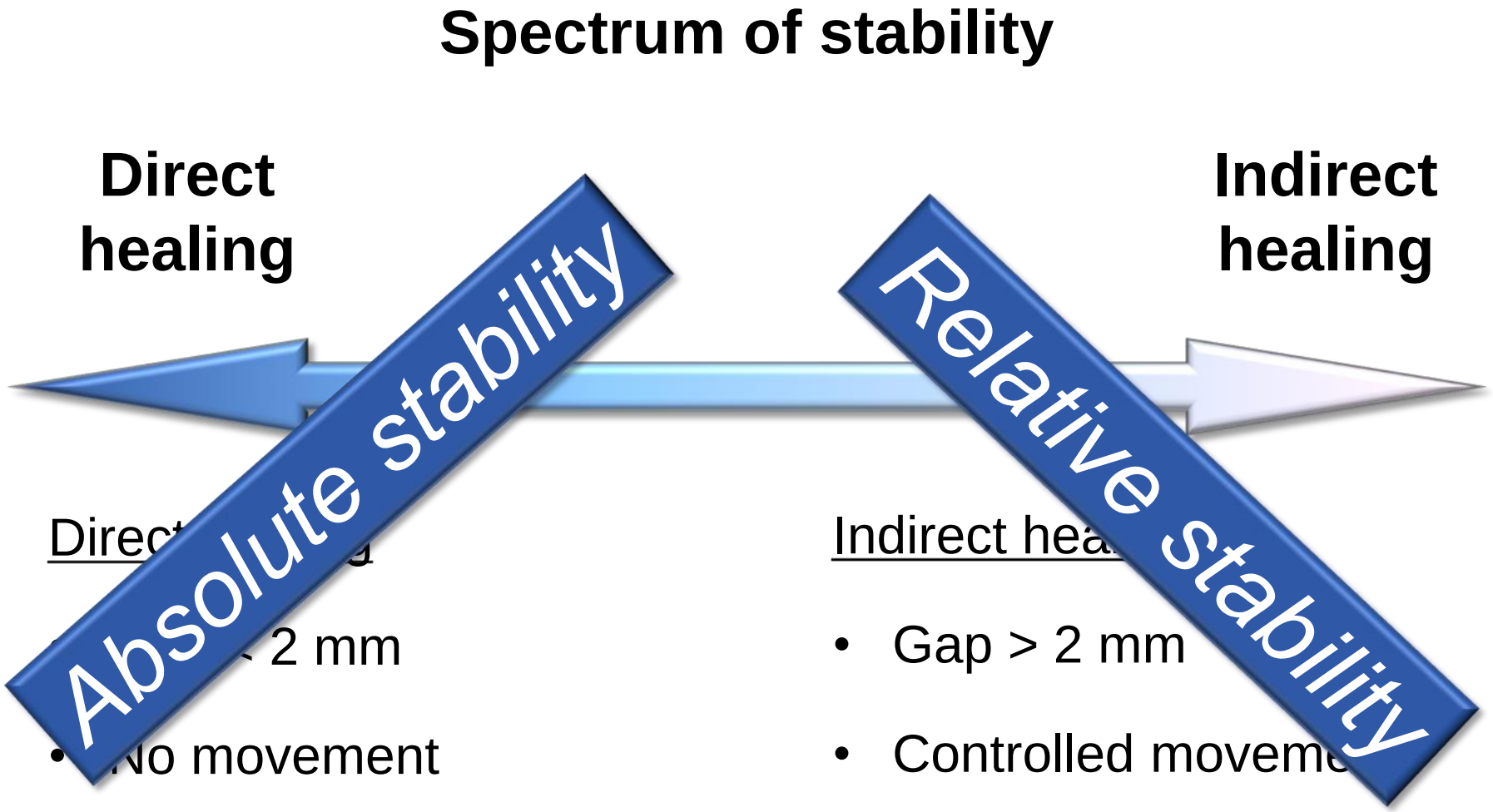
Take-home messages

- Complex structure heals by replication and remodelling
- Bone is programmed to heal:
  - Must be living
  - Controlled movement
- Type of healing varies with mechanical environment

Take-home messages

- Bone healing is a cascade of biological events leading to restoration of the continuity and mechanical properties of the bone
- Healing is dependent on mechanical and biological factors that are closely associated with bone blood supply
- Fracture stability dictates the biologic response:
  - Absolute stability = direct healing
  - Relative stability = callus healing

Take-home messages



Take-home message

- Nonunion has different types according to biology and stability.
- Always rule out infection
- Different methods of treatments depends on types , bone involved and whether infection is a cause.