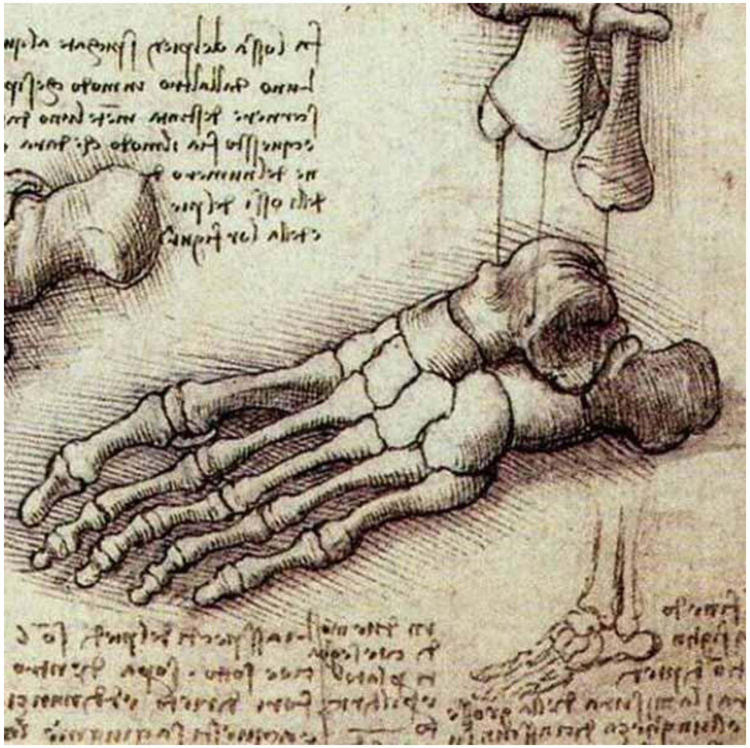
PLEASE CLICK ON THE FOLLOWING LINK TO WATCH THE LECTURE ONLINE:-

https://www.youtube.com/watch?v=V5tRbL-picY&list=PLuBRb5B7fa_cjuGL06zhWXRxCDRoGpJlh&index=3

Ankle and foot biomechanics



The human foot is a masterpiece of engineering and a work of art.

Leonardo Da Vinci

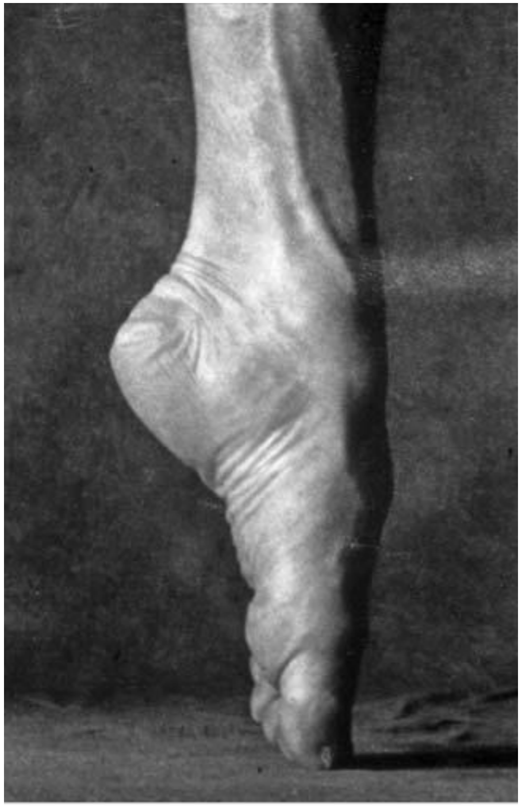
Abdullah Alkhawaldah MD

Trying to understand ……

objectives

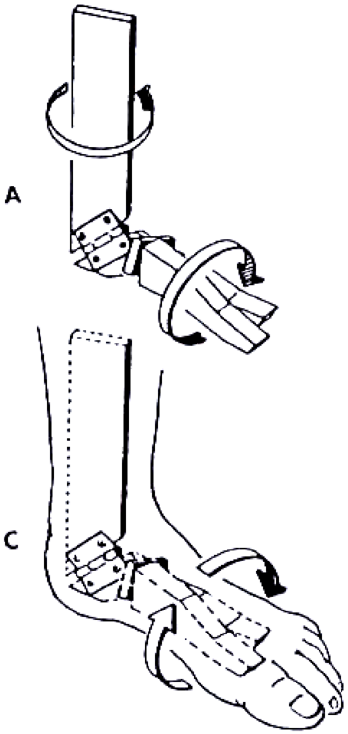
- Review foot normal anatomy and biomechanics.

- Bones , joints , muscles
- Arches
- function



B

Foot function



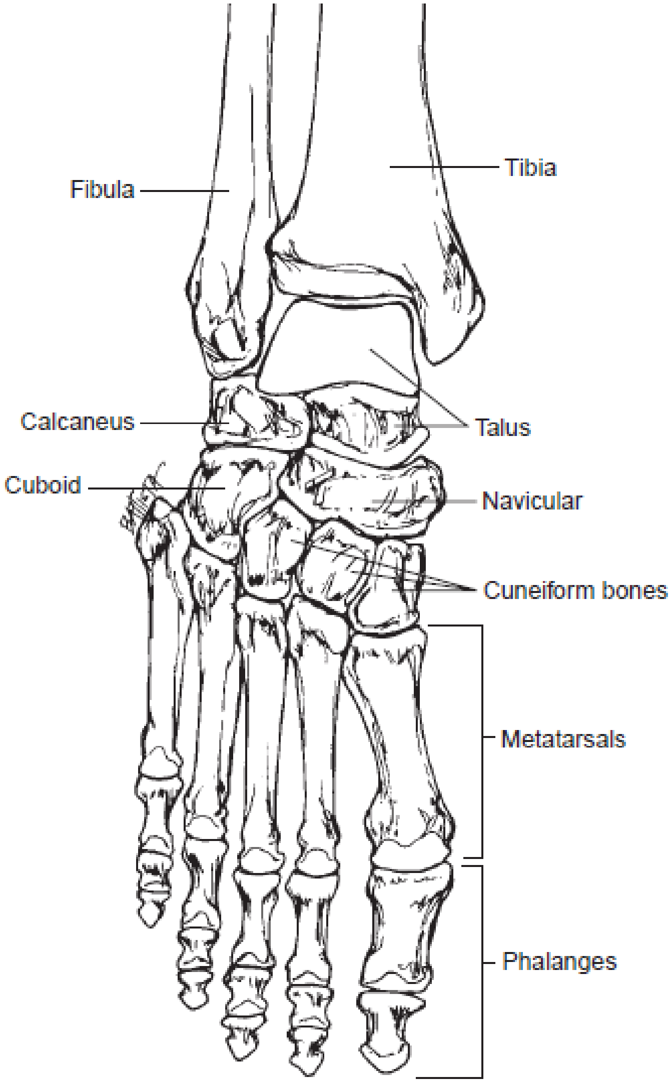
One of the principal functions of the foot is its shock-absorbing capability during heel strike and its adaptation to the uneven surface of the ground during gait. In this function the subtalar joint plays a basic role

A base of support provides a stable platform

A mobile adapter generates propulsion

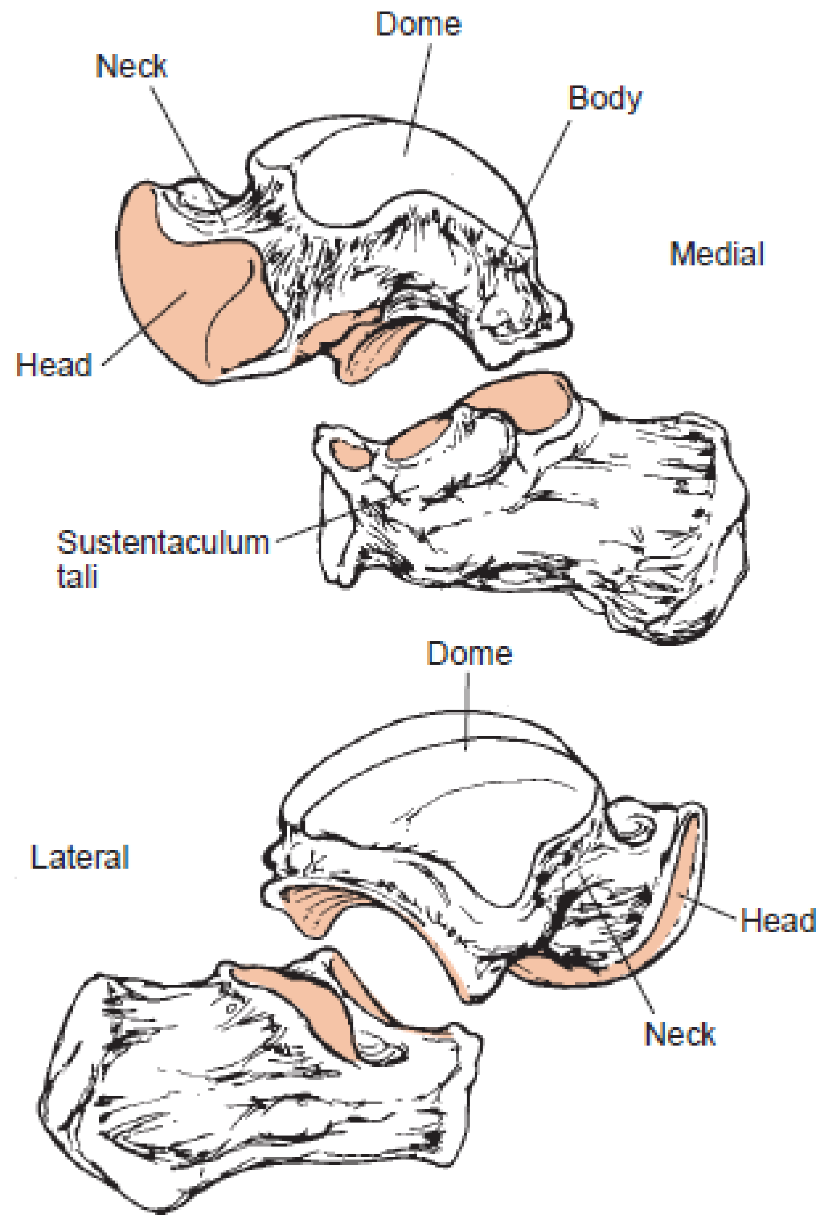
A rigid lever at push-off

Ankle



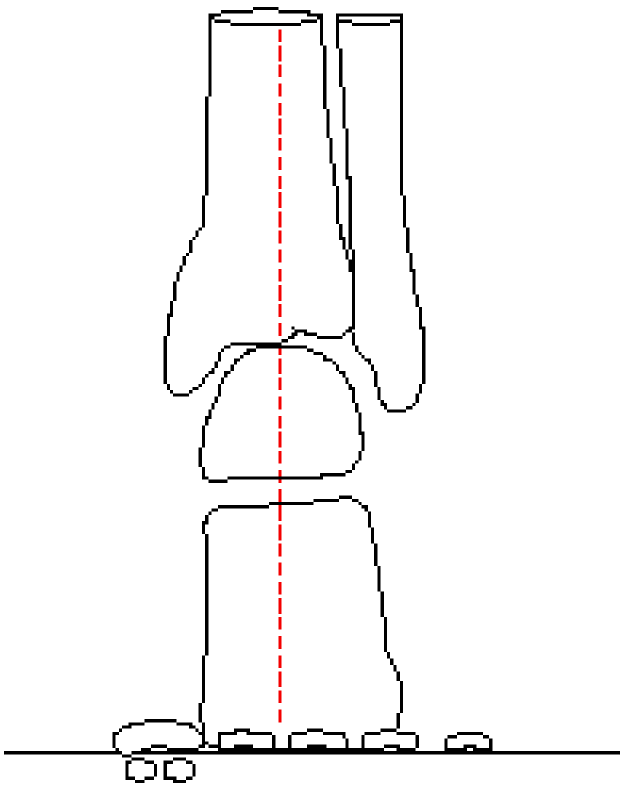
From the ankle joint to the tip of the toes, there are ***28 bones joined by more than 35 joints.***

Hindfoot

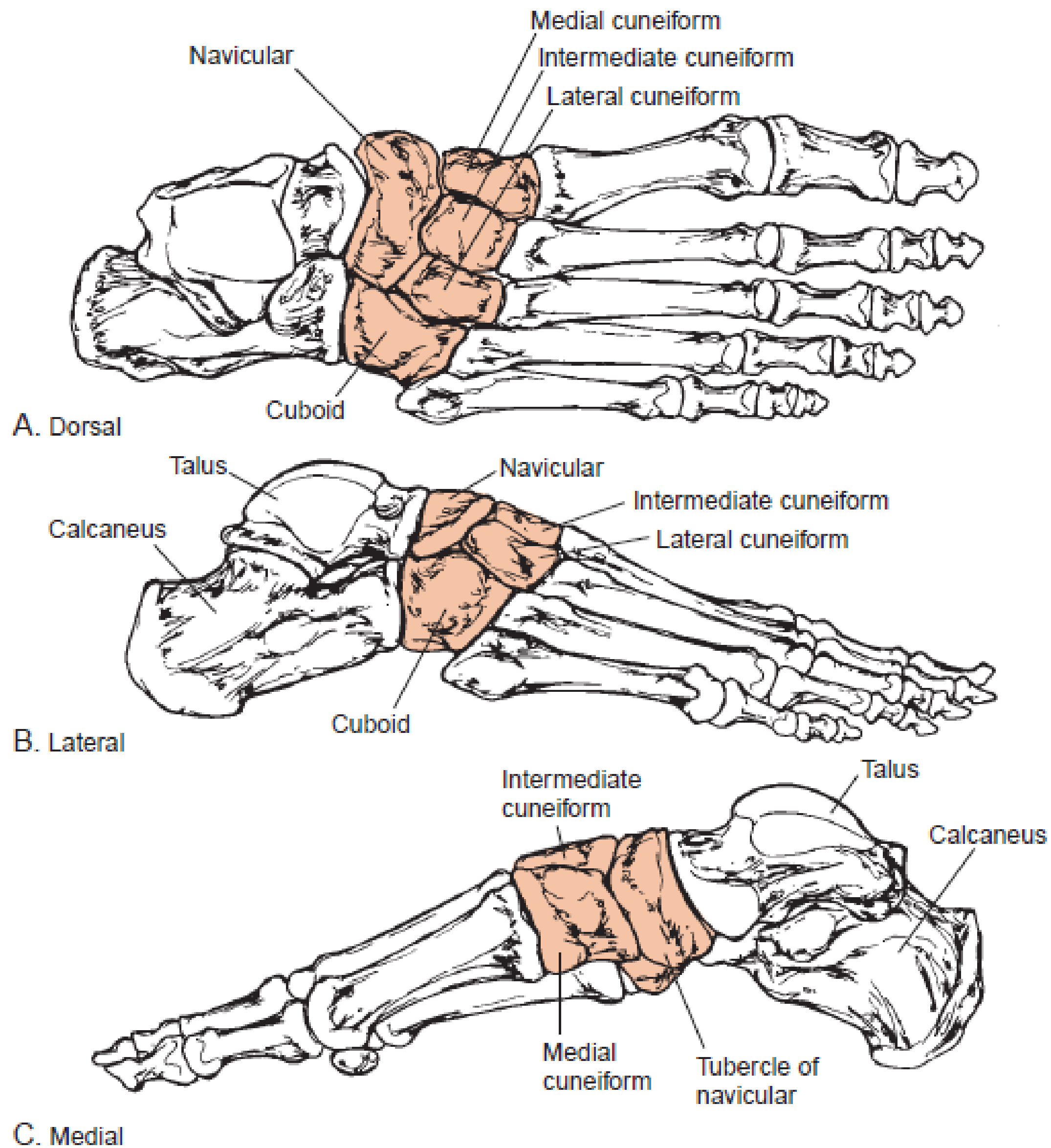


44.5: The talus and calcaneus compose the hindfoot and

Ideal Rearfoot Alignment

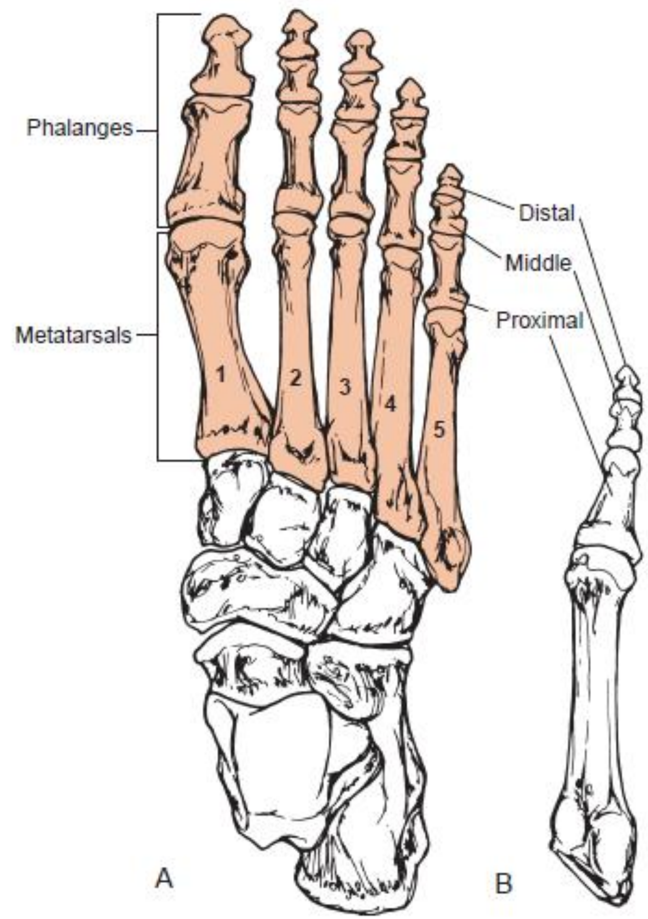


Midfoot

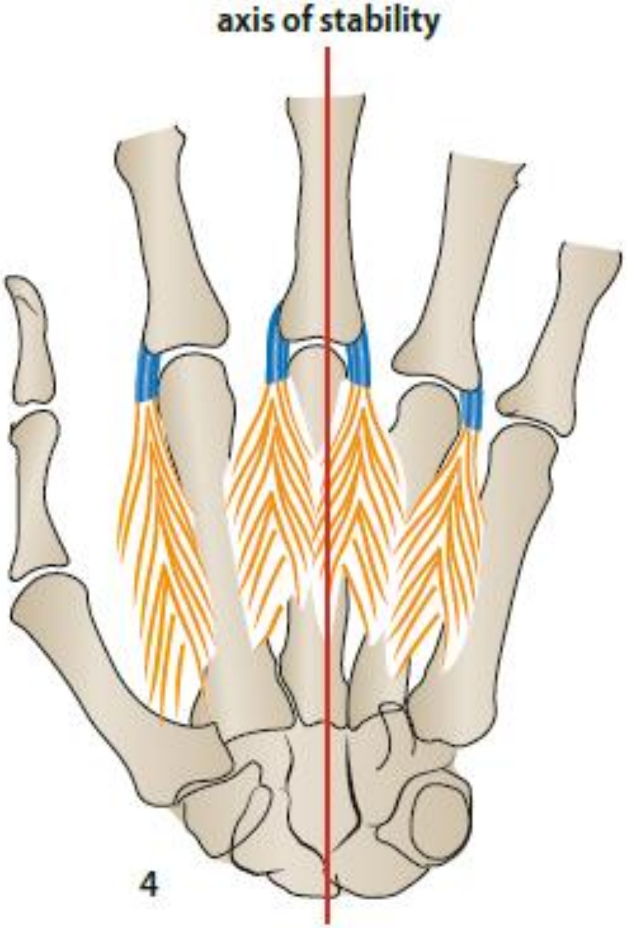

Medial cuneiform
Navicular
Intermediate cuneiform
Lateral cuneiform
A. Dorsal
Cuboid
Talus
Navicular
Intermediate cuneiform
Calcaneus
Lateral cuneiform
B. Lateral
Cuboid
Intermediate cuneiform
Talus
Calcaneus
Medial cuneiform
Tubercle of navicular
C. Medial

Forefoot

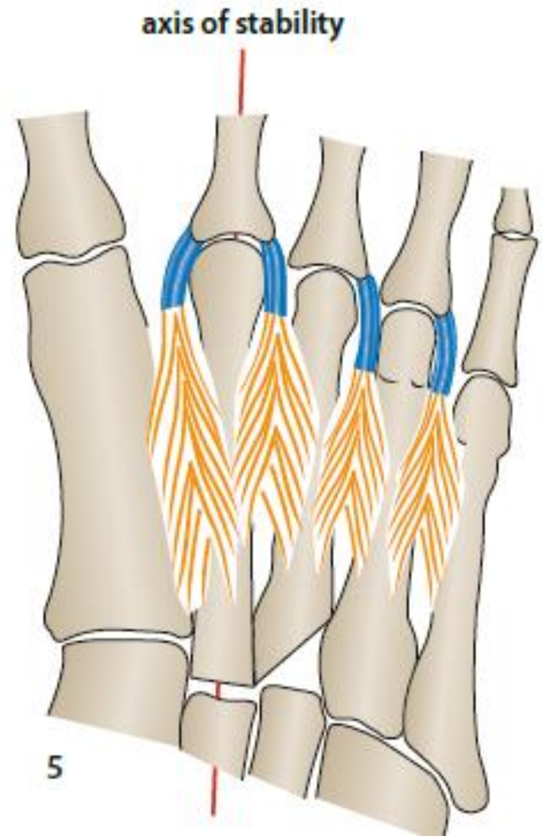
- includes all structures distal to the TMT joints
- **First metatarsal** is the widest and shortest and bears 50% of the weight during gait.
- **Second metatarsal** is usually the longest and experiences more stress than the other lesser metatarsals.
- **Second metatarsal** is more commonly involved in stress fractures.



“navicular” and the “cuboid” forefoot.



4



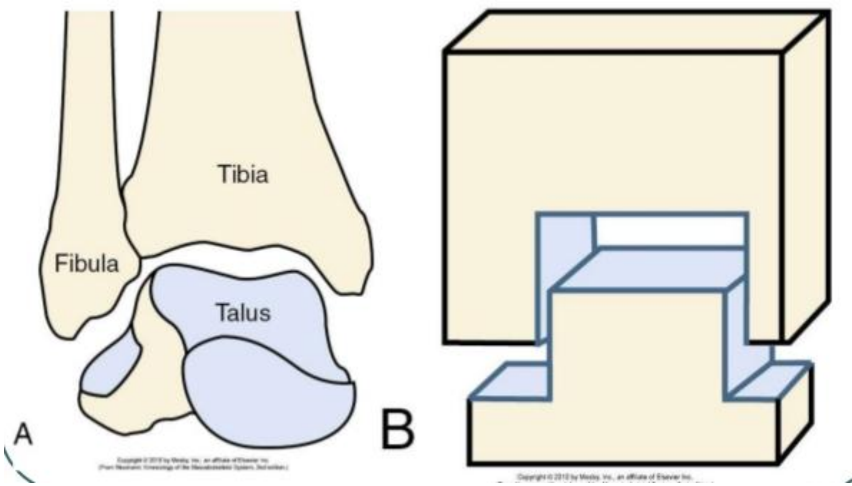
5

During evolution, the ***central axis of the foot shifted from the third ray (hand)*** axis of stability ***to the second ray (foot).***

Ankle mortise

- formed by tibial plafond, medial malleolus, and lateral malleolus Talocrural joint
- widens and ankle becomes more stable in dorsiflexion
- Mortise widens 1 to 1.5 mm during motion from plantar flexion to dorsiflexion

a synovial Hinge joint

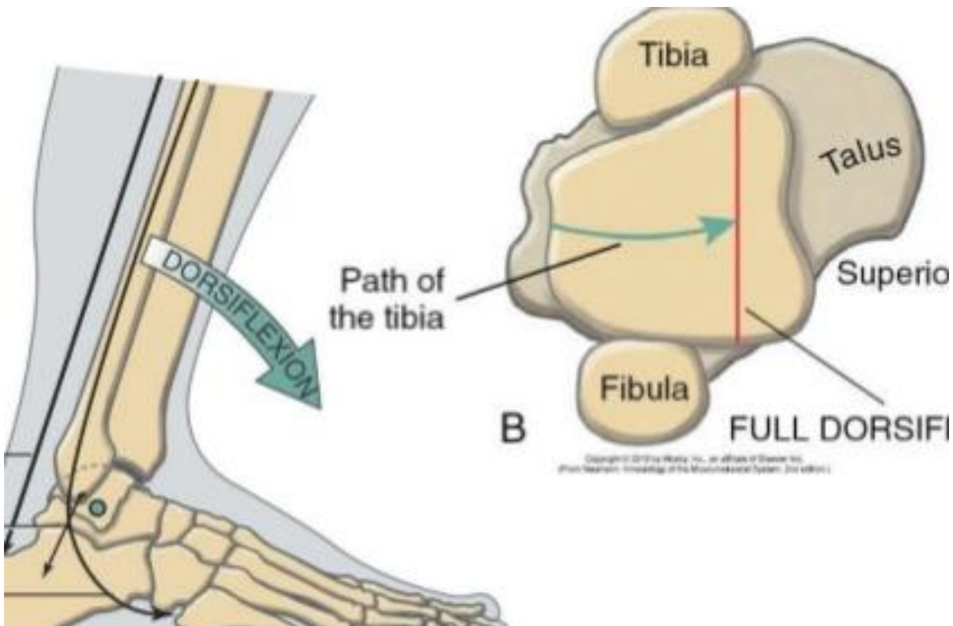


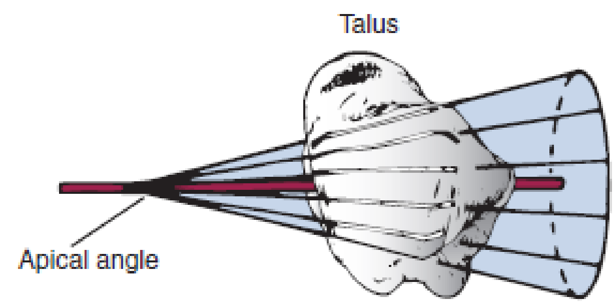
Talocrural joint /ligments

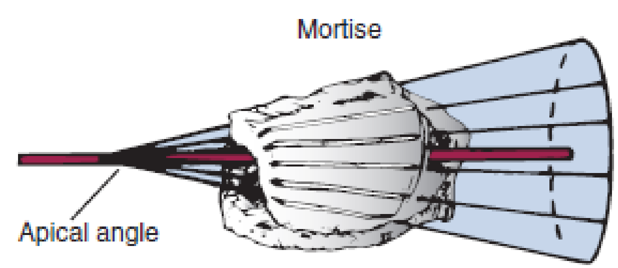
The trochlea is wider anteriorly than posteriorly

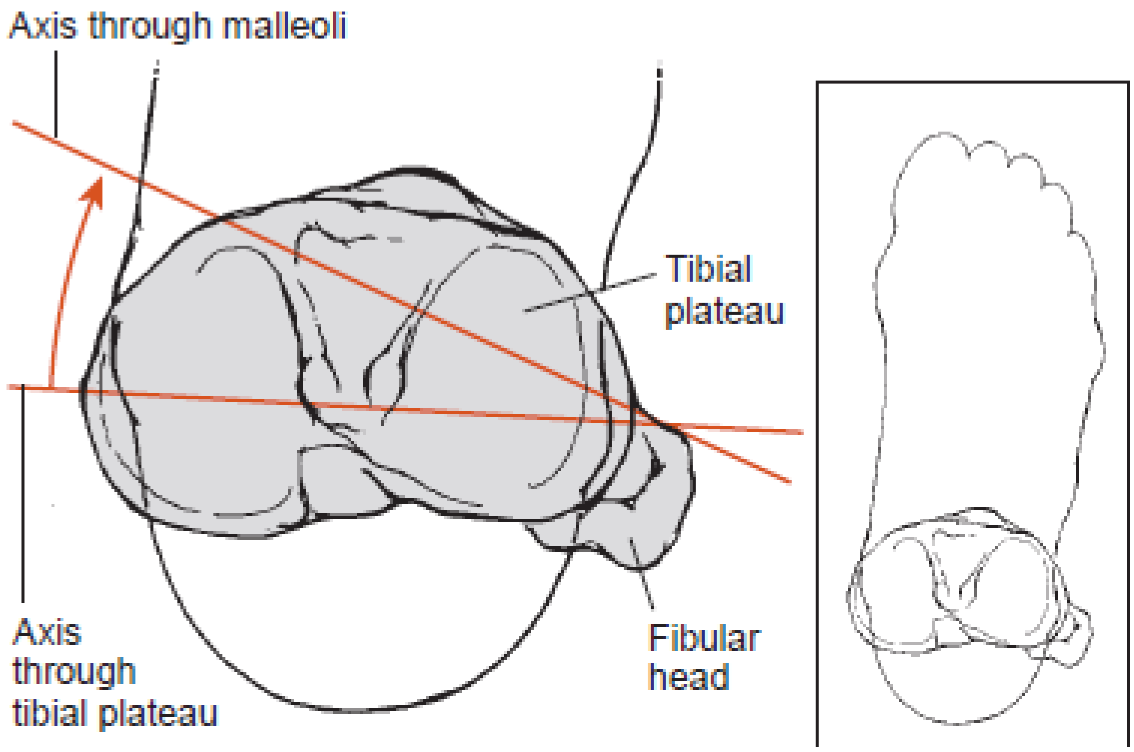
The lateral (fibular) facet is substantially larger than the medial (tibial) facet and its surface is oriented slightly obliquely to that of medial facet.

- This resembles a truncated cone.
- This causes greater displacement of fibular malleolus on lateral facet of talus than the tibial on medial facet



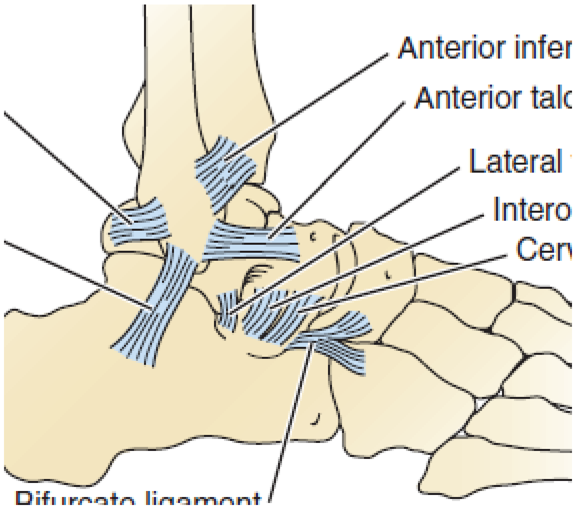






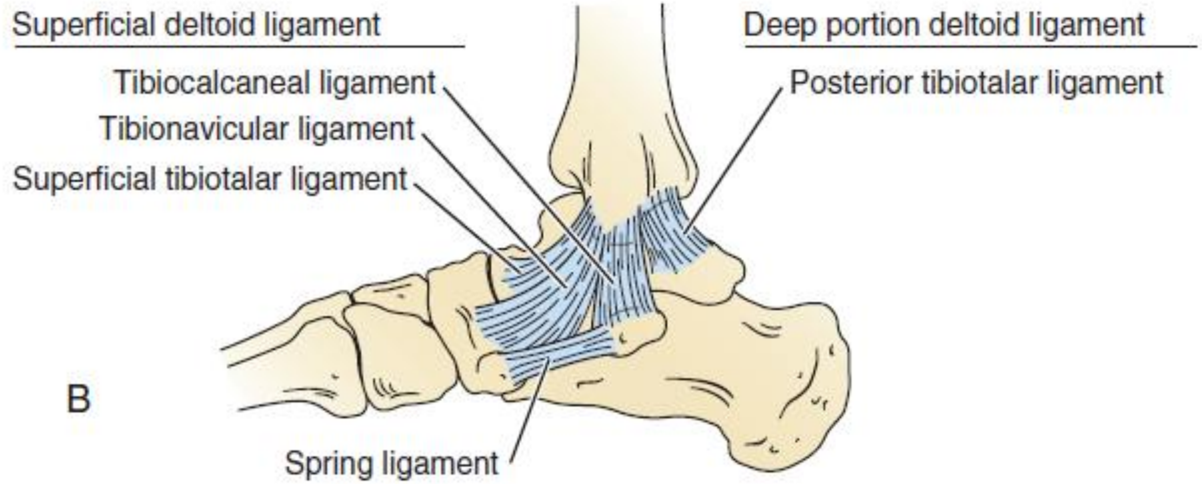
Average tibial torsion in adults without pathology,
indicated by an angle between a line through the tibial plateaus and the medial and lateral malleoli, ranges from 20 to 40° of lateral torsion.

ATFL is the weakest ankle ligament; PTFL is the strongest



Deep deltoid ligament extends from apex of medial malleolus to medial talar body and functions primarily to resist lateral talar translation.

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).



Deltoid ligament complex

- **MAIN ankle stabilizer during stance**

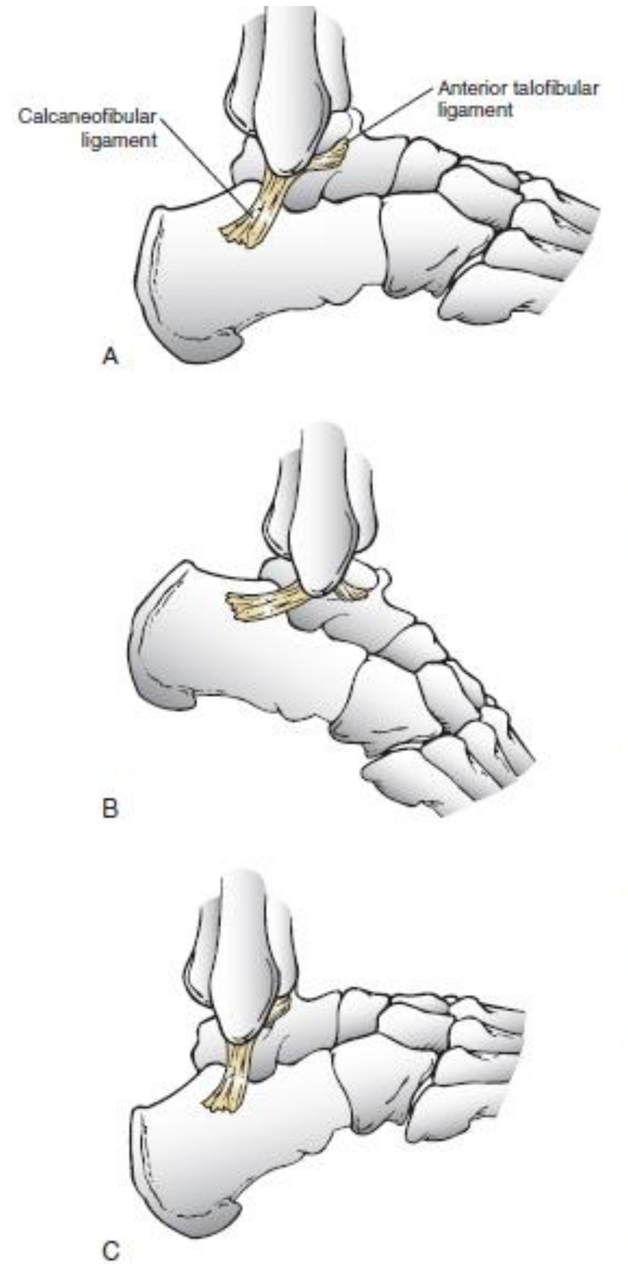
1-Deep deltoid ligament :

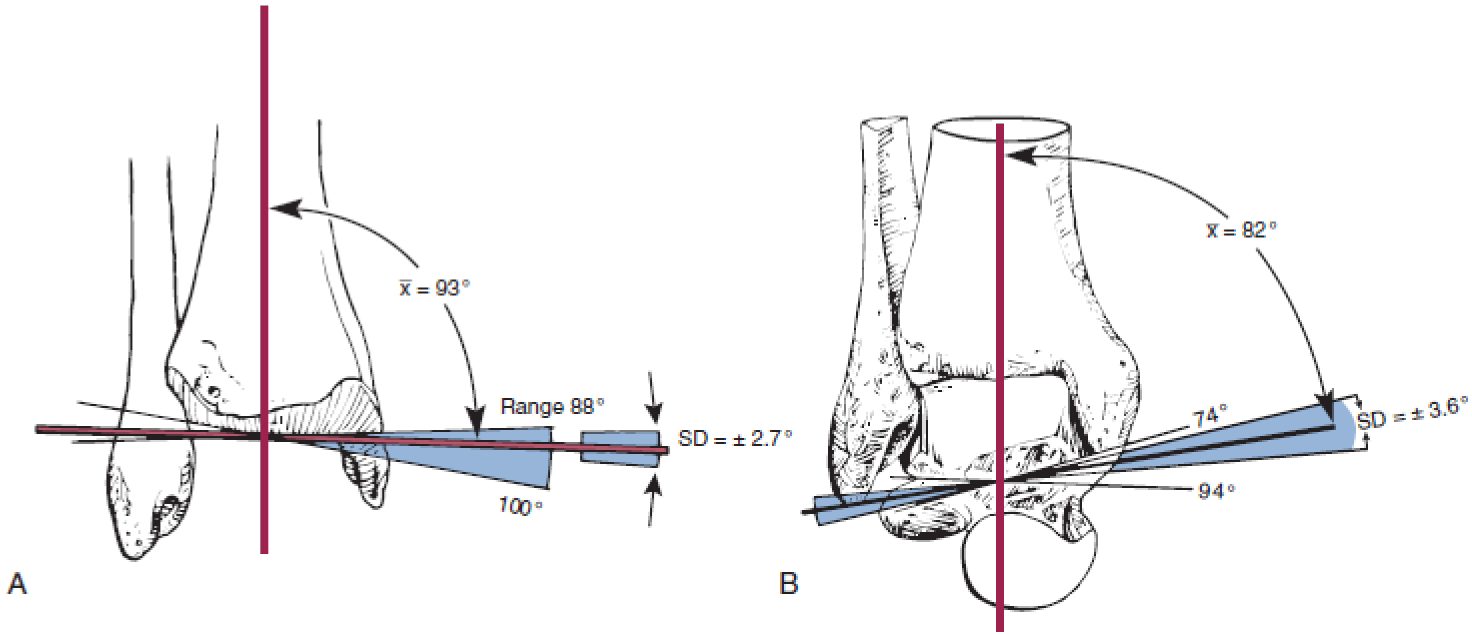
resist lateral talar translation.

2- Superficial deltoid ligament:

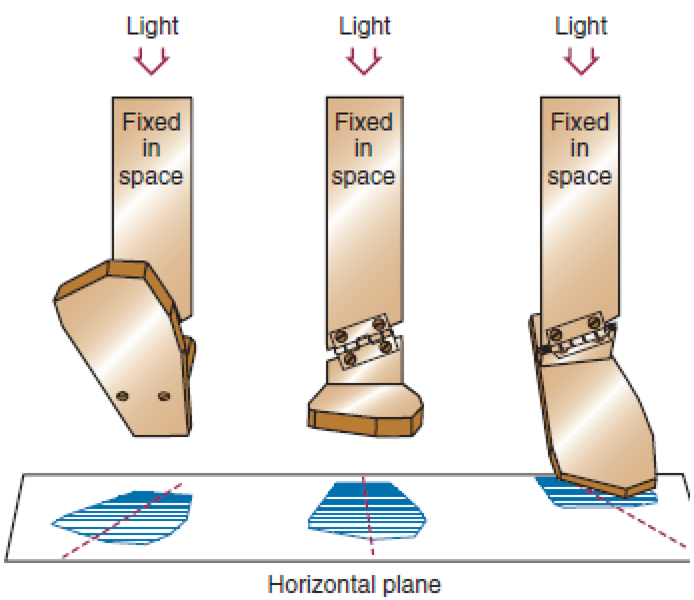
resist valgus/eversion ankle forces (i.e., talar tilt).

Calcaneal fibular ligament and anterior talofibular ligament.
A, In neutral position of ankle joint, both anterior talofibular and calcaneofibular ligaments
provide support to joint.
B, In plantar flexion, anterior talofibular ligament is in line with fibula and provides most of support to lateral aspect of ankle joint.
C, In dorsiflexion, calcaneofibular ligament is in line with the fibula and provides support to the lateral aspect of ankle joint.

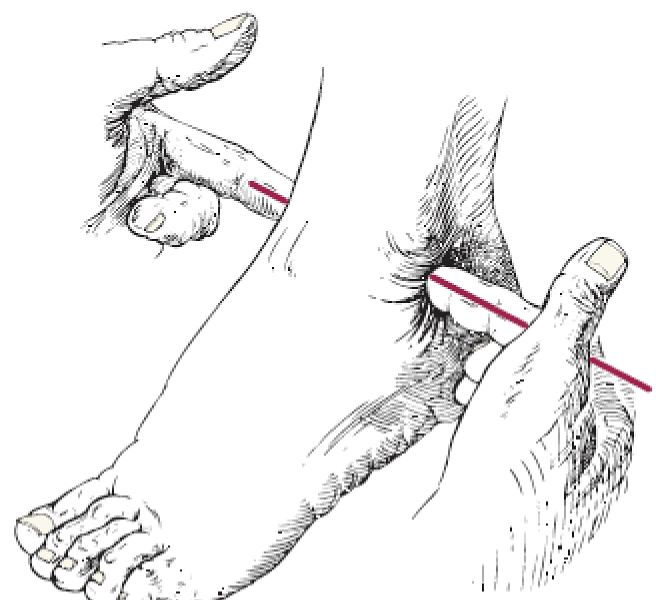




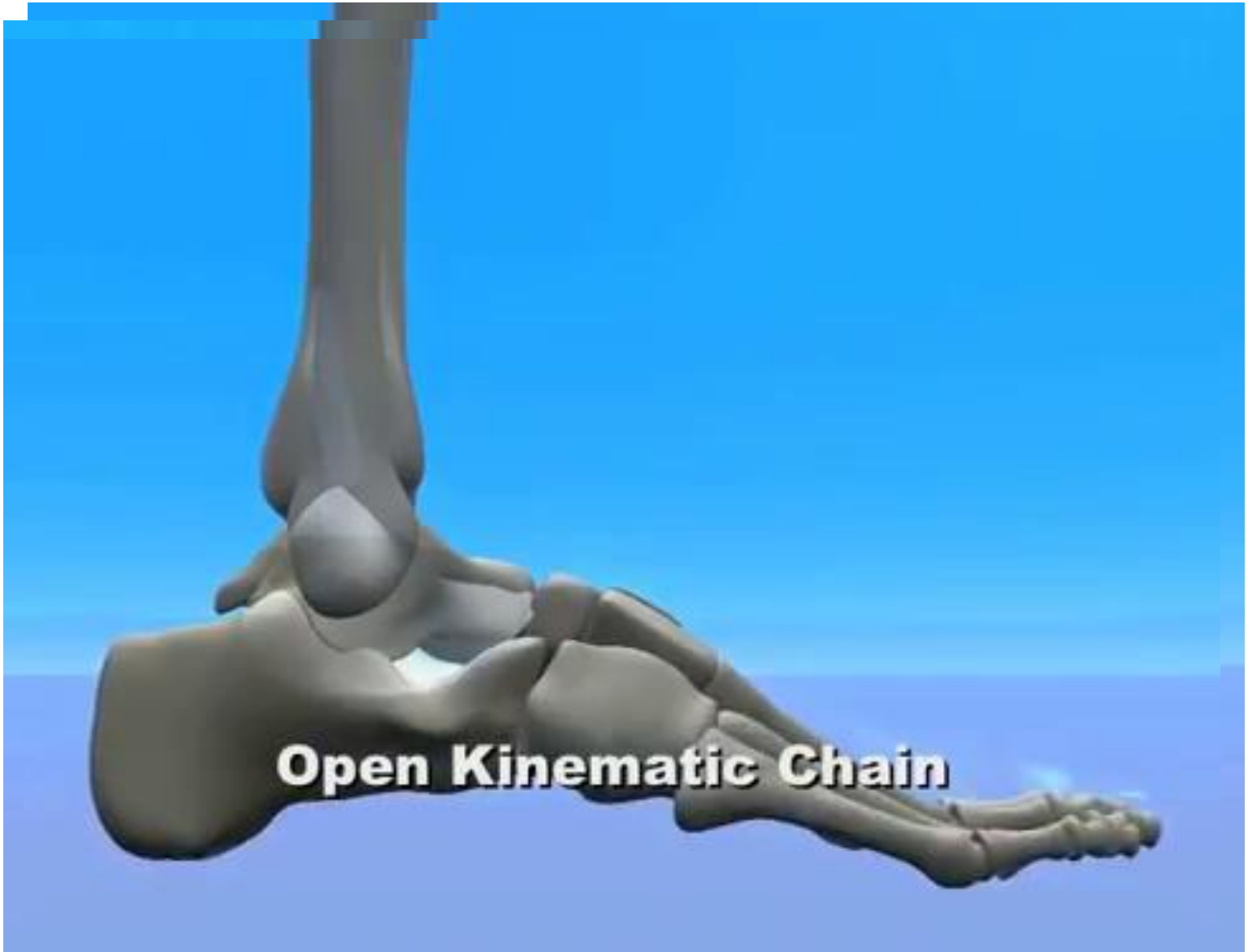
x̄ = 93°
Range 88°
SD = ± 2.7°
100°
A
x̄ = 82°
74°
SD = ± 3.6°
94°
B



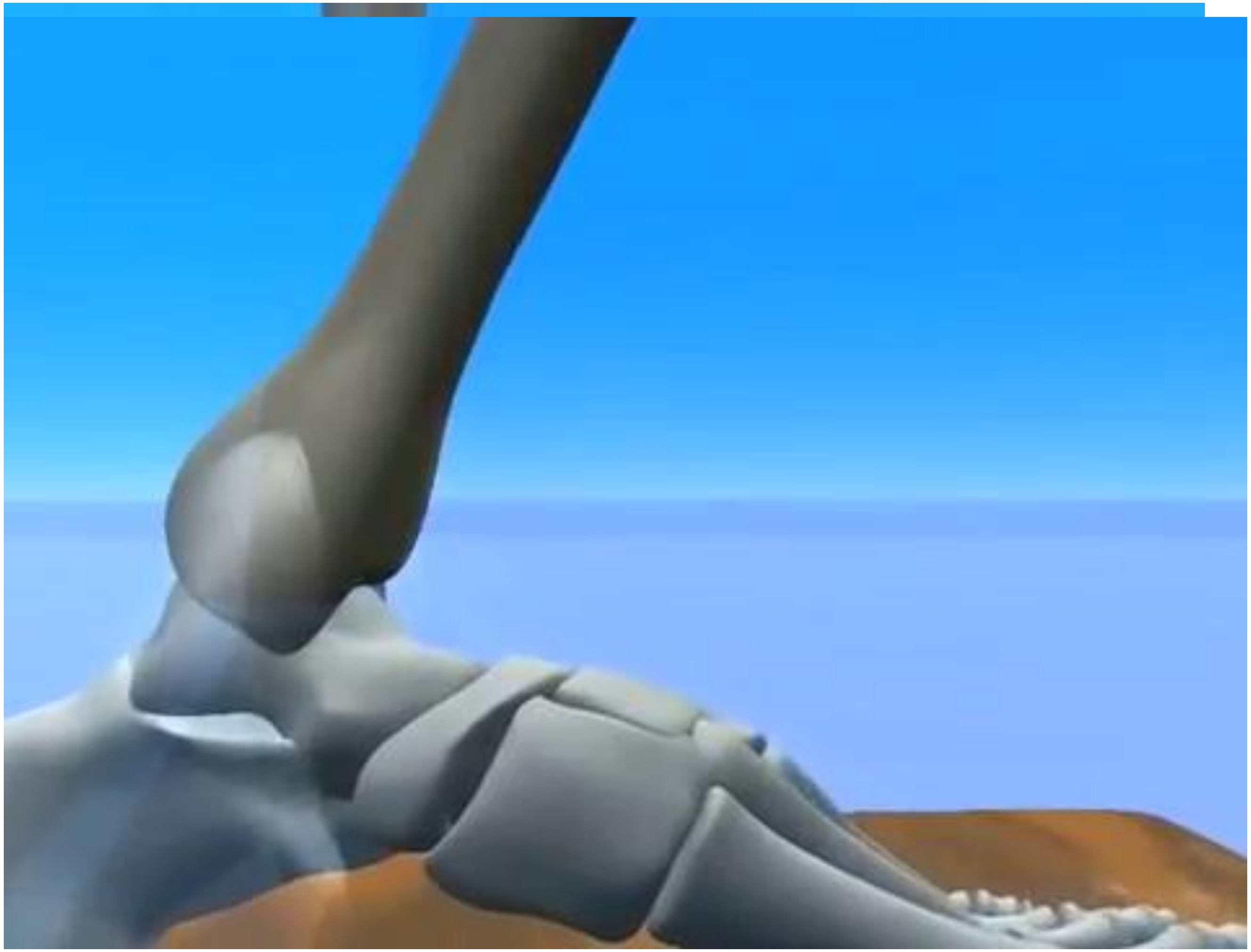
Light
Fixed in space
Light
Fixed in space
Light
Fixed in space
Horizontal plane



Open kinematic chain



Closed kinematic chain



Subtalar joint

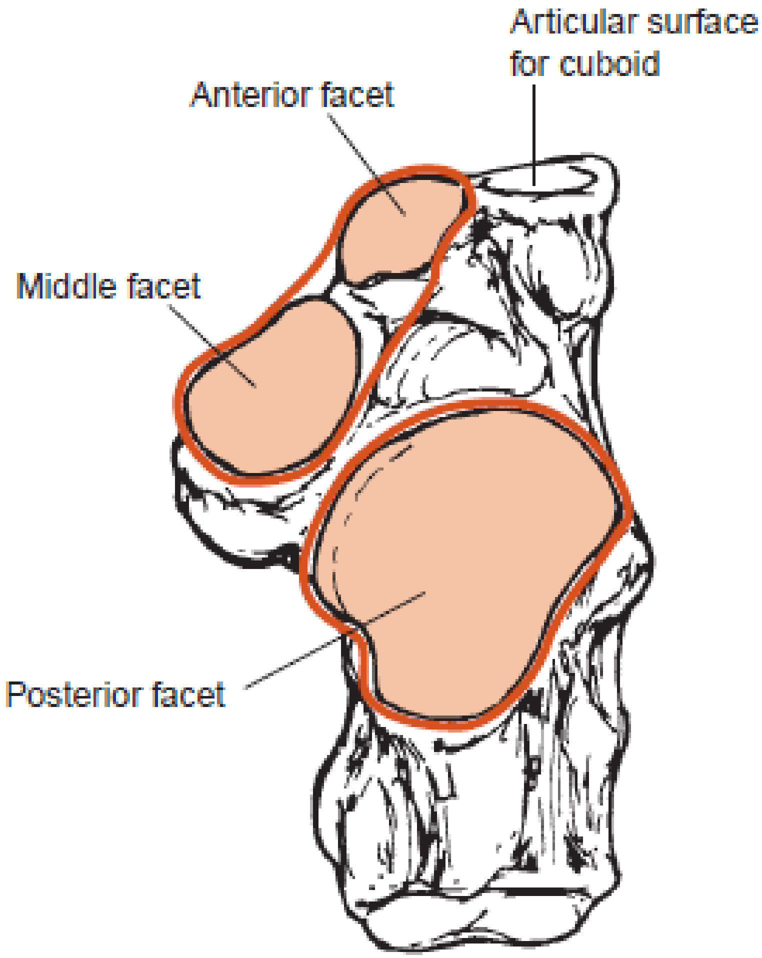
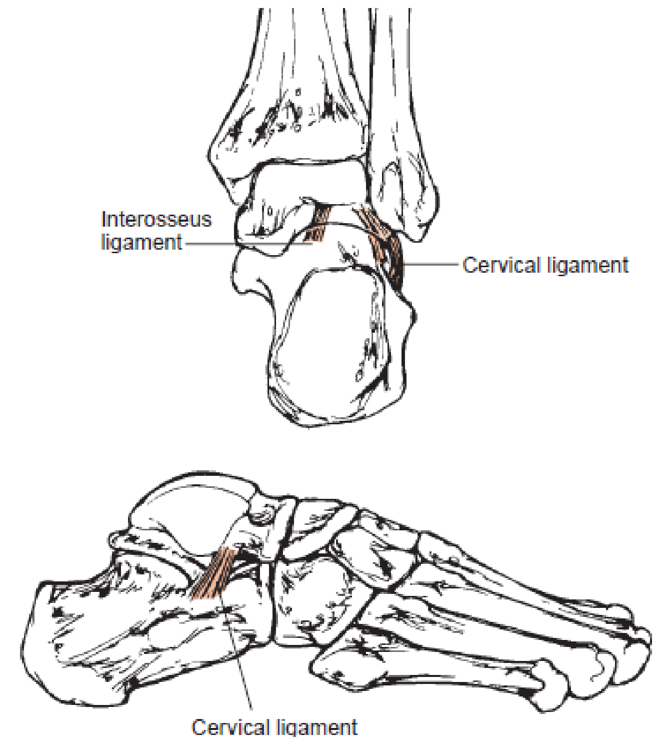
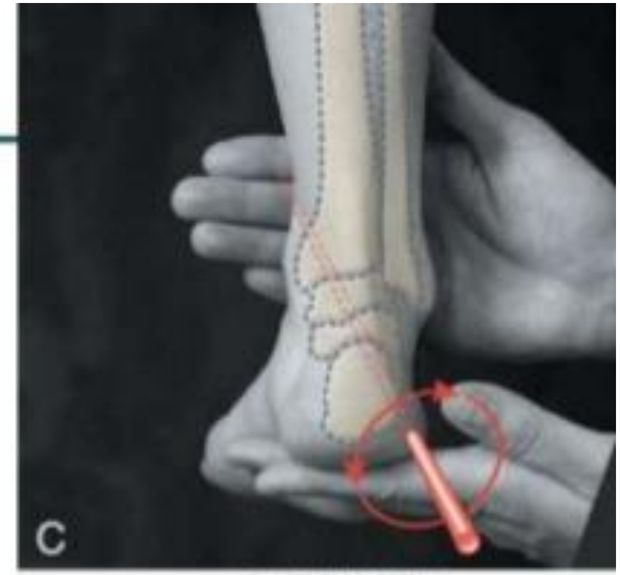


Figure 44.17: The subtalar joint contains two joint capsules, one surrounding the posterior facets of the talus and calcaneus and the other surrounding the anterior and middle facets of the talus and calcaneus as well as the proximal articulating surface of the navicular.



Spring ligament connects calcaneus to navicular along the medial hindfoot

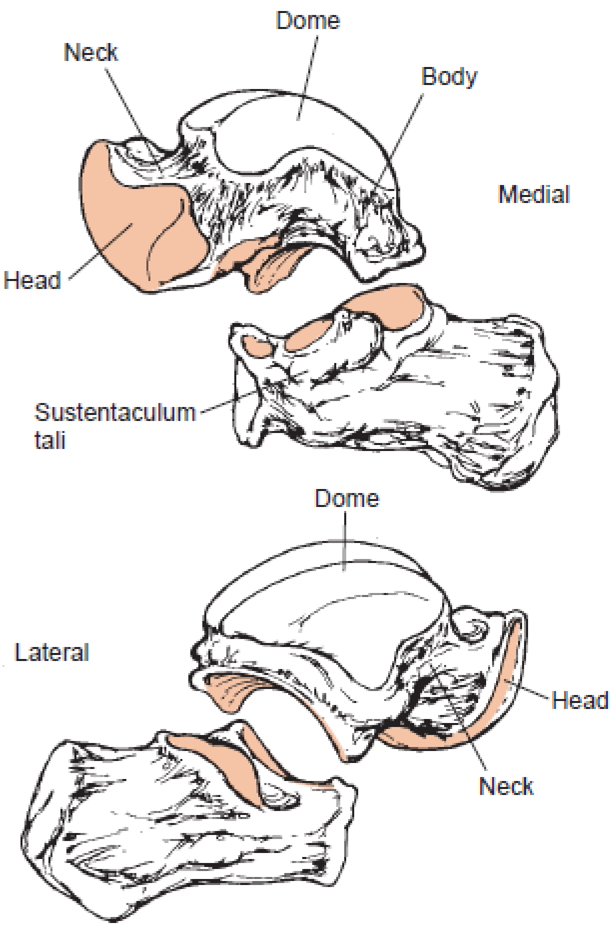
Motion at Subtalar

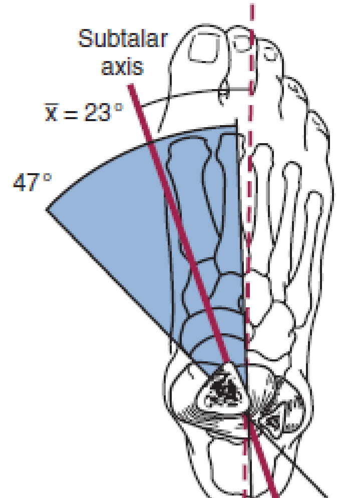


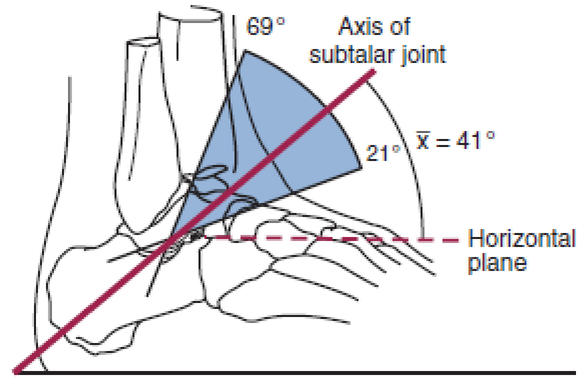
anteriorly, medially and superiorly

Inversion = 2 X eversion?
(22.6°, 12.5°)

- Lateral malleolus
- Deltoid ligament


Dome
Neck
Body
Medial
Head
Sustentaculum tali
Dome
Lateral
Head
Neck


Subtalar axis
x̄ = 23°
47°

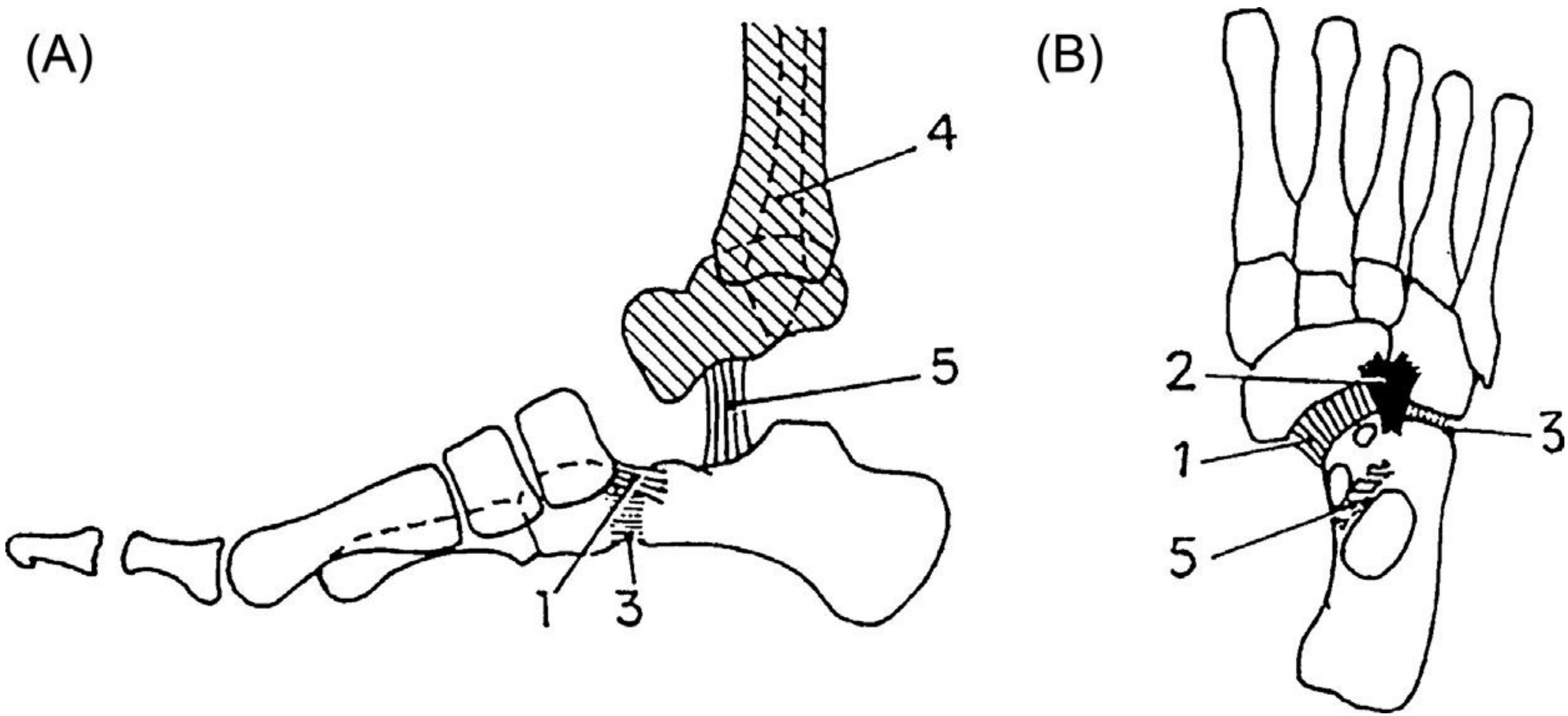

69°
Axis of subtalar joint
21°
x̄ = 41°
Horizontal plane

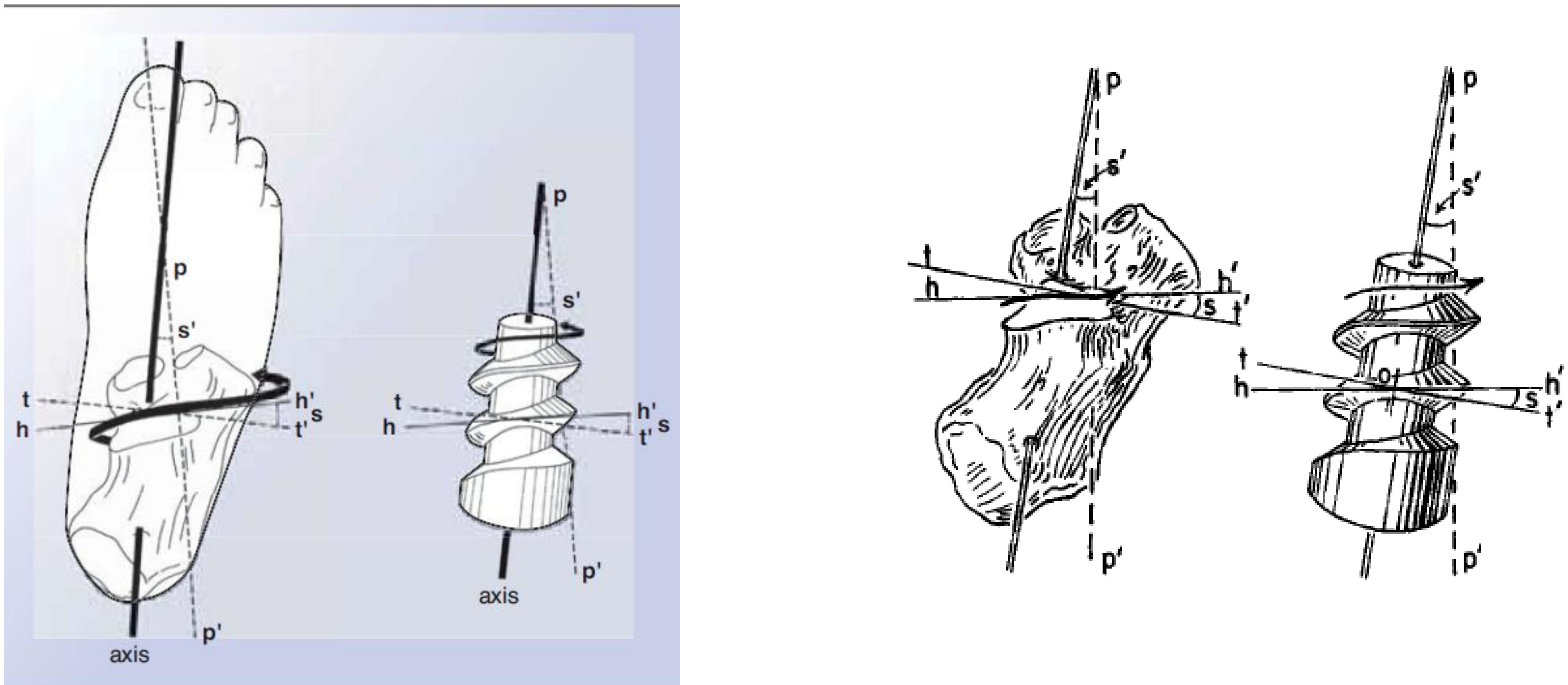
During weight bearing
(pronation), the navicular is pulled laterally,
following the calcaneus, which moves posteriorly.
During push-off, motored by the strong pull of
the tibialis posterior muscle, the navicular moves
medially, preceding the anterior move of the calcaneus
(supination).

The calcaneus moves posteriorly during heel strike,

and ***moves toward the anterior during push-off,***

In maximal pronation, the talus abuts the calcaneus
laterally (angle of Gissane),

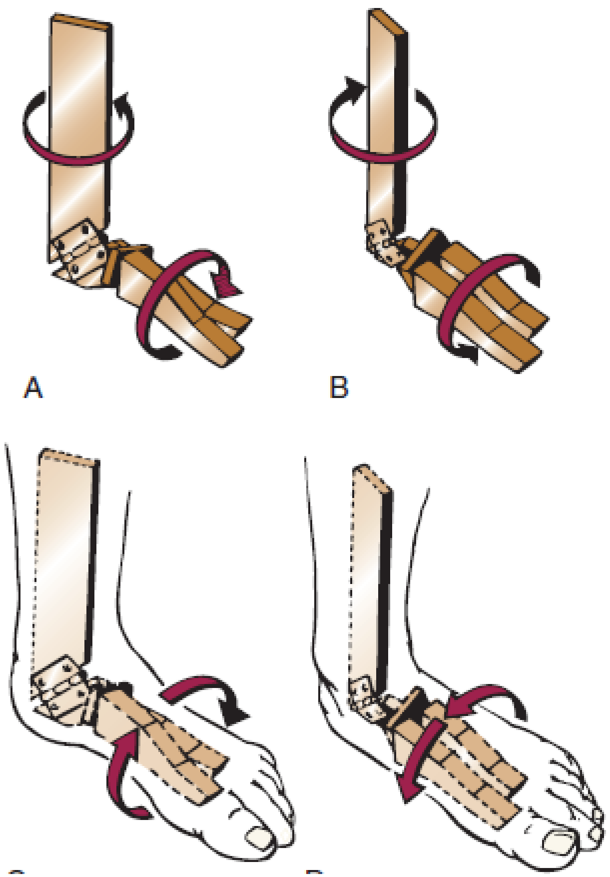

(A)
4
5
1
3
(B)
2
3
1
5



Comparison of the posterior calcaneal facet of the right subtalar joint with a right-handed screw. The *arrow* represents the path of the body following the screw. The horizontal plane in which motion is occurring is *hh′*; *tt′* is a plane perpendicular to the axis of the screw; *s* is the helix angle of the screw, equal to *s′*, which is obtained by dropping a perpendicular (*pp′*) from the axis. As the calcaneus inverts, it rotates clockwise and translates forward along the axis. *Reprinted with permission from Manter, J.T. (1941). Movements of the subtalar and transverse tarsal joints. Anat Rec, 80, 397.*

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



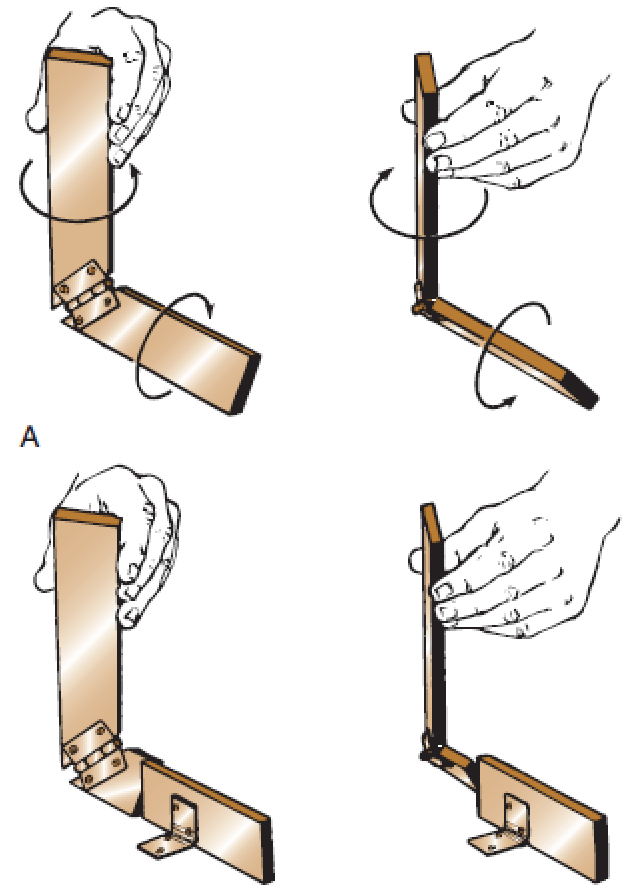
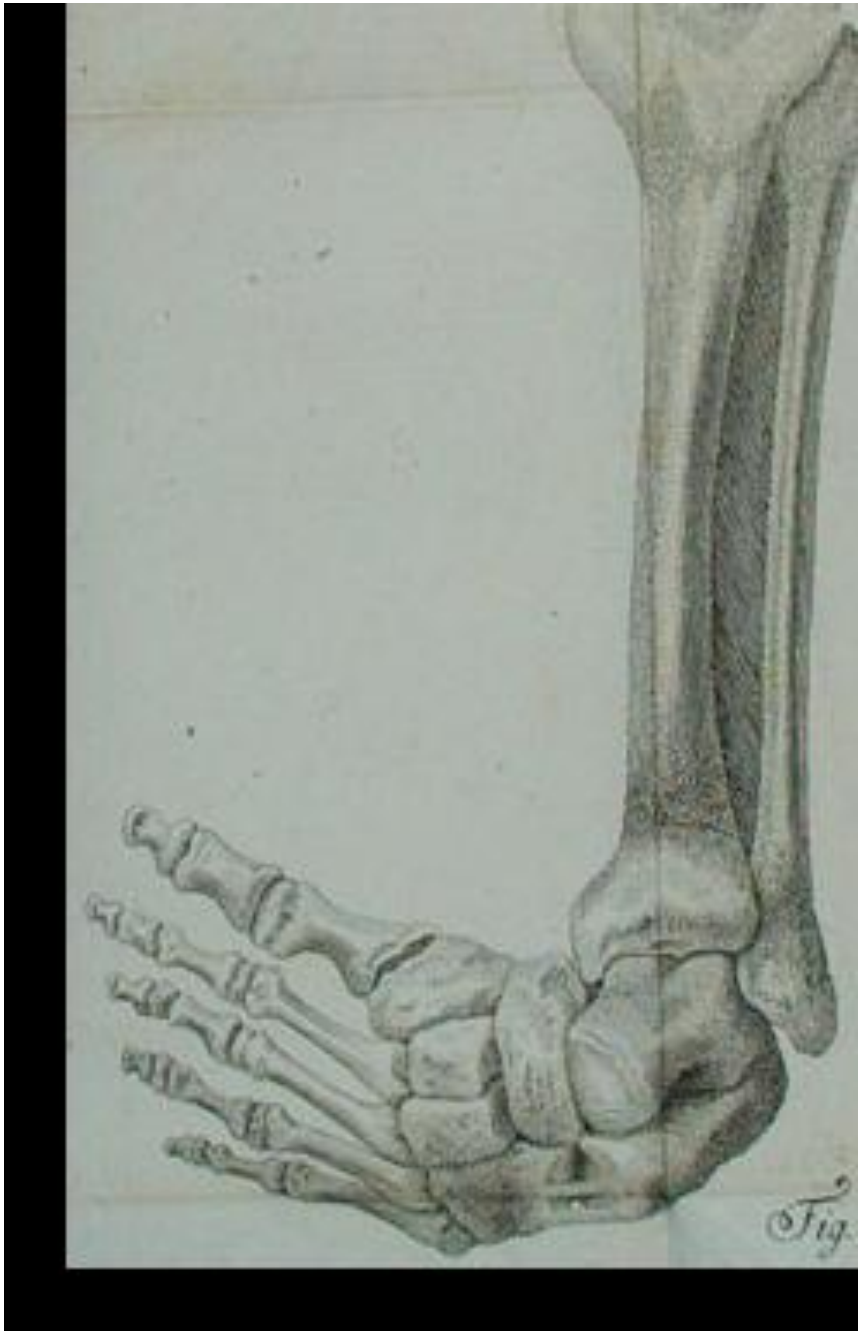


Figure 1-25 Simple mechanism demonstrating functional

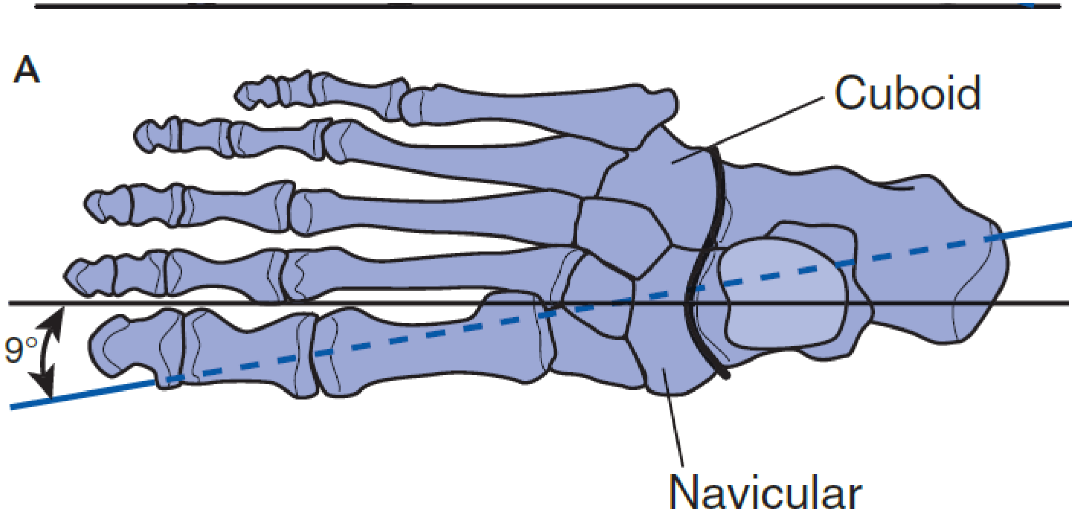
Midfoot

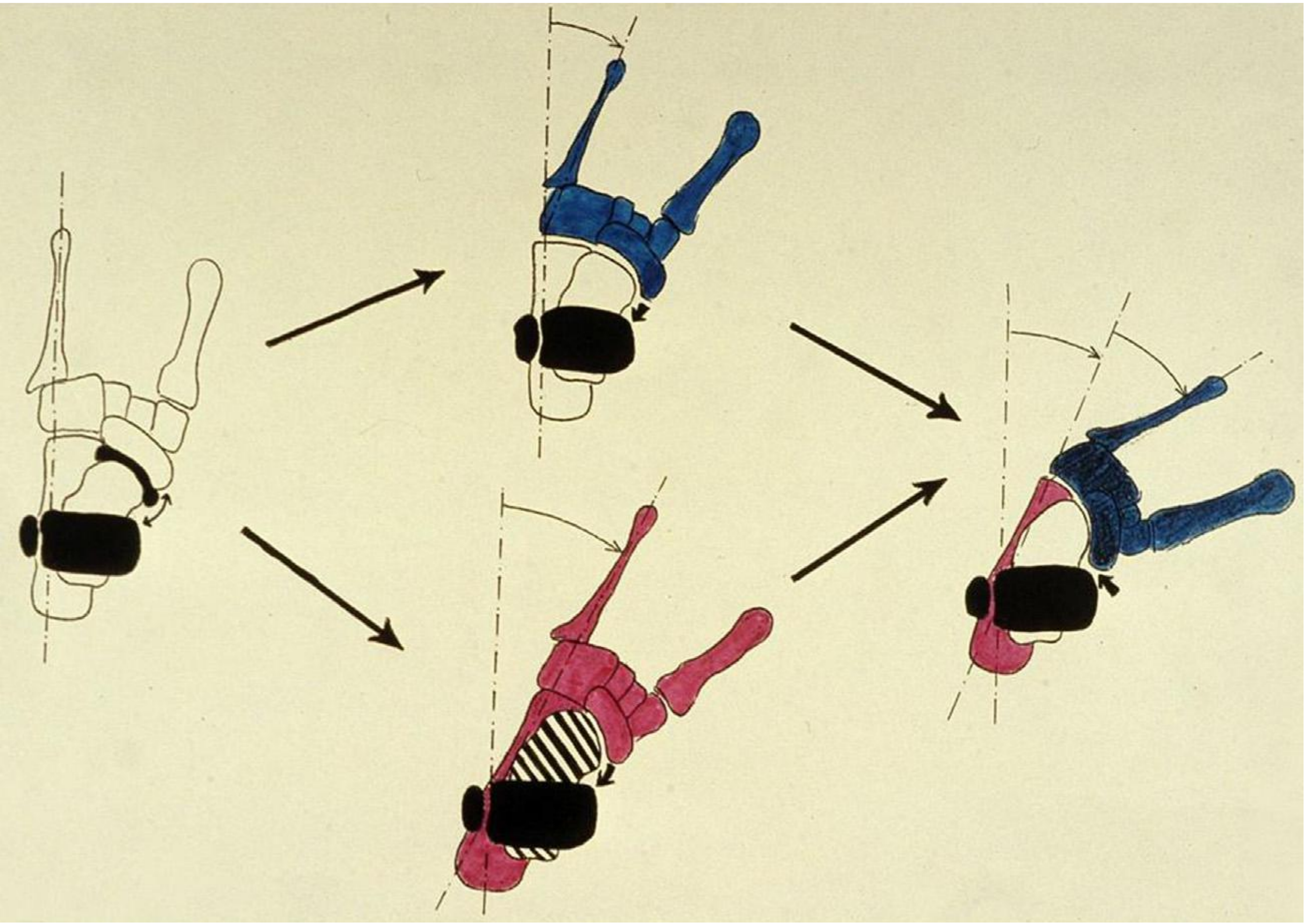


Transverse tarsal (mid tarsal) joint

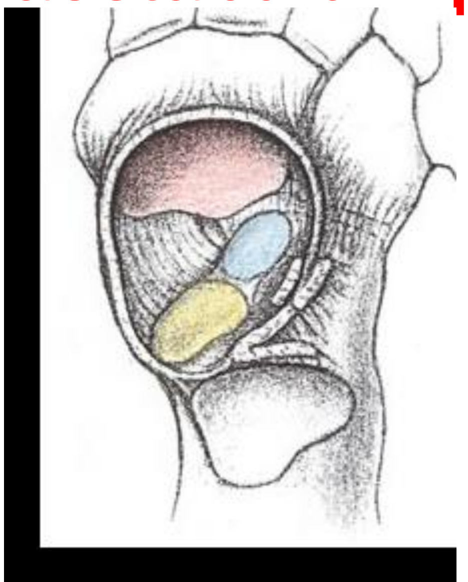
Midfoot functions in adduction and abduction.

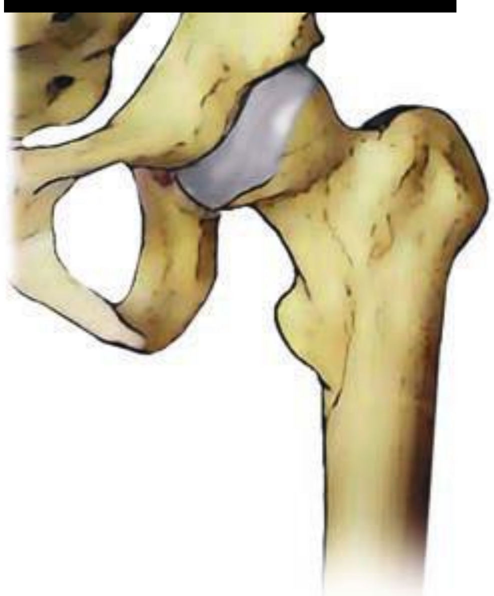
- CC and TN joints are collectively referred to as the *midtarsal,* transverse *tarsal, or Chopart joint.*
- This joint is important for providing hindfoot and midfoot stability to produce a rigid lever at heel rise.
- During foot flat (hindfoot valgus, forefoot abduction, and dorsiflexion of ankle), the transverse tarsal joints are parallel and supple, adapting to uneven ground.
- During toe-off (hindfoot varus, forefoot adduction, and plantar flexion of ankle), these joints become





The acetabulum pedis





Ball rotates within socket Socket rotates around ball

Ligamentous stability to midfoot

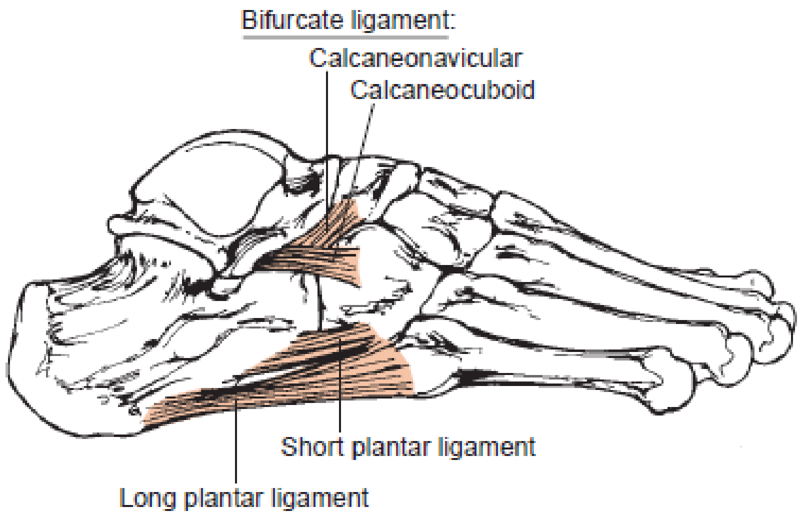
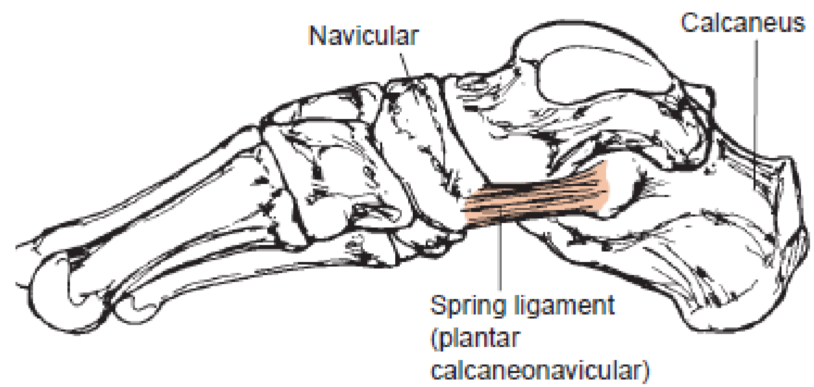


Figure 44.26: The supporting structures of the calcaneocuboid joint consist of the bifurcate ligament and the long and short plantar ligaments.



igure 44.25: The primary supporting structure of the talonavicu

- Plantar ligaments are thicker and stronger than their dorsal counterparts

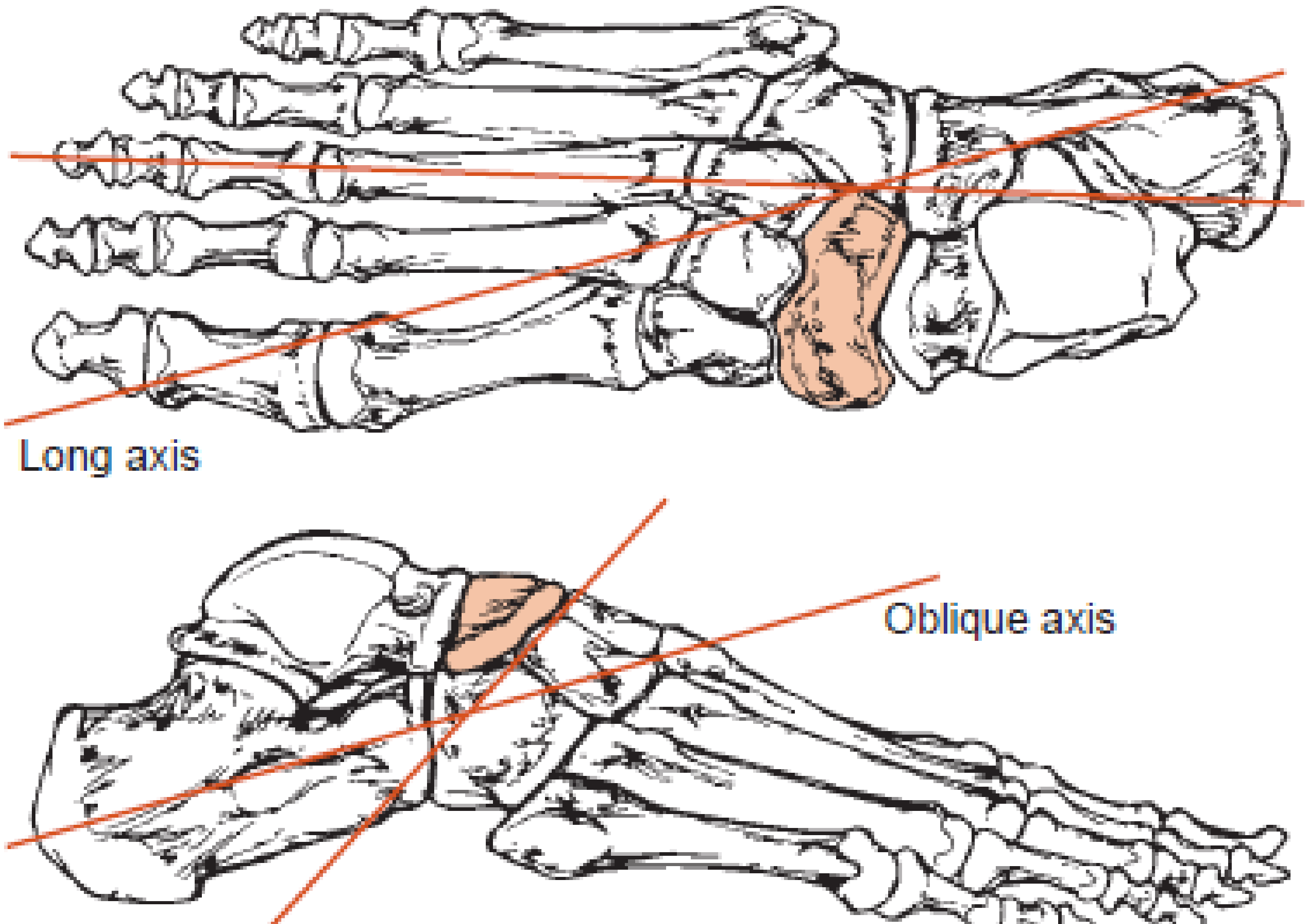


Figure 44.27: Motion about the theoretical long axis of the transverse tarsal joint contributes more eversion and inversion of the foot, while motion about the theoretical oblique axis of the transverse tarsal joint contributes mostly dorsiflexion and plantarflexion of the foot.

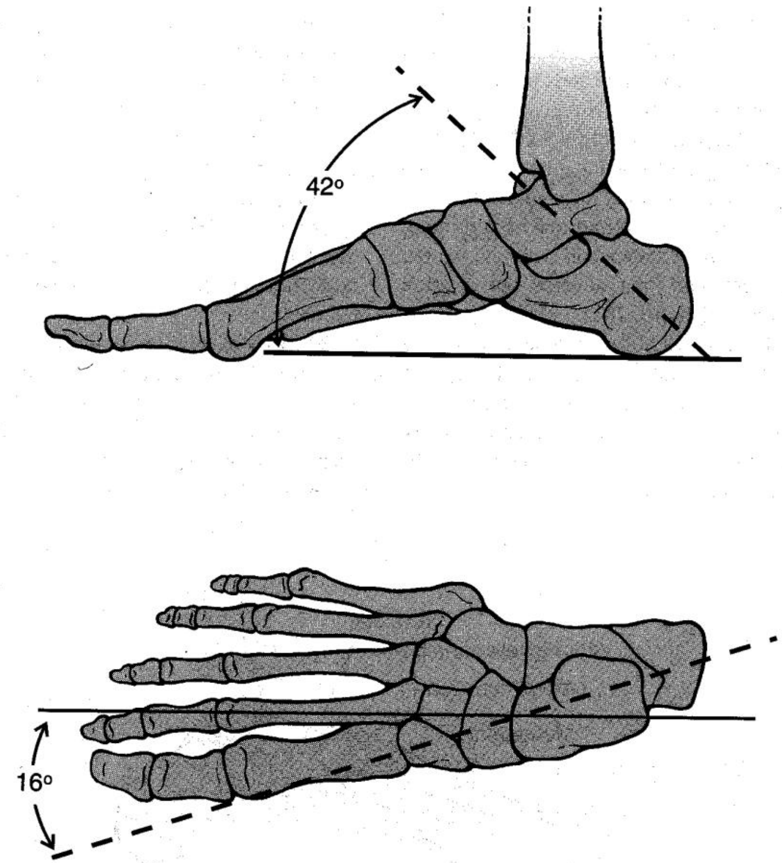
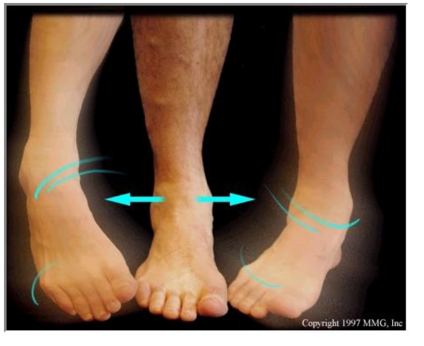


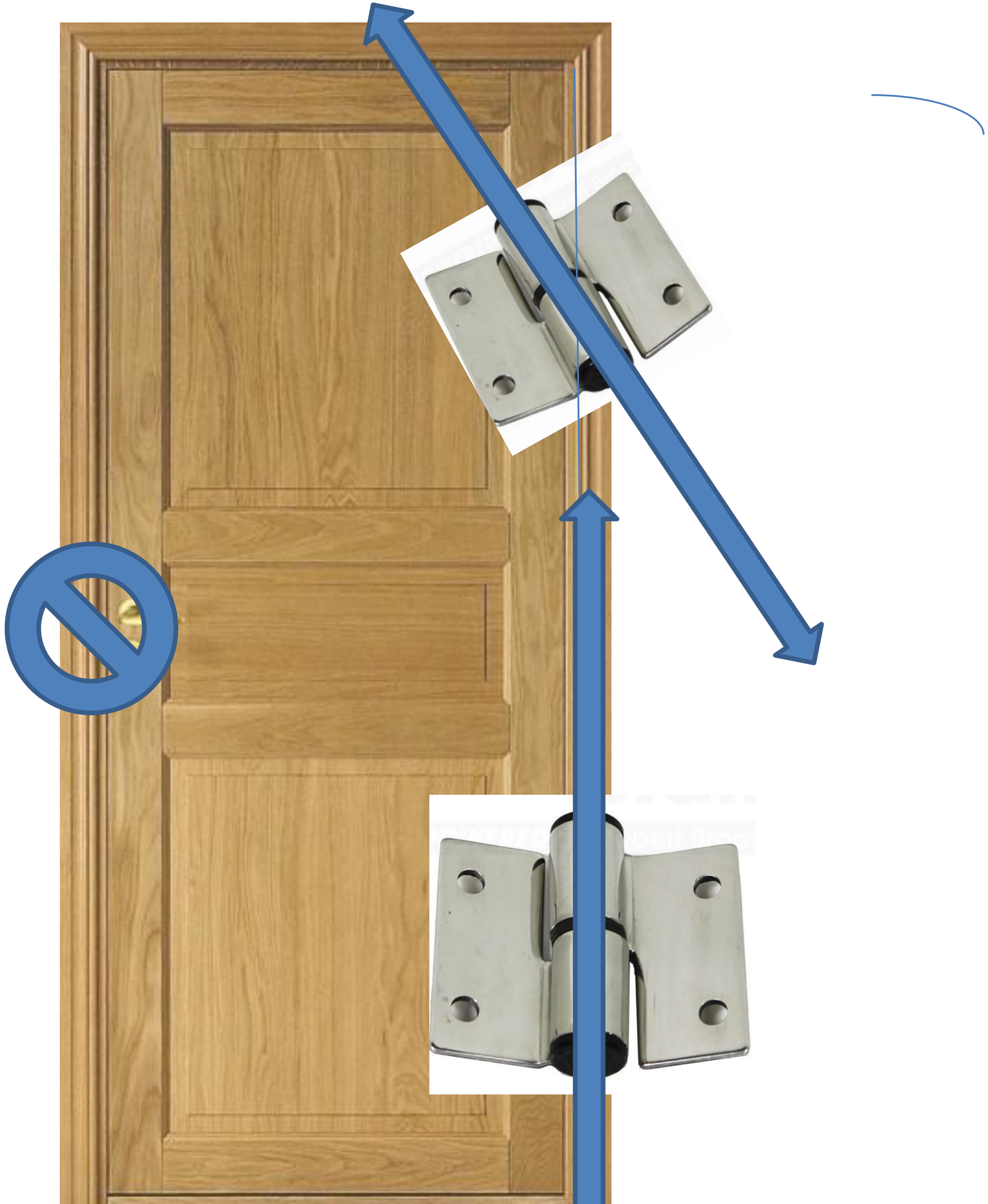
FIGURE 6–36. The axis of rotation for the subtalar joint runs diagonally from the posterior, lateral, plantar surface to the anterior, medial, dorsal surface. The axis is situated approximately 42 degrees in the sagittal plane and 16 degrees in the transverse plane.

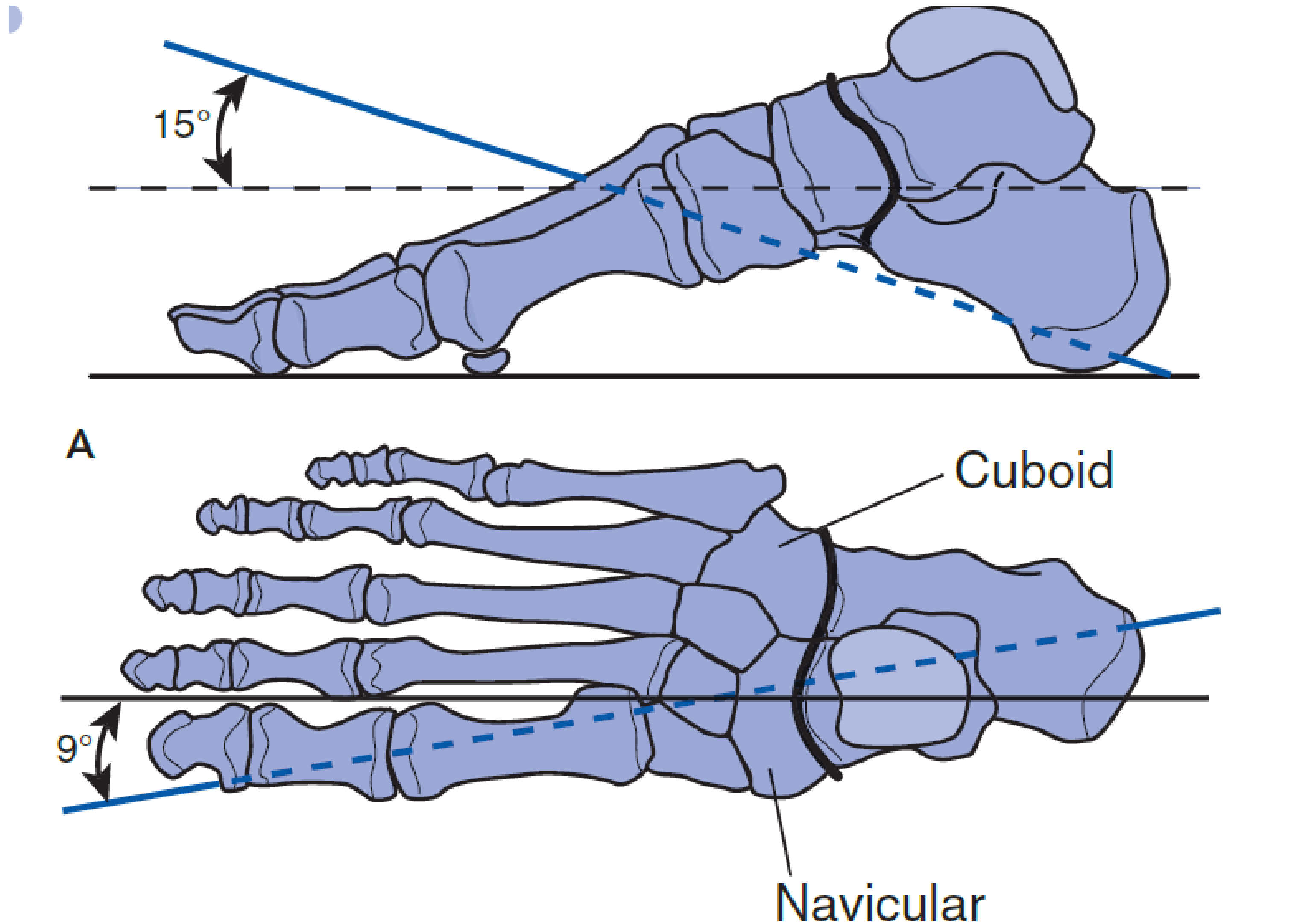
Midfoot functions in adduction and abduction.

- 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.



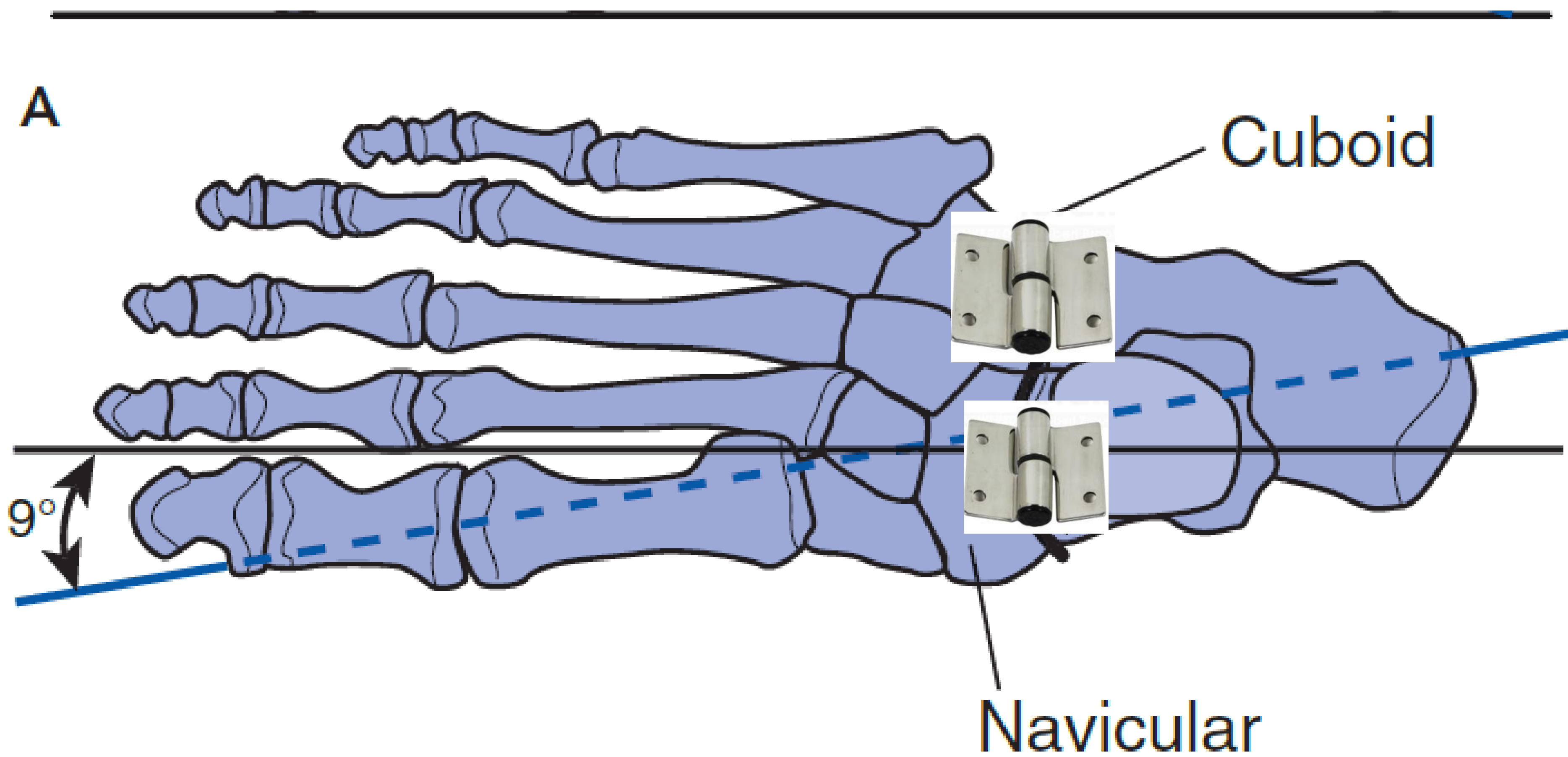
- During foot flat (hindfoot valgus, forefoot abduction, and dorsiflexion of ankle), the transverse tarsal joints are ***parallel*** and supple, adapting to uneven ground.
- During toe-off (hindfoot varus, forefoot adduction, and plantar flexion of ankle), these joints become **divergent and lock**, providing stiffness to the foot for forward propulsion





Longitudinal axis of the transverse tarsal joint. Inversion and eversion occur about this axis. **A.** Lateral view. **B.** Top view.

Eversion



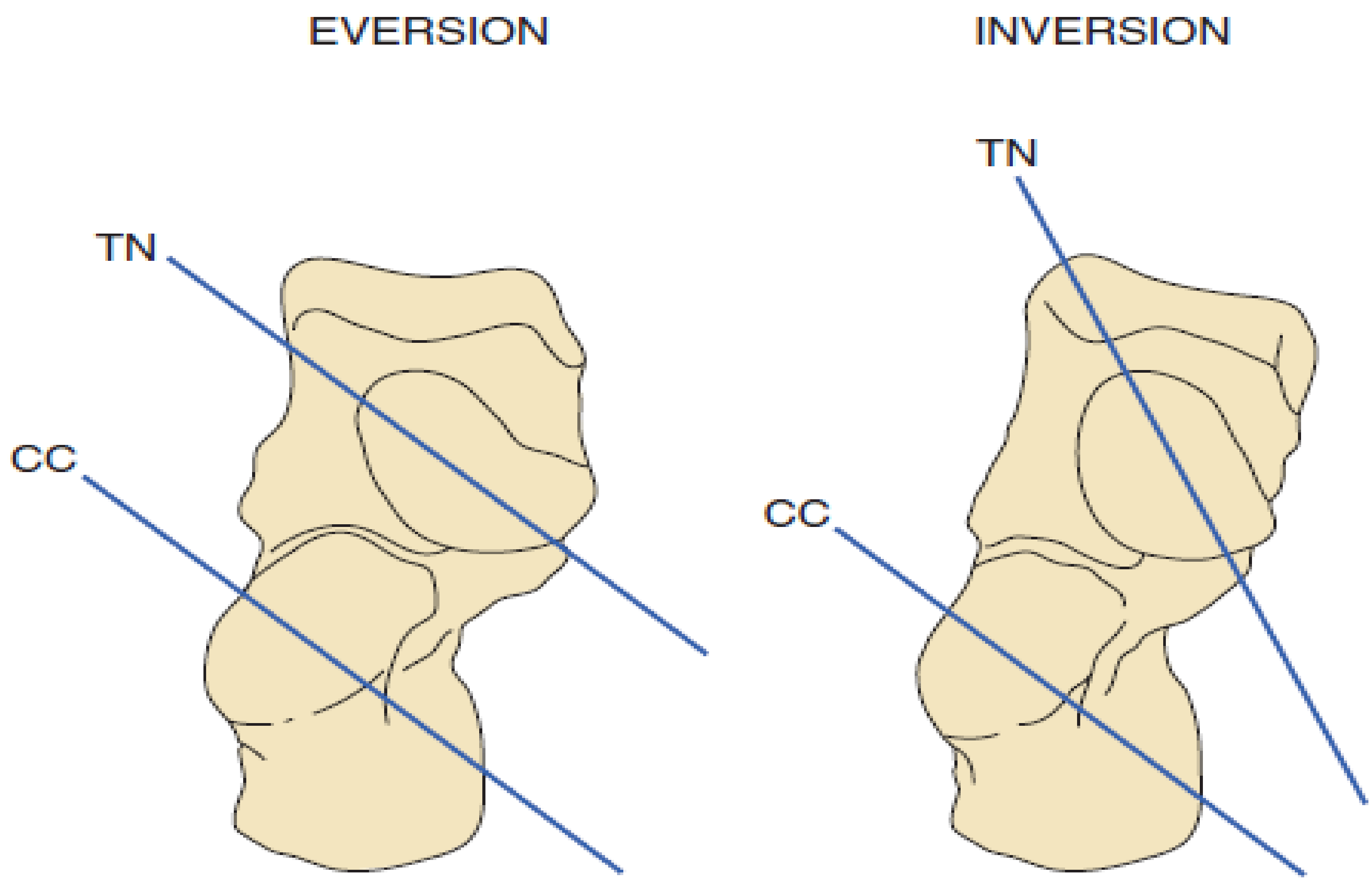
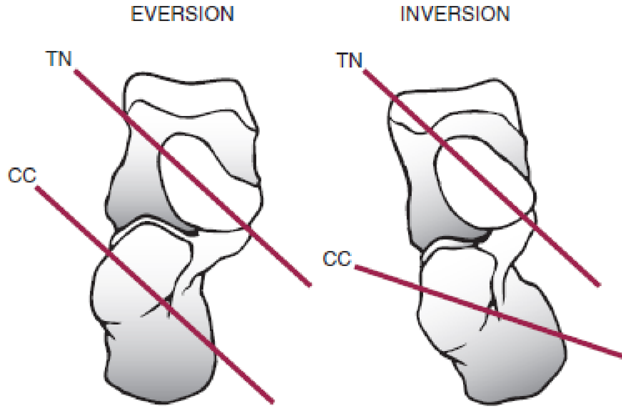
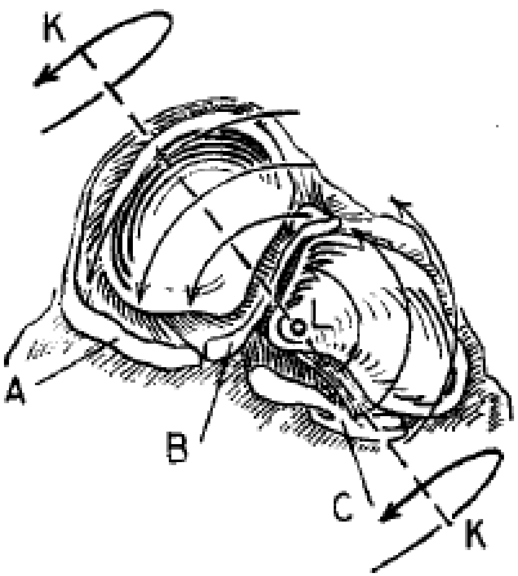
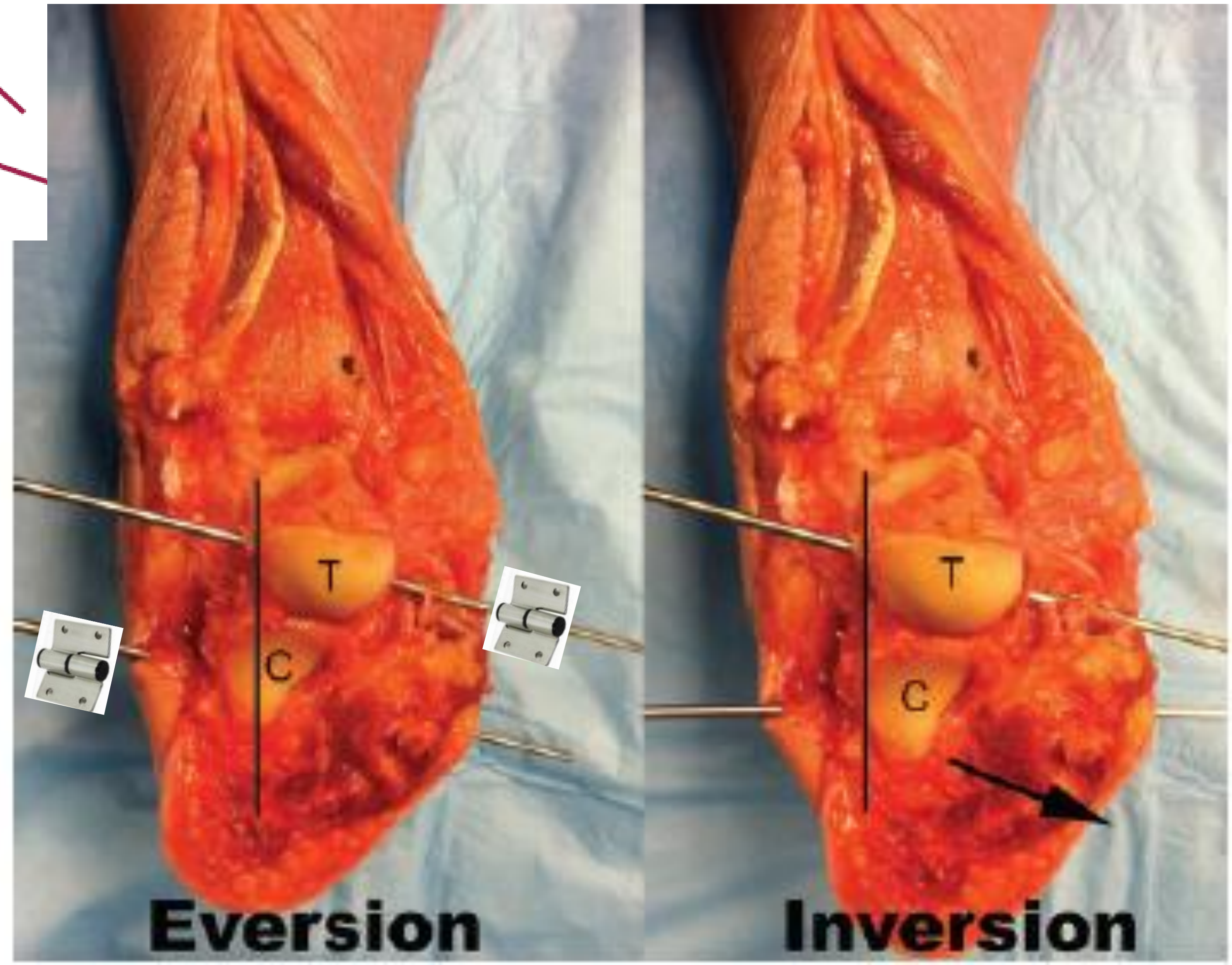
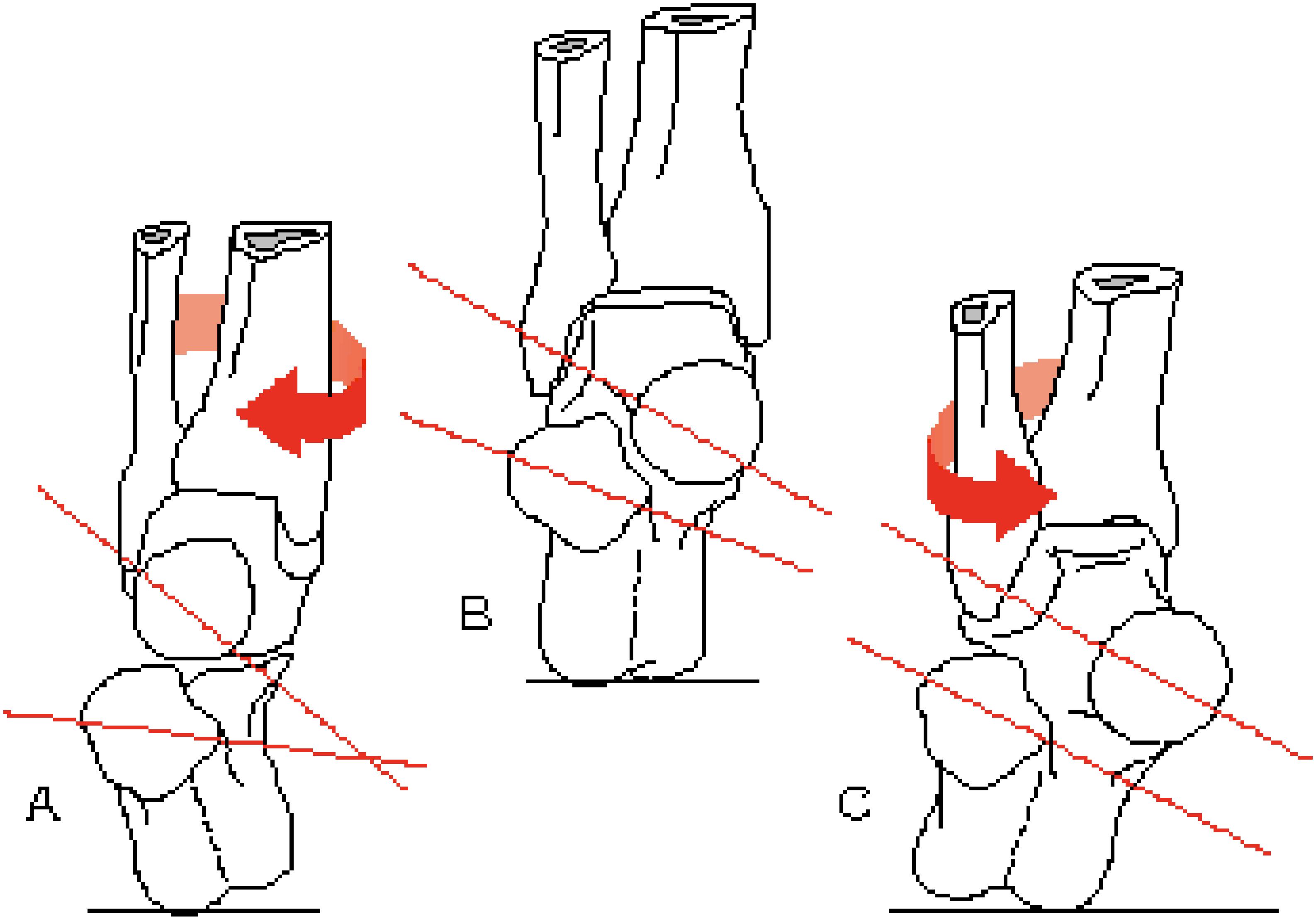


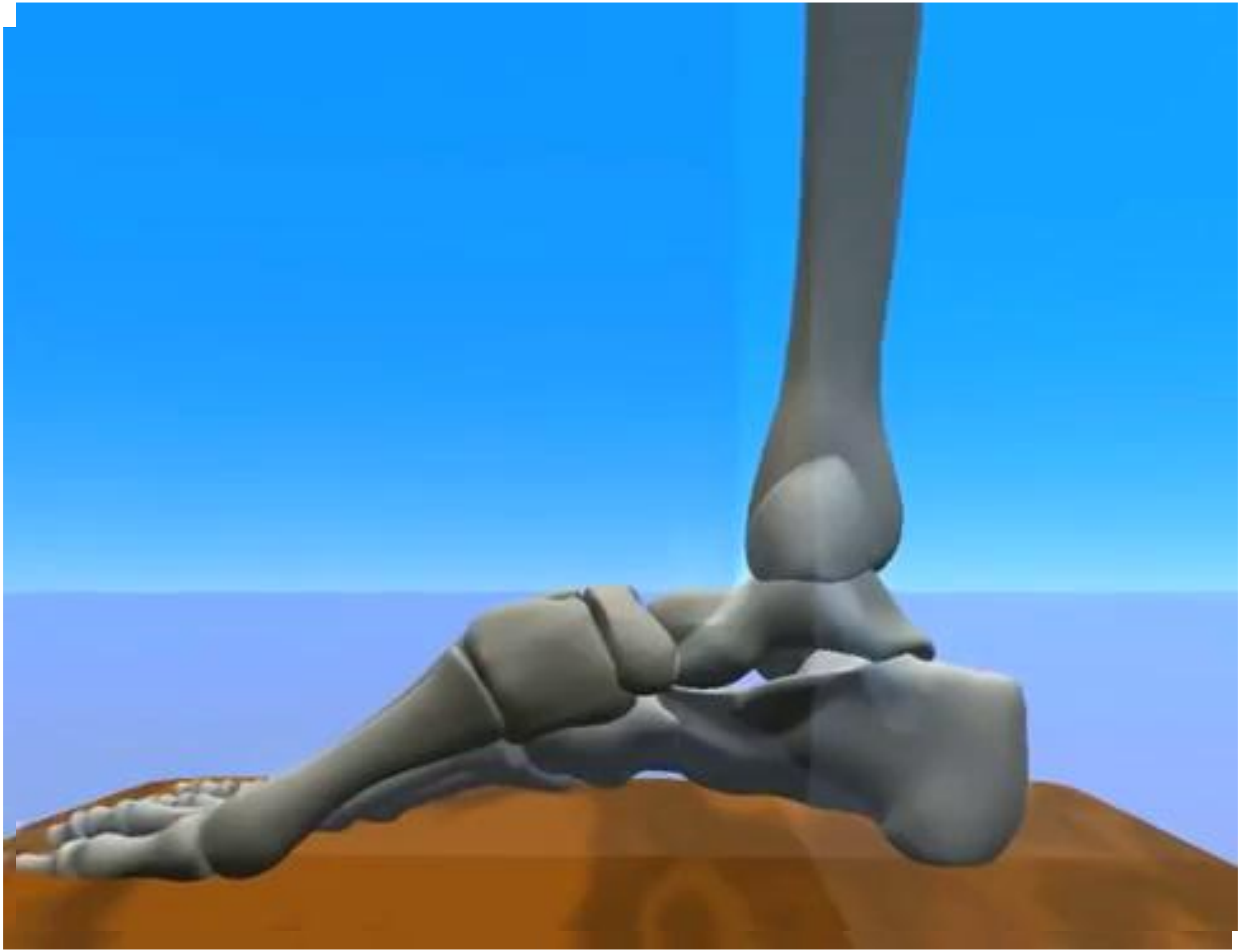
FIGURE 6-5 Function of the transverse tarsal joint. When the heel is everted, the transverse tarsal joints are parallel and unlocked, allowing the foot to be supple and pronate and accommodate to the floor. When the heel is inverted (varus), the transverse tarsal joint is divergent and locked, allowing for a stable hindfoot/midfoot complex for toe-off. *CC,* Calcaneocuboid; *TN,* talonavicular.

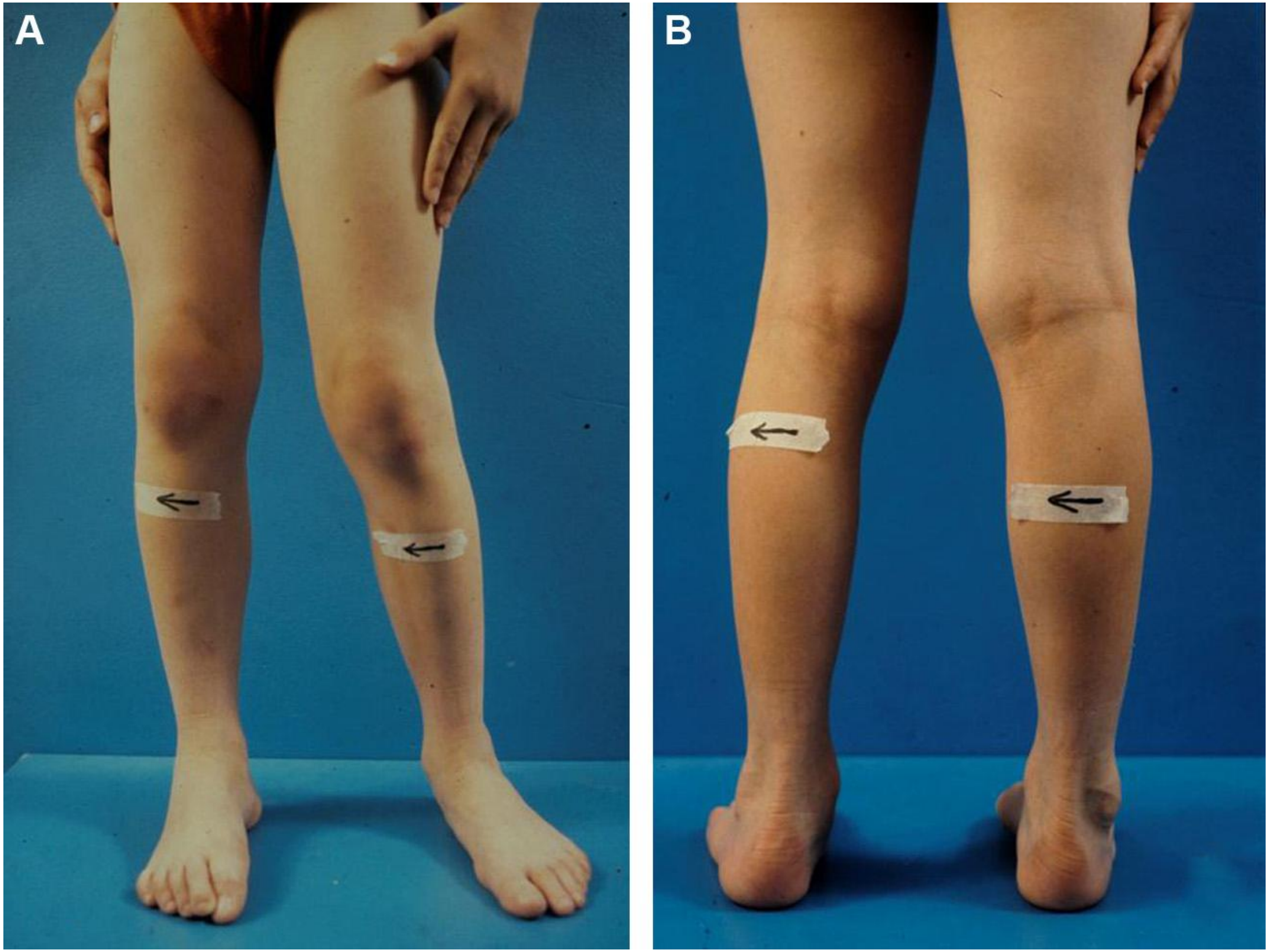

EVERSION
INVERSION
TN
CC
TN
CC


K
A
B
C
K


T
C
T
C
Eversion
Inversion


A
B
C




A
B

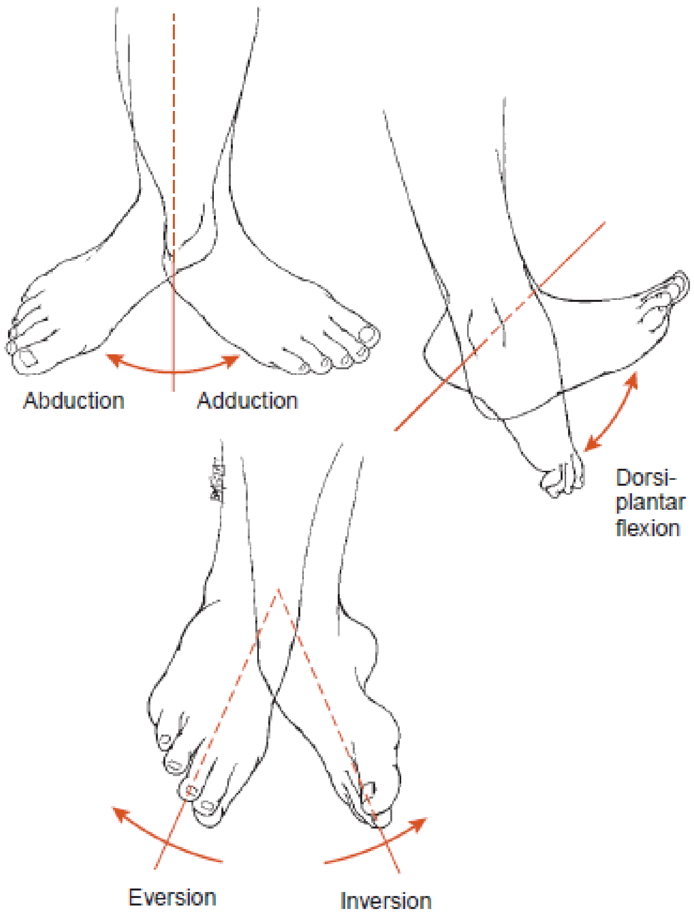


Table 6-1 Motions of the Foot and Ankle

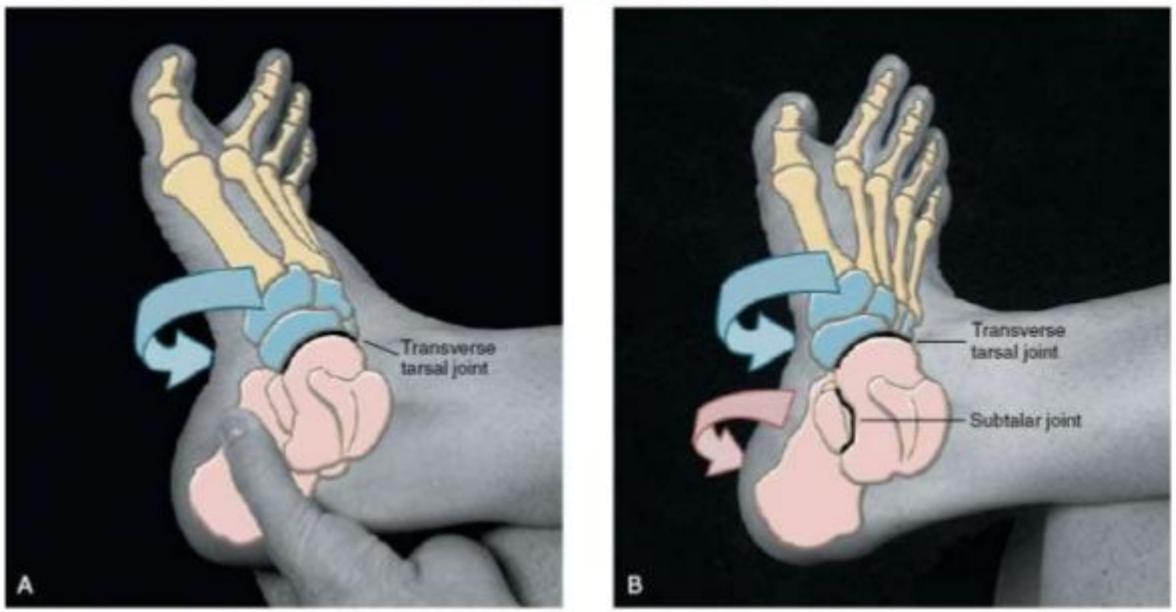
PLANE OF MOTION	MOTION
Sagittal (X-axis)	Dorsiflexion Plantar flexion
Frontal (coronal) (Z-axis)	Inversion Eversion

Transverse (Y-axis)	Forefoot/midfoot
	  Adduction
	  Abduction
	Ankle/hindfoot
	  Internal rotation
	  External rotation

Triplanar motion	Supination
	  Adduction
	  Inversion
	  Plantar flexion
	Pronation
	  Abduction
	  Eversion
	  Dorsiflexion

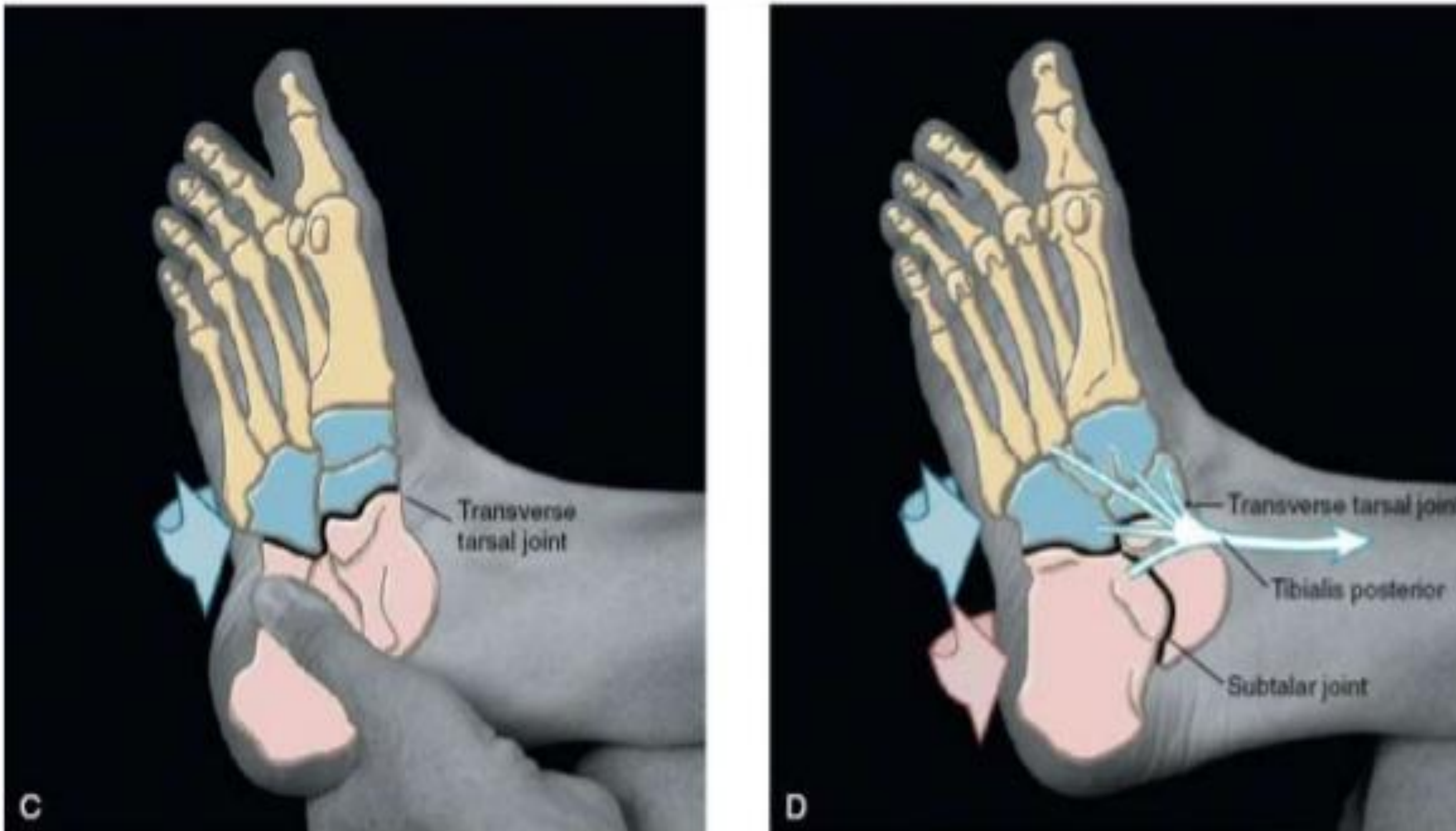
FOOT PRONATION

PRONATION of the foot (dorsal-medial view)



FOOT SUPINATION

SUPINATION of the foot (plantar-medial view)



(From Neumann: Kinesiology of the Musculoskeletal System, 2nd edition.)

- **Primary stabilizer of longitudinal arch is the interosseous ligaments, NOT the plantar fascia;**

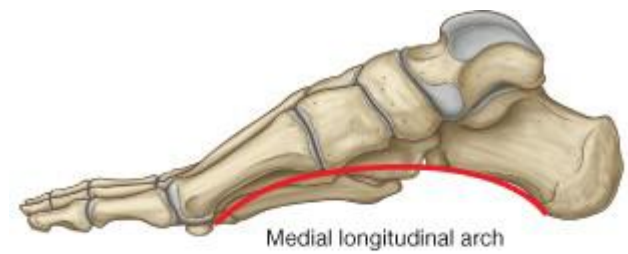
- plantar fascia is a secondary stabilizer!!

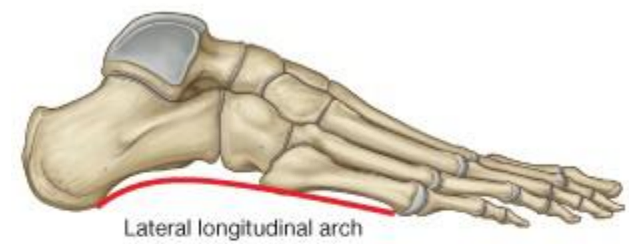
The foot is also divided into three columns

- **Medial column** : the first metatarsal, the medial cuneiform, and the navicular.
- **Middle column** : the second and third metatarsals, the middle cuneiform, and the lateral cuneiform.
- **Lateral column includes**: the fourth and fifth metatarsals and the cuboid.

Functions of Arches

Support
• Shock absorption
–Medial Longitudinal Arch
• Weight transmission
–Lateral Longitudinal Arch
• Increase mobility





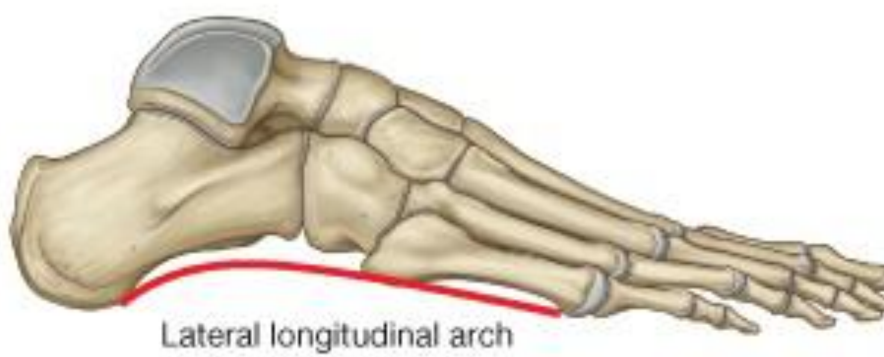
The arches serve several purposes

they protect the nerves, blood vessels, and muscles on the plantar surface of the foot from compression during weight bearing;

they help the foot to absorb shock during impact with the ground; and they help store mechanical energy then release it to improve the efficiency of locomotion

- Lateral column has the most sagittal mobility (≈10 degrees in dorsiflexion and plantar flexion), and middle column has the least (≈2 degrees in dorsiflexion and plantar flexion).
- Sagittal mobility of the lateral column imparts

flexibility necessary for walking on uneven ground



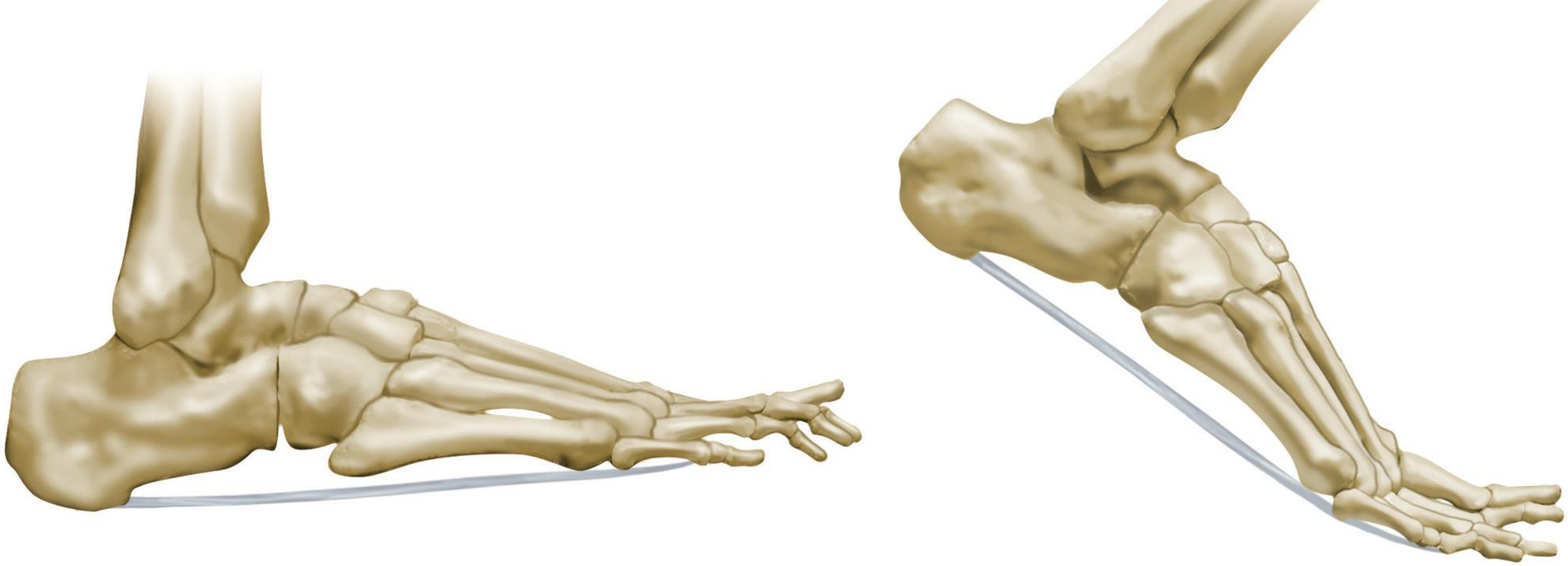
MEDIAL LONGITUDINAL ARCH OF FOOT

- Load bearing and shock absorbing
- Keystone-talonavicular joint

Primary stabilizer of longitudinal arch is the interosseous ligaments, NOT the plantar fascia; plantar fascia is a secondary stabilizer

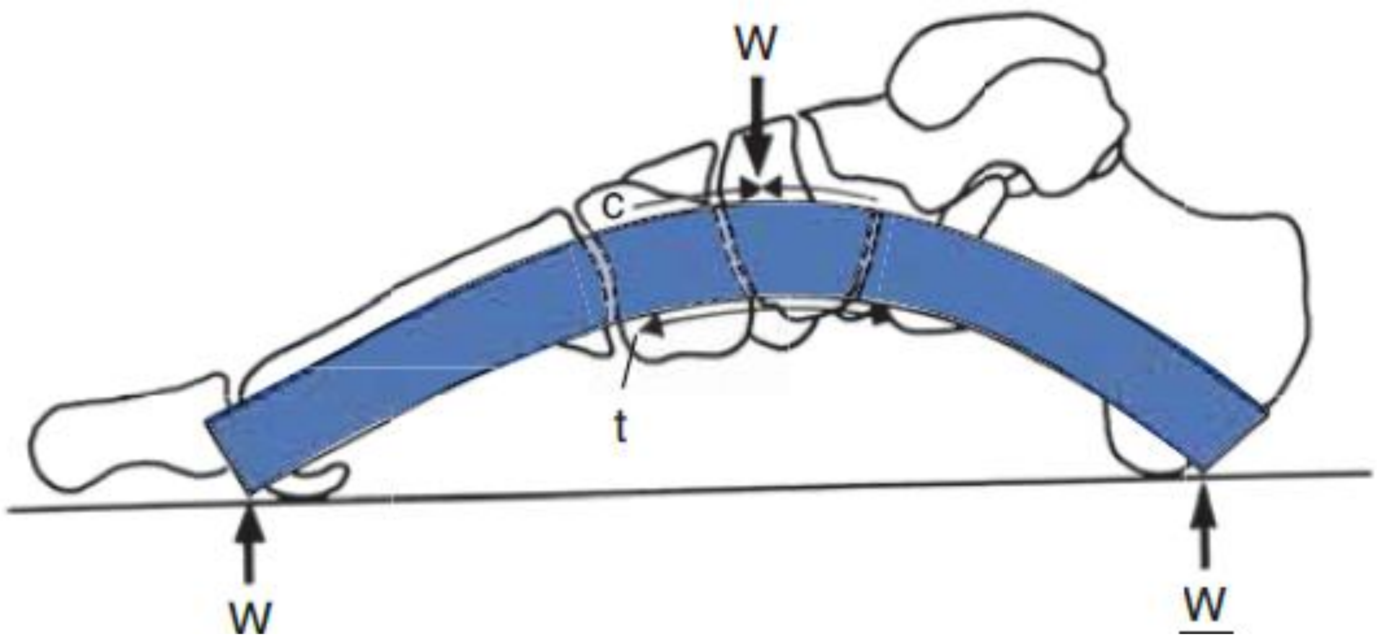
Windlass EFFECT

- A “windlass” is the tightening of a rope or cable. The plantar fascia simulates a cable attached to the calcaneus and the metatarsophalangeal joints. Dorsiflexion during the propulsive phase of gait winds the plantar fascia around the head of the metatarsal.
- .



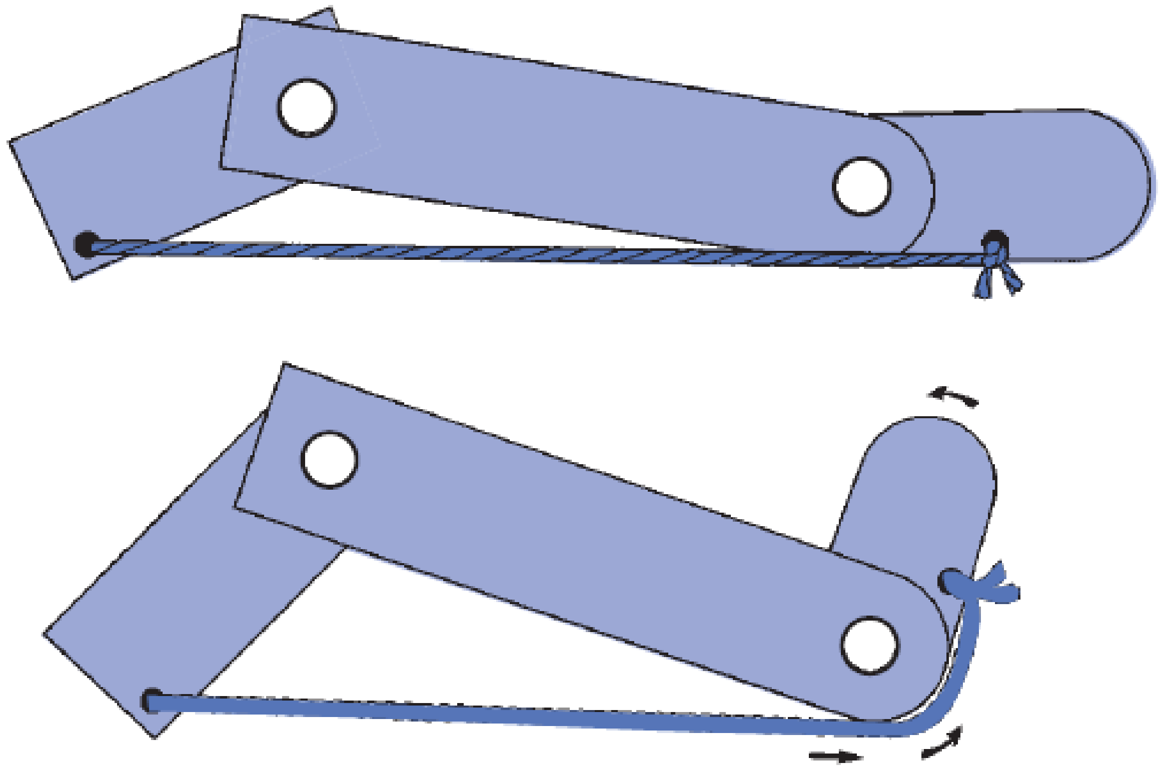
Windlass mechanism and function of the plantar fascia. When the foot is at rest, there is some mobility between the bones of
the midfoot, allowing flexibility. During the push-off phase of gait, this flexibility would be detrimental. The plantar fascia, which inserts distal
to the metatarsophalangeal joints, tightens as the toes are dorsiflexed, which pulls the tarsal bones together and “locks” 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.

Beam model

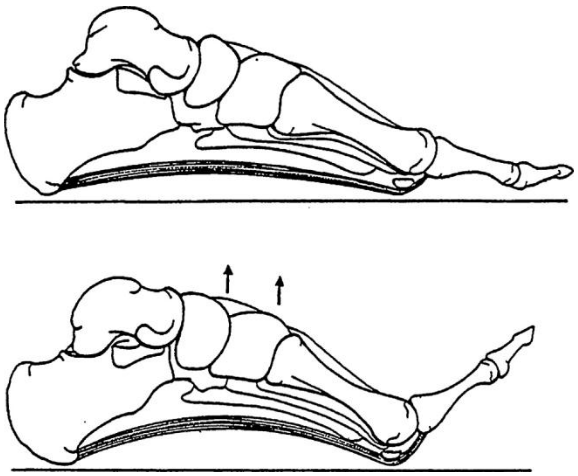


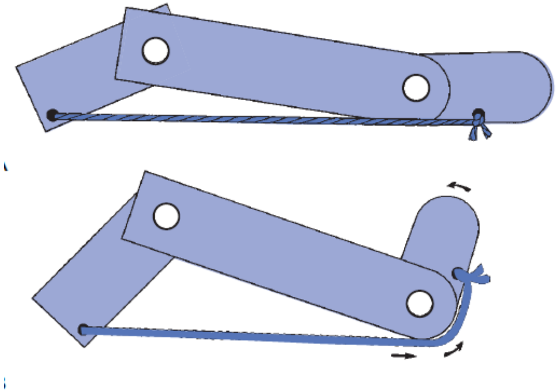
The beam model of the longitudinal arch. The arch is a curved beam consisting of interconnecting joints and supporting plantar ligaments. Tensile forces are concentrated on the inferior beam surface; compressive forces are generated at the superior surface.

Truss model



A. Schematic of a truss. The *far left* wooden segment represents the hindfoot, the *middle* wooden segment represents the forefoot, and the *far right* wooden segment is the proximal phalanx. The rope is the plantar fascia. **B.** Dorsiflexion of the proximal phalanx raises the arch through traction on the plantar fascia.





- This winding of the plantar fascia shortens the distance between the calcaneus and metatarsals to elevate the medial longitudinal arch.
- The plantar fascia shortening that results from hallux dorsiflexion is the essence of the windlass mechanism principle

■ Foot positions versus 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 TABLE:

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

Muscles

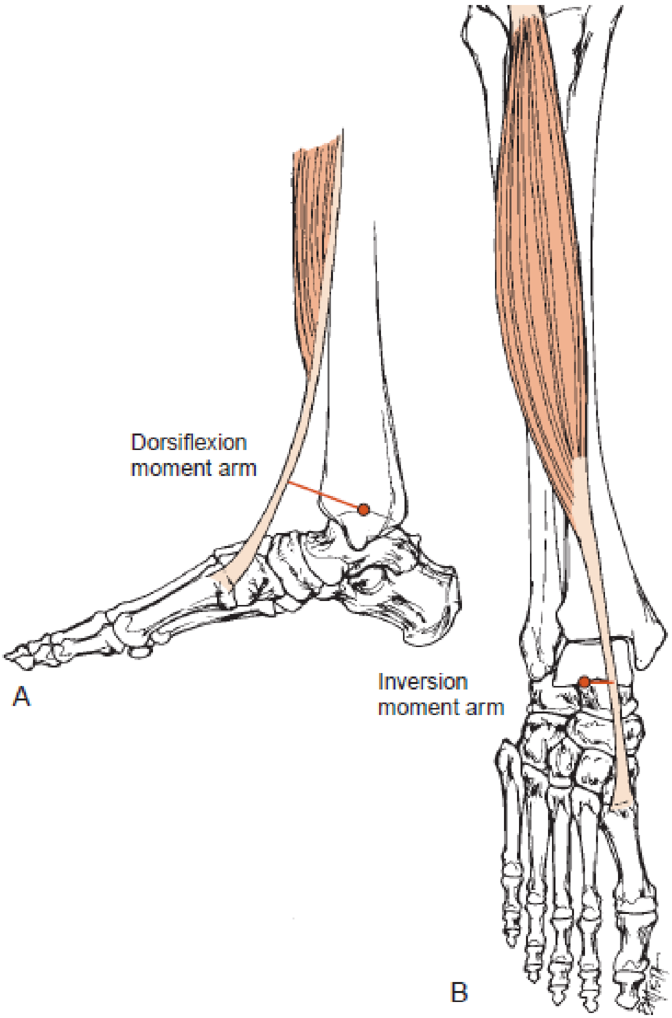


Figure 45.3: The tibialis anterior exhibits a large dorsiflexion moment arm **(A)**, but has a much smaller moment arm for inversion **(B)**.

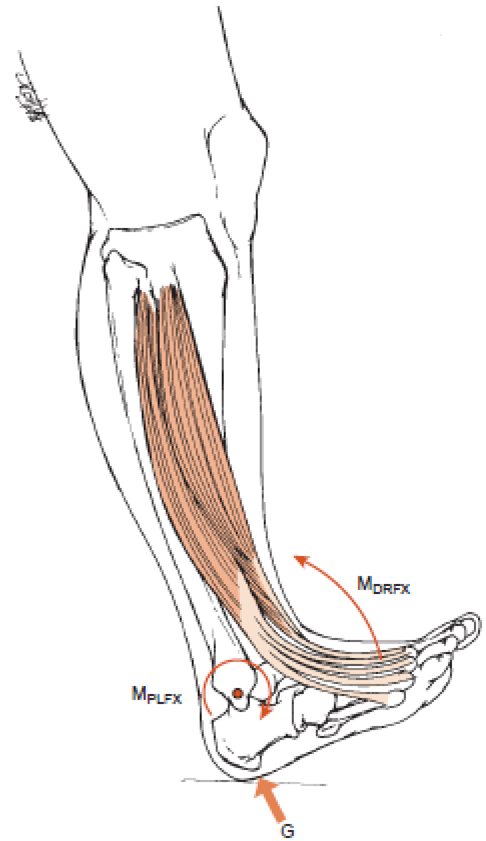


Figure 45.2: The dorsiflexor muscles must generate an extension (dorsiflexion) moment *(M_{DRFX})* to balance the flexion (plantarflexion) moment *(M_{PLFX})* applied by the ground reaction force *(G)*.

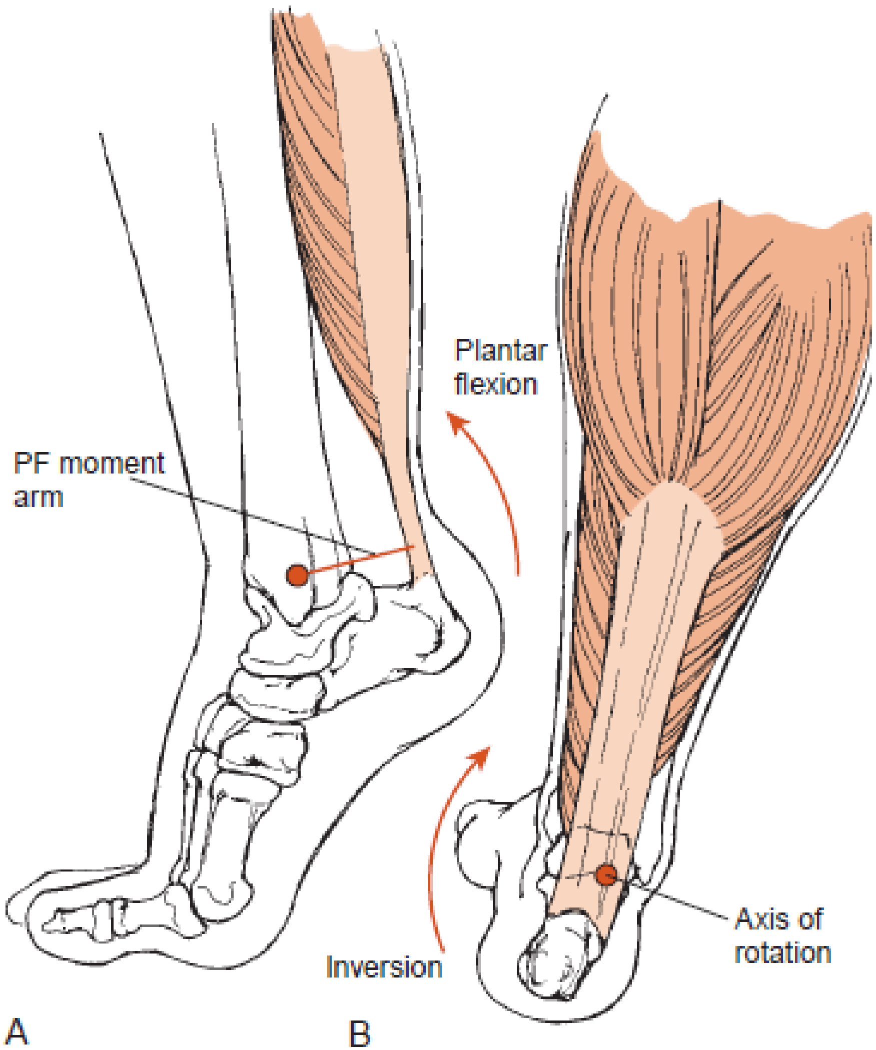


Figure 45.6: The Achilles tendon has a large moment arm for plantarflexion **(A)** and a small moment arm for inversion **(B)**.

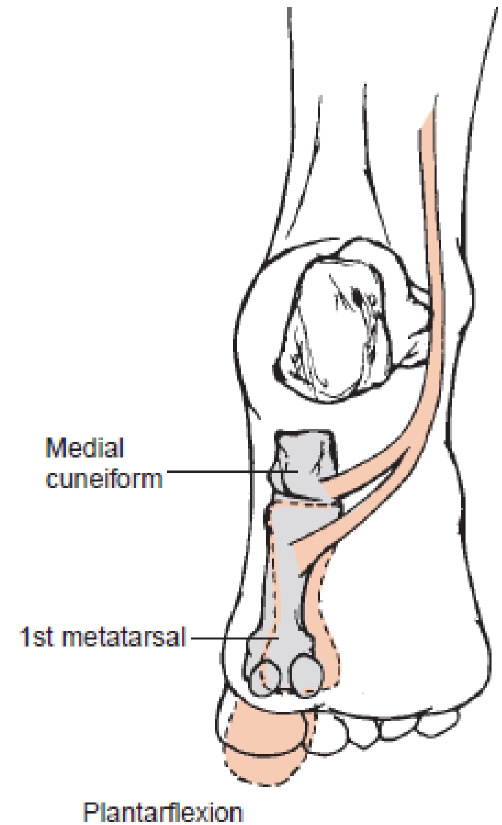


Figure 45.17: The peroneus longus pulls on the medial cuneiform and first metatarsal bone, producing plantarflexion of the first ray.

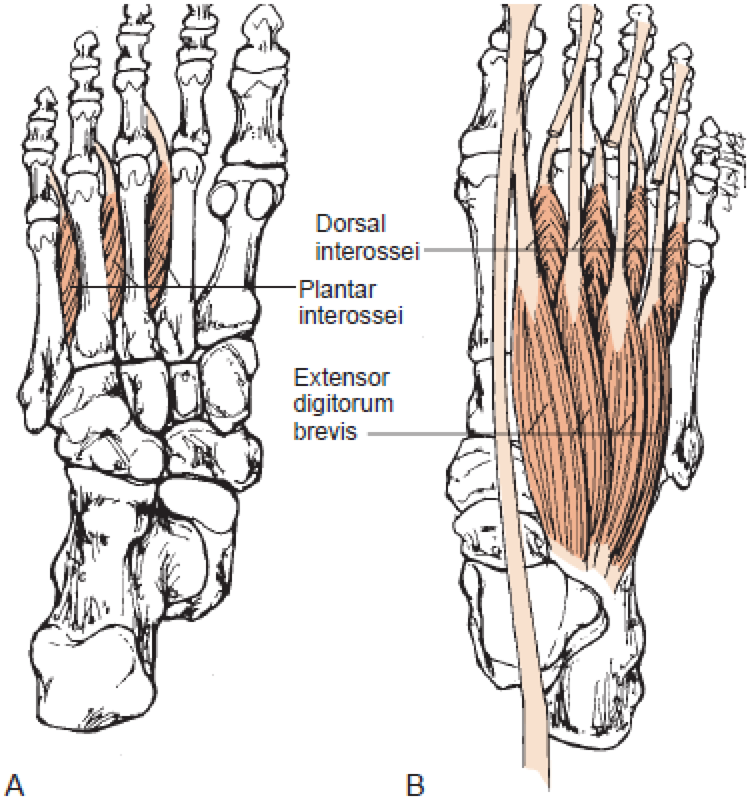
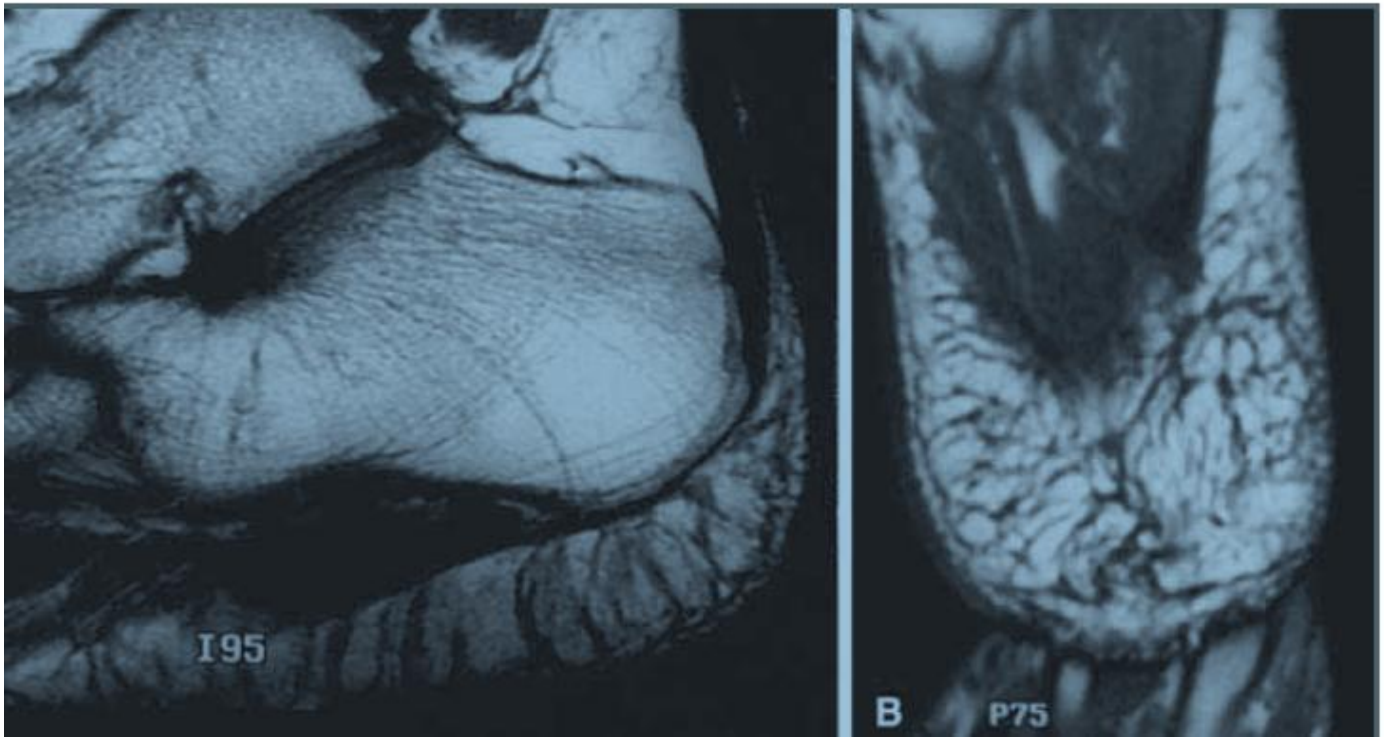


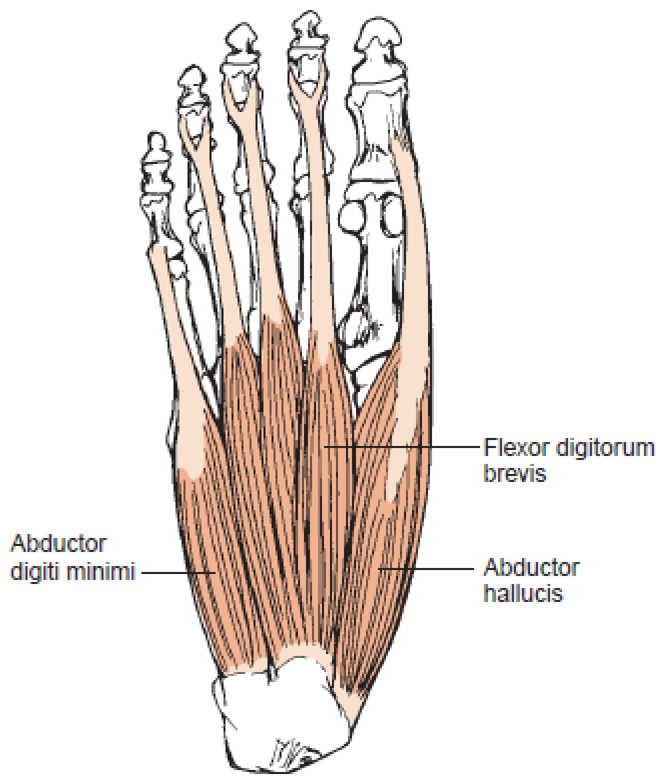
Figure 45.23: The plantar and dorsal interossei form the fourth layer of the intrinsic muscles of the foot. The extensor digiti brevis is palpable on the dorsal surface of the foot. **A.** Plantar view containing the plantar interossei. **B.** Dorsal view containing the dorsal interossei and the extensor digitorum brevis.

Layers in the Foot



Structure of a normal heel pad as seen on magnetic resonance imaging (MRI). **A.** Lateral view. Note vertically oriented fat-filled columns. **B.** Top view of the heel pad demonstrating the spiral structure of the septae, which separate the fat-filled cells.

The first muscular layer



Second Muscular Layer in the Foot

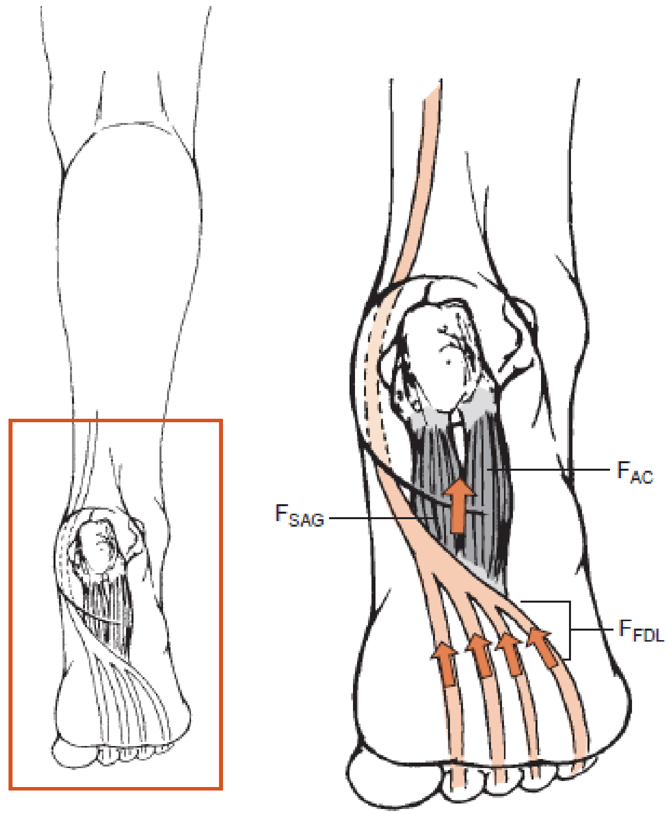


Figure 45.21: The pull of the flexor accessorius (F_{AC}) on the tendons of the flexor digitorum longus adds to the force (F_{FDL}) of the flexor digitorum longus to produce a flexion force (F_{SAG}) on the toes in the sagittal plane.

Third Muscular Layer in the Foot

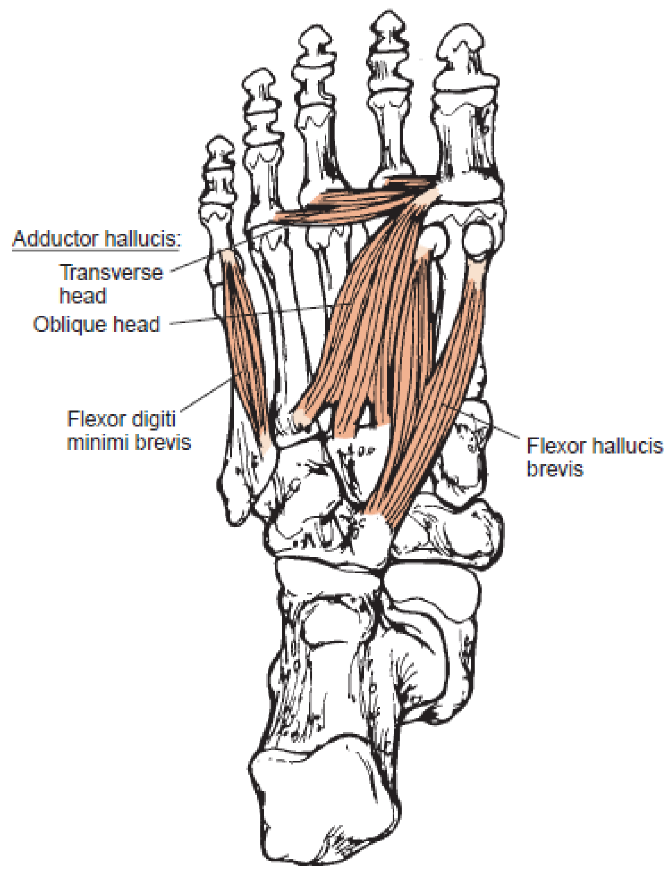
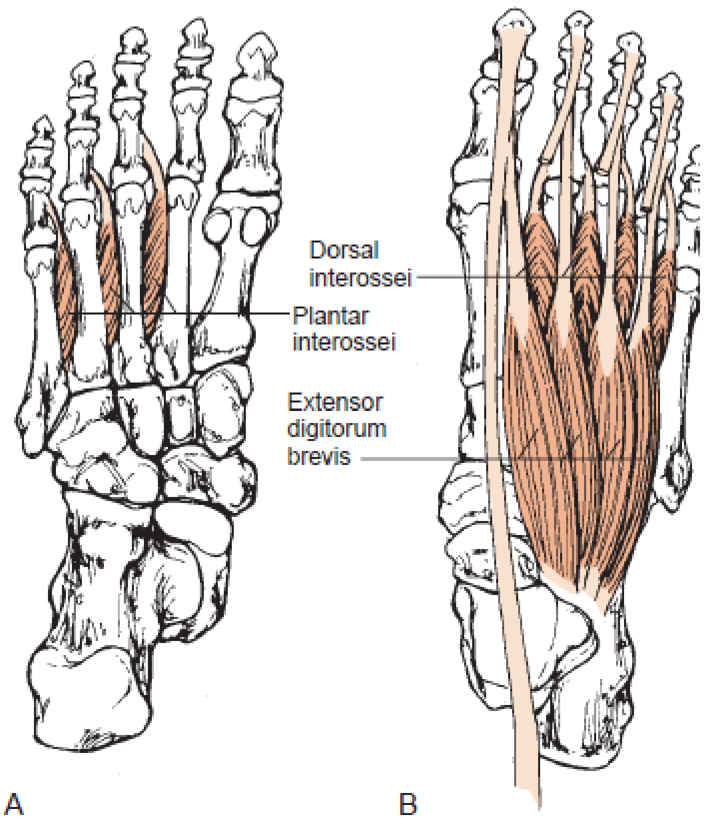


Figure 45.22: The third layer of the intrinsic muscles includes the flexor hallucis brevis, adductor hallucis, and flexor digiti minimi brevis.

Fourth Muscular Layer in the Foot



summary

- The foot must be stable
- The foot must also be mobile
- "The human foot is a masterpiece of engineering and a work of art."

B