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Bonica's Management of Pain, 3rd Edition

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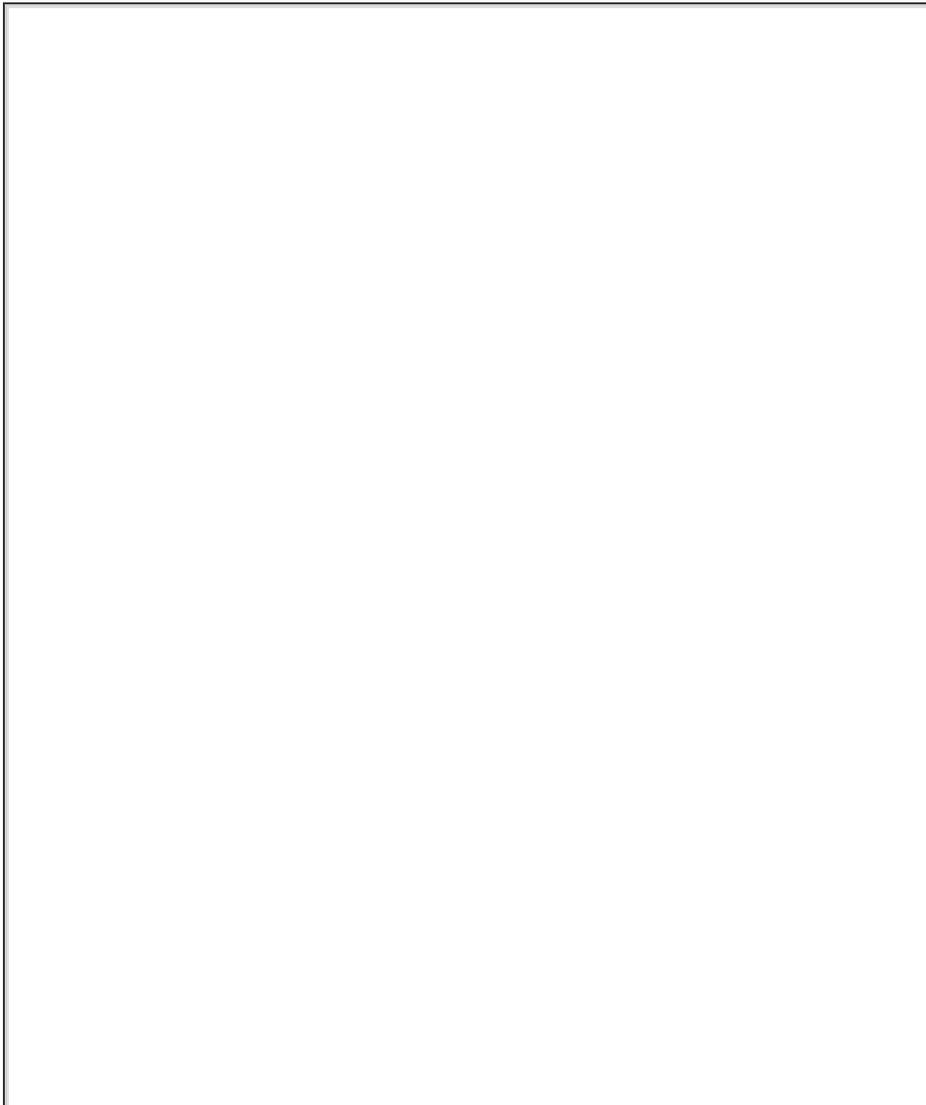
## CHAPTER 80

# BASIC CONSIDERATIONS

*Part of "CHAPTER 80 - Pain in the Leg, Ankle, and Foot"*

### ***Etiology***

Table 80-1 lists the most important painful disorders that affect the leg, ankle, and foot. Those listed in the first three major categories are discussed in this chapter. Those in the fourth and fifth categories are covered in Chapter 19, Chapter 20, Chapter 21, Chapter 22 and Chapter 23, Chapter 28, Chapter 29 and Chapter 30, Chapter 33, and Chapter 77.



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- I. Musculoskeletal disorders of the leg
    - A. Trauma: fractures; dislocations; compartment syndrome; rupture of muscle or tendons
    - B. Infections: acute or chronic osteomyelitis; other infections
    - C. Tumors: benign; benign aggressive; malignant; metastases
  - II. Musculoskeletal disorders of the ankle
    - A. Arthritides: osteoarthritic; rheumatoid; septic; gouty; hemophilic; neuropathic
    - B. Trauma: fracture; dislocation or subluxation; recurrent subluxation; laxity; tendinitis
    - C. Other diseases of bone: benign, benign aggressive or malignant tumor; osteochondritis ossificans
  - III. Musculoskeletal disorders of the foot
    - A. Hindfoot: plantar fasciitis; tarsal coalition; Achilles tendinitis; heel pad deficiency; tarsal tunnel syndrome
    - B. Midfoot: medial arch strain; midtarsal fracture or dislocation; posttibial insufficiency; ganglion
    - C. Forefoot: metatarsalgia; callosities; stress fracture
    - D. Great toe: hallux valgus (bunion); hallux rigidus; hypermobility; sesamoiditis; gout
    - E. Small toes: hammertoe; claw toe; soft or hard corns; neuroma; overlapping toes; bunionette; neuropathy; vascular problems
  - IV. Other painful disorders that affect the leg, foot, and ankle
    - A. Neuropathic painful disorders: radiculalgia, neuralgia, causalgia; central nervous system disease; postamputation pain; entrapment syndromes
    - B. Myofascial syndromes: thigh muscle, leg muscle, or foot muscle involvement
    - C. Peripheral vascular disease: acute arterial obstruction; arteriosclerosis obliterans; Buerger's disease; Raynaud's disease (phenomenon); other disorders of the microcirculation; cold injuries
  - V. Referred pain
    - A. Pain referred from the pelvic viscera
    - B. Pain referred from the thigh and spine
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**TABLE 80-1.** Classification of painful disorders in the leg, ankle, and foot

## ***Epidemiology***

The National Ambulatory Medical Care Survey 1980–1981 (1) estimated that in 1986 acute pain in the knee, leg, ankle, and foot resulted in approximately 5 million visits to physicians in the United States. This is second only to the number of physician visits caused by ear

pain. Chronic painful conditions in the foot and ankle result in nearly 4 million visits to physicians, representing 10% of all visits for chronic painful conditions (2). Estimates have been made for the type, number, morbidity, and health services required by various musculoskeletal disorders and injuries of the leg, ankle, and foot (Table 80-2).

Injury type	Morbidity				Health services required		
	Total number	Restricted activity (days)	Bed disability (days)	Workdays lost	Visits to physicians	Hospital discharges	Total hospital stay (days)
<b>Fracture</b>							
Tibia or fibula	212	8,056	3,138	3,201	578	108	1,026
Ankle or foot	900	13,860	2,700	4,500	978	36	342
<b>Sprain</b>							
Knee or leg	1,810	17,195	3,620	5,792	752	36	234
Ankle or foot	5,222	24,021	6,266	7,310	1,883	18	91
<b>Dislocation</b>							
Open wound	176	2,886	968	1,196	440	148	641
Open wound	3,500	11,550	3,150	4,900	1,820	43	172
<b>Total</b>	<b>11,820</b>	<b>77,568</b>	<b>19,042</b>	<b>26,899</b>	<b>6,451</b>	<b>389</b>	<b>2,506</b>

Note: 1986 estimates of incidence, morbidity, and health services required (in thousands).  
Data extrapolated from Holbrook TL, et al. The frequency of occurrence, impact, and cost of musculoskeletal conditions in the United States. Chicago: American Academy of Orthopedic Surgeons, 1984; and from the National Center for Health Statistics. Current estimates for the National Health Institute Survey, United States, 1982. Ser 10, No 150. Hyattsville, MD: DHHS publication no (PHS) 85-1578, 1986.

**TABLE 80-2.** Musculoskeletal injuries involving the leg, ankle, and foot

Table 80-2 also lists the incidence of musculoskeletal injuries involving bones, joints, and soft tissues of the leg, ankle, and foot (1,2). These injuries, together with arthritis and other conditions affecting the leg, ankle, and foot, are among the most frequent causes of pain and disability in the United States. Similar trends are expected in other industrialized nations. The economic impact is significant and, taking into account the 1984 cost for workdays lost, visits to physicians, and hospital stays for acute injuries and pain, amounts to approximately \$2.4 billion (3). This number does not take into account the economic impact of arthritis, infections, tumors, and other chronic painful conditions. The estimated cost for all conditions probably exceeds \$8.5 billion (5).

### ***Anatomy and Function of the Leg, Ankle, and Foot***

Although the anatomy of the lower and upper extremities shares similarities, the functions are very different (6). The distal part of the upper limb is structured for versatility of movement, whereas the lower limb is built for weight-bearing and locomotion. Evolution and embryologic development demonstrate rotation and extension of the lower limb that position the foot for erect stance. Therefore, the flexor aspect of the leg faces posteriorly and the extensor aspect, anteriorly. In the anatomic position, the thumb is on the hand's lateral margin, whereas the great toe is on the foot's medial margin (6). The sole of the foot faces backward, and the palm of the hand faces forward. The foot is positioned at right angles to the leg. Flexion of the foot is described as *plantar flexion* and extension is called *dorsiflexion* (6).

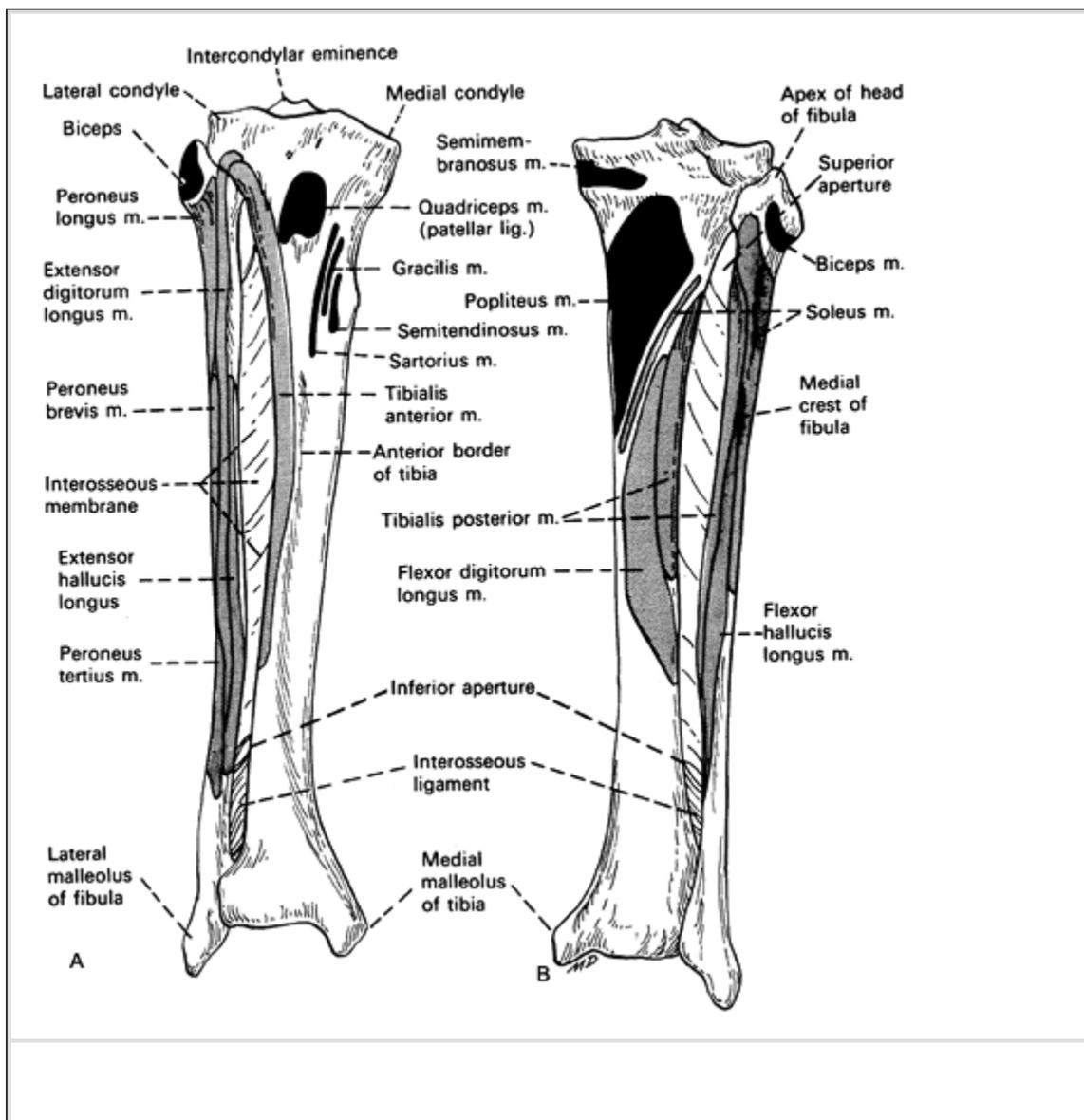
The total body weight during weight-bearing is transmitted through the ankle and foot. Thick heel and toe pads act as shock absorbers during walking and running, and the joints are

capable of making adjustments necessary for fine balance on various terrain (7). In some forms of strenuous physical activity, the ground reaction force is five times body weight. Because of the mechanics of the foot and ankle, the forces in the ankle are two to three times larger than the ground reaction force. Peak ankle joint forces may exceed 15 to 20 times body weight (7).

## Anatomy

### *Tibia and Fibula.*

The tibia and fibula, two parallel bones, constitute the skeleton of the leg corresponding to the radius and ulna. However, unlike the radius and ulna, little motion occurs between the lower limb bones at the proximal and distal articulation (6). The fibula does not articulate at the knee as the radius does at the elbow. The fibula acts mainly as an origin for muscles and has little weight-bearing role (8) (Fig. 80-1).



**Figure 80-1.** Anatomy of the tibia and fibula showing the sites of origin (*gray areas*) and insertion (*black areas*) of the muscles that move the ankle and foot. **A:** Anterior view. **B:** Posterior view. The lateral condyle has a raised area into which most of the iliotibial tract inserts. The facet for articulation with the head of the fibula is on the curved inferior surface of the lateral condyle. The semimembranosus muscle inserts on the medial condyle into a posteriorly placed deep transverse groove. The anterior border and medial surface of the tibia are largely subcutaneous. The posterior surface gives origin to most of the soleus, tibialis posterior, and flexor digitorum longus muscles. The posterior tibia receives the insertion of the popliteus and two of the hamstring muscles. The medial border of the tibia extends into the medial malleolus. This has an articular surface on the medial side continuous with the distal tibia. These articular surfaces, with the lateral malleolus formed by the distal fibula, form the ankle mortise articulating with the dome of the talus. The fibula articulates with the lateral border of the distal tibia at the fibular notch. The proximal head of the fibula is subcutaneous and rises laterally to its apex; the facet for its articulation with the tibia is on its medial crest. The lateral malleolus is the expanded lower end of the fibula and is also subcutaneous. Its medial articular surface forms the lateral part of the ankle mortise. (Modified from Clemente CD, ed. *Gray's anatomy of the human body*, 30th Am ed. Philadelphia: Lea & Febiger, 1985.)

The tibia and fibula articulate at proximal and distal tibiofibular joints and are joined together by the capsules of both joints as well as the intraosseous membrane. The superior tibiofibular joint is a synovial joint between the head of the fibula and a posterolateral part of the lower surface of the lateral tibial condyle. The anterior and posterior ligaments of the head of the fibula run upward and medial to the tibia and strengthen its capsule (see Fig. 80-1). This joint is innervated by the common peroneal nerve and the nerve to the popliteus muscle, a branch of the tibial nerve.

The interosseous membrane consists of thin but strong fibers passing downward and laterally joining the interosseous margin of the tibia to the sharp medial border of the fibula (see Fig. 80-1). The membrane separates the muscles of the anterior compartment from the posterior compartment and forms a large surface for the origin of muscles in both compartments. Above the proximal end of the membrane, just below the superior tibiofibular joint, is a large oval aperture for passage of the anterior tibial vessels to the anterior compartment. Close to its distal

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end (approximately 5 cm above the lateral malleolus) is a smaller aperture for the perforating branch of the peroneal artery. Between the adjacent distal ends of the tibia and fibula, the membrane is continuous with the crural tibiofibular interosseous ligament.

The tibiofibular interosseous ligament is composed of thick, short, strong fibers that run from the tibia to the fibula ending short of the articular margin of the ankle joint (6,8). The interosseous ligament is much stronger than the interosseous membrane. It prevents separation of the distal tibia and fibula and stabilizes the ankle joint. Rosse (9) has pointed out that the ligament is so strong that, when these forces are excessive (e.g., in an eversion injury), the fibula fractures distal to the ligament rather than the ligament rupturing. These injury patterns depend on the ratio of the strength of the ligaments and bones. Very old and very young patients will fracture bone, whereas the patients between these ages are more likely to tear ligaments. The tibiofibular interosseous ligament allows rotational displacement of the malleolus, with greater motion occurring at the proximal tibiofibular joint (see Fig. 80-1) (7).

The inferior tibiofibular joint is a fibrous joint stabilizing the distal end of the fibula in a groove on the lateral aspect of the tibia. It is essential for the integrity of the ankle joint. The inferior tibiofibular joint is stabilized by the interosseous ligament and the thinner, weaker anterior and posterior inferior tibiofibular ligaments, placed superficially on the front and back of the joint. The joint is innervated by the tibial and peroneal nerves as outlined in Hilton's law (6).

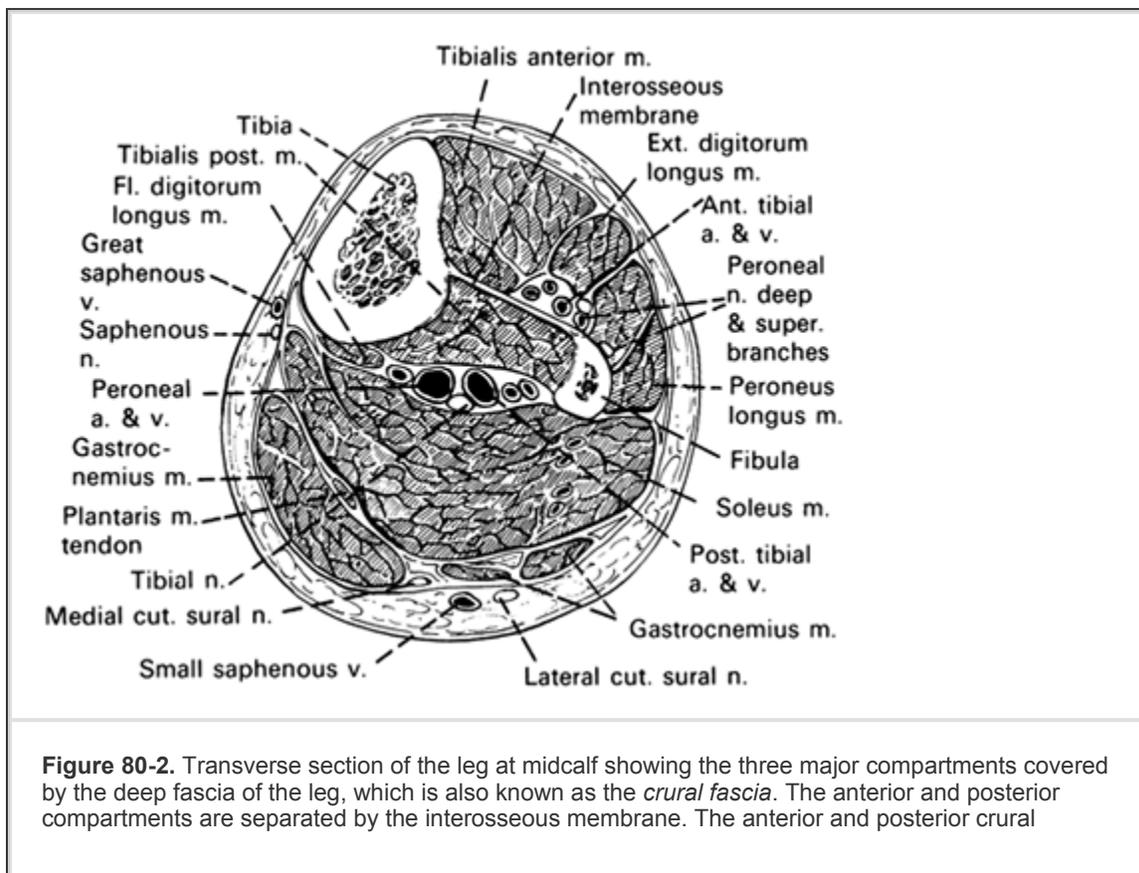
## Muscles of the Leg and Foot

### Muscular Compartments of the Leg.

Figure 80-2 illustrates the compartments of the leg at midcalf level (10). The muscles within these compartments provide movement at the ankle, tarsus, and toes and flexion at the knee (gastrocnemius). The muscles are arranged in a manner similar to that of the prime movers of the wrist and carpus. The anterior compartment contains the extensors; the deep posterior compartment contains the flexors of the toes and tarsus. The superficial posterior compartment contains the flexors of the ankle, the triceps surae (6). A third compartment containing the peroneal muscles is present laterally for which there is no counterpart in the forearm. Each compartment is supplied by a nerve. The tibial nerve supplies the flexor

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compartment, the deep peroneal nerve supplies the extensors, and the superficial peroneal nerve supplies the peroneal compartment. Table 80-3 lists the muscles of the leg and foot, their function, and their nerve supply.



intermuscular septa enclose the peroneus longus and brevis, which separate the peroneal compartment from the anterior and posterior compartments. Note the location of the major vessels and nerves. (Modified from Eycleshymer AC, Schoemaker DM. *A cross-sectional anatomy*. New York: Appleton- Century-Crofts, 1911:96.)

Region/muscle group/function	Peripheral nerve supply	Segmental nerve supply*
<b>Ankle and foot motion</b>		
<b>Dorsiflexion</b>		
Tibialis anterior	Deep peroneal	L-4, <u>L-5</u> , S-1
Peroneus tertius	Superficial peroneal	L-4, <u>L-5</u> , S-1
<b>Plantar flexion</b>		
Gastrocnemius	Tibial	<u>S-1</u> , S-2
Soleus	Tibial	<u>S-1</u> , S-2
Plantaris	Tibial	<u>S-1</u> , S-2
<b>Eversion: peroneus longus and brevis</b>		
<b>Inversion</b>		
Tibialis anterior	Deep peroneal	L-4, <u>L-5</u> , S-1
Tibialis posterior	Tibial	<u>L-5</u> , S-1
<b>Toes</b>		
<b>Flexion</b>		
Flexor digitorum longus and brevis	Tibial (medial plantar)	<u>L-5</u> , S-1
Flexor hallucis longus and brevis	Tibial (medial plantar)	<u>L-5</u> , S-1
<b>Extension</b>		
Extensor hallucis longus	Deep peroneal	<u>L-5</u> , S-1
Extensor digitorum longus and brevis	Deep peroneal	<u>L-5</u> , S-1
<b>Abduction</b>		
Abductor hallucis	Medial plantar	<u>L-5</u> , S-1
Abductor digiti minimi	Lateral plantar	<u>S-1</u> , S-2
Abductor of first toe: abductor hallucis	Lateral plantar	<u>S-1</u> , S-2
<b>Other foot muscles</b>		
Quadratus plantae—flexor terminal phalanx	Lateral plantar	S-1, S-2
Flexor digiti minimi—flexor proximal phalanx	Lateral plantar	S-1, S-2
First lumbrical—flexor proximal phalanx of second toe	Medial plantar	L-5, S-1
Second, third lumbricals—extend two distal phalanges of third, fourth, fifth toes	Lateral plantar	S-1, S-2
Dorsal interossei (abduct second, third, fourth toes)	Lateral plantar	S-1, S-2
Plantar interossei (adduct third, fourth, fifth toes)	Lateral plantar	S-1, S-2

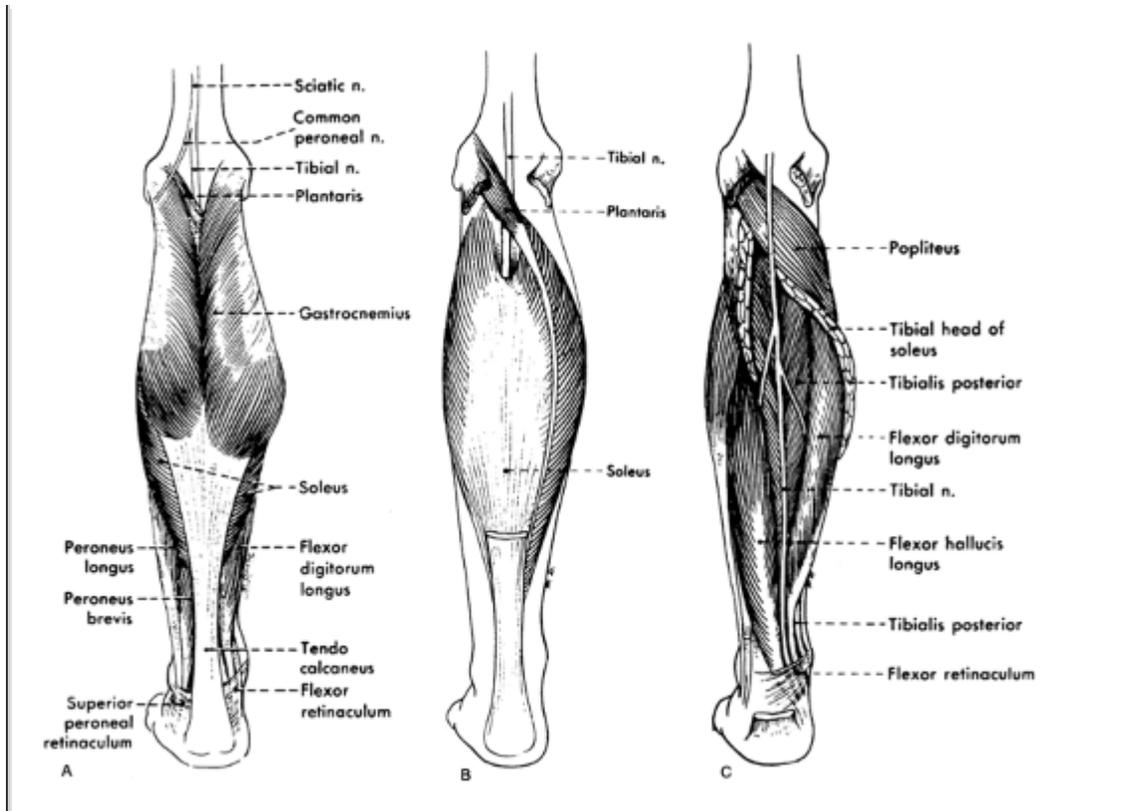
\*Underline indicates the main roots.

**TABLE 80-3.** Muscles of the leg, ankle, and foot and their nerve supply

## Prime Movers of the Ankle

### ***FLEXOR COMPARTMENT (PLANTAR FLEXORS).***

Figure 80-3 shows the muscles of the back of the leg (11). The gastrocnemius, soleus, and plantaris act together as the triceps surae within the superficial posterior compartment. These three muscle bellies are the most powerful plantar flexors of the foot (6,8). Other muscles pass behind the axis of the ankle but, because they are smaller and have a less efficient lever arm, they are less powerful plantar flexors of the ankle (6,8). These muscles include the tibialis posterior, peroneus longus and brevis, flexor hallucis longus, and flexor digitorum longus.

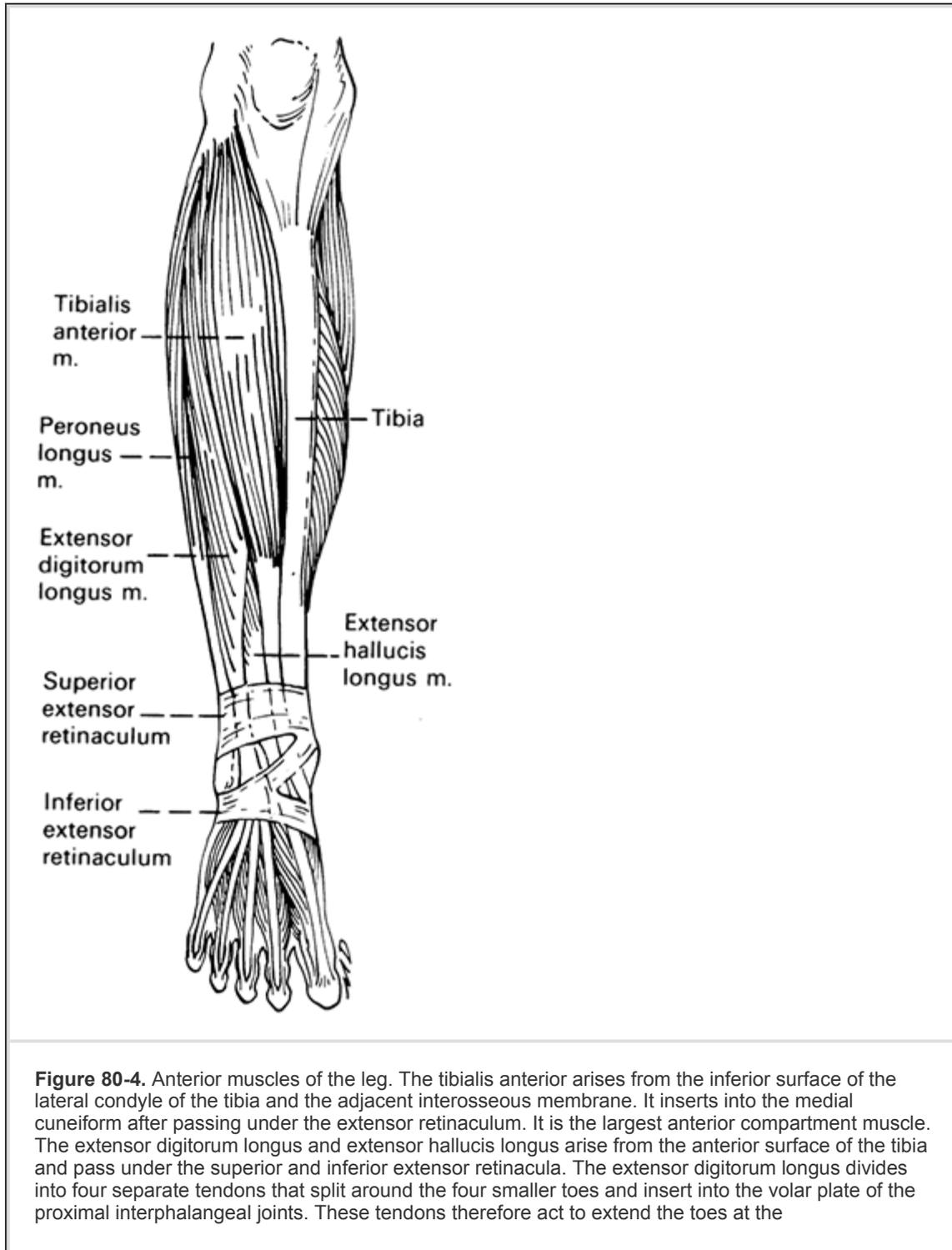


**Figure 80-3.** Posterior muscles of the left leg. All are plantar flexors, although some also act to flex and invert the foot or toes. **A:** The gastrocnemius muscle is superficial, with heads originating from the posterior aspect of the medial and lateral femoral condyles. Each head inserts onto the soleus, together forming the Achilles tendon, which inserts into the posterior surface of the calcaneus. **B:** The second layer consists of the soleus and plantaris muscles. The soleus arises from two heads, one on the tibia and the other on the fibula and interosseus membrane. A tendinous arch unites the two heads from which additional fibers arise. Under the fibrous arch runs the tibial nerve. Its muscular fibers end in a broad aponeurosis into which the gastrocnemius muscle inserts. The plantaris arises from the lateral condyle of the femur, passes obliquely medially, and forms a thin tendon that inserts just medial to the tendo calcaneus on the calcaneus. **C:** The deep muscles of the calf showing the tibial nerve. The soleus, gastrocnemius, and plantaris form the superficial posterior compartment. The tibial nerve is superficial to the muscles of the deep posterior compartment. The tibialis posterior arises from the interosseous membrane and from the adjoining parts of the posterior surfaces of the tibia and fibula (see Fig. 80-1B). The tendon lies deep to the flexor digitorum longus and lies beside it in a tendon sheath on a groove on the medial malleolus. The tendon passes deep to the flexor retinaculum and superficial to the deltoid ligament. It inserts into the tuberosity of the navicular bone with fibers going to other bones in the midfoot (see Fig. 80-15). This muscle (with the tibialis anterior) inverts the foot. The flexor digitorum longus arises from the tibia and the flexor hallucis arises from the fibula. Both tendons enter the sole of the foot behind the medial malleolus, and both are invested in tendon sheaths. The common tendon of the flexor digitorum longus splits into four tendons with their own sheaths to insert into the base of the distal phalanges of the second, third, fourth, and fifth toes, and the flexor hallucis inserts into the base of the distal phalanx of the great toe. These muscles flex the toes (see Fig. 80-15 for insertions of these muscles). (Reprinted from Rosse C. *Hollinshead's textbook of anatomy*, 5th ed. Philadelphia: Lippincott–Raven Publishers, 1997:371, 372, with permission.)

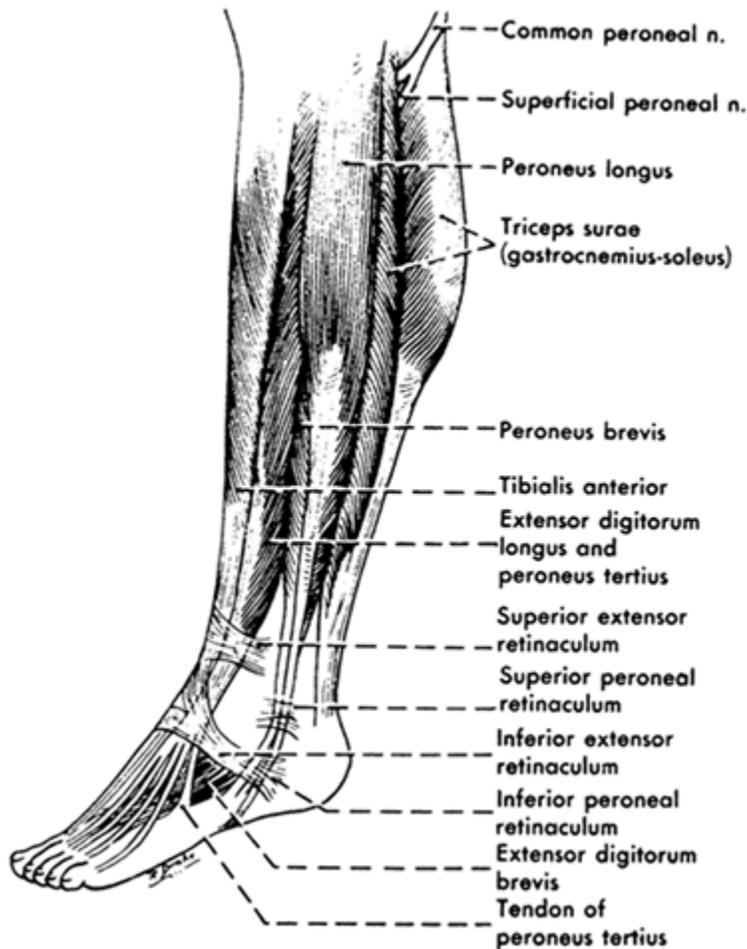
### **EXTENSOR COMPARTMENT (DORSIFLEXORS).**

The tibialis anterior and peroneus tertius are the two main dorsiflexors of the ankle and

also act on the midtarsal joint. The extensor hallucis longus and extensor digitorum longus act primarily to extend the great toe and lesser toes, respectively. They also weakly dorsiflex the ankle and midtarsal joints (Fig. 80-4) (7). The tibialis anterior is the bulkiest muscle in the anterior compartment and acts to dorsiflex and invert the foot. The peroneus tertius arises with the muscle belly of the digital extensor but, because its tendon inserts into the base of the fifth metatarsal, dorsiflexes the ankle (Fig. 80-5).



metatarsophalangeal joint but not at the interphalangeal joints. The extensor hallucis longus inserts into the distal phalanx of the great toe. The peroneus tertius arises from a small area on the anterior tibia and adjacent interosseous membrane. The tendon passes under the extensor retinaculum lateral to the extensor digitorum brevis and inserts into the fifth metatarsal base. The tibialis anterior acts as an ankle dorsiflexor and inverter, whereas the peroneus tertius acts as a dorsiflexor and everter (see Fig. 80-15 and Fig. 80-16 for insertions of these muscles). (Modified from Clemente CD, ed. *Gray's anatomy of the human body*, 30th Am ed. Philadelphia: Lea & Febiger, 1985.)



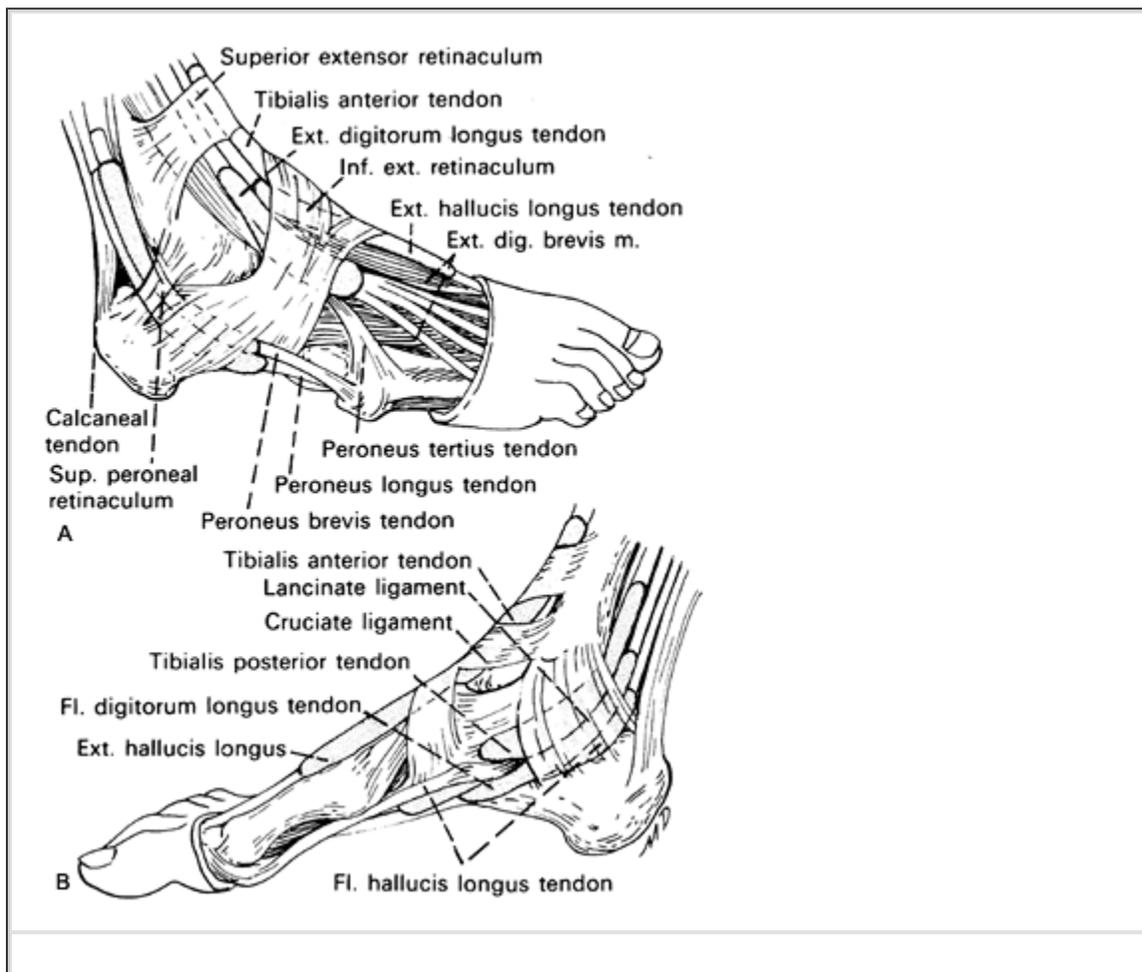
**Figure 80-5.** Lateral muscles of the left leg. The two anterolateral compartment muscles are the peroneus longus and peroneus brevis arising from the head and upper two-thirds of the lateral surface of the tibia (see Fig. 80-1A). The two tendons pass behind the lateral malleolus, lateral to the axis of the subtalar joint. The brevis inserts into the base of the fifth metatarsal. The longus enters the sole of the foot in a groove of the cuboid bone and crosses the sole before inserting into the base of the first metatarsal and the bones around it (see Fig. 80-16 for the insertions of these muscles). The brevis muscle everts the foot, and the longus acts to plantar flex the great ray and everts the ankle. (Reprinted from Rosse C. *Hollinshead's textbook of anatomy*, 5th ed. Philadelphia: Lippincott-Raven Publishers, 1997:377, with permission.)

## Extrinsic Flexors and Extensors of the Toes.

The superficial flexor of the arm is analogous to the soleus. The soleus muscle belly forms a tendon inserting onto the calcaneus. The tendon insertion continues distal to the heel, forming in the same plane

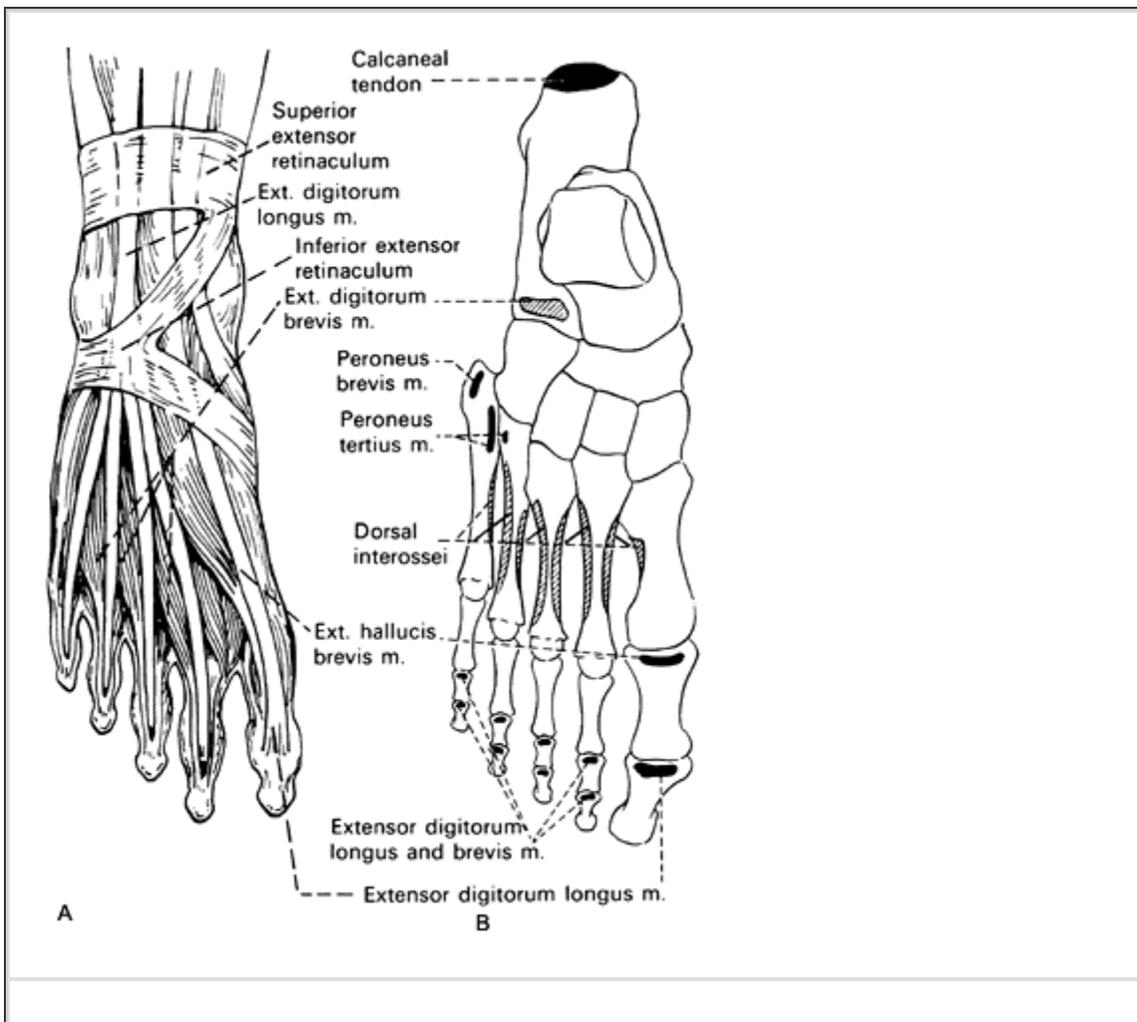
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the flexor digitorum brevis, which inserts into the middle phalanx of the toes similar to the profundus in the hand. Therefore, only one common extrinsic digital flexor is found in the calf, the flexor digitorum longus (see Fig. 80-3C), analogous to the flexor digitorum profundus in the forearm (6) (see Fig. 80-4). The flexor hallucis longus corresponds to the flexor pollicis longus. The flexor digitorum longus arises from the tibia, and the flexor hallucis arises from the fibula (see Fig. 80-1B); the tendons pass on the medial side of the heel and enter the sole of the foot through the tarsal tunnel behind the malleolus (Fig. 80-6). Also contained in the tarsal tunnel are, from medial to lateral, the tibialis posterior tendon, the digitorum longus, the blood vessels, the tibial nerve, and the hallucis longus. The tendons are invested in synovial sheaths and are kept in place by the flexor retinaculum, which is much thinner than the corresponding structure in the wrist (6,10) (see Fig. 80-6). The flexor tendons insert into the distal phalanges. The anatomic arrangement of synovial and fibrous flexor sheaths in the toes through which the tendons pass is similar to that of the fingers.



**Figure 80-6.** Synovial sheaths of the tendons around the ankle. **A:** Anterolateral aspect showing the tendons and synovial sheaths of the tibialis anterior and extensor digitorum longus passing under the superior and inferior extensor retinacula. Beyond the sheath, the extensor digitorum longus divides into four tendons. The extensor hallucis longus inserts into the base of the distal phalanx of the great toe. Note the insertion of the peroneus tertius onto the bases of the fifth metatarsal (see Fig. 80-16B). The peroneus longus and brevis have individual synovial sheaths that pass under the peroneal retinaculum. **B:** Medial aspect showing the synovial sheaths of the tibialis posterior, flexor digitorum longus, and flexor hallucis longus passing behind the medial malleolus. These tendons are covered by the flexor retinaculum covering the end of the tibial nerve and the beginning of two plantar nerves. This is a site for entrapment of these nerves. (Modified from Clemente CD, ed. *Gray's anatomy of the human body*, 30th Am ed. Philadelphia: Lea & Febiger, 1985.)

The extensor hallucis longus and extensor digitorum longus are located in the anterior compartment (see Fig. 80-4). Both originate from the fibula and insert into the toes through the dorsal digital expansions, analogous to those in the fingers, and act mainly to extend the metatarsophalangeal (MP) joints (see Fig. 80-16). The tendons are held in place in front of the ankle by the superior and inferior extensor retinacula and are enclosed in a synovial membrane (see Fig. 80-4). Unlike the hand, an additional short extensor muscle exists on the dorsum of the foot extending all of the toes.



**Figure 80-16. A:** Muscles of the dorsal surface of the right foot. **B:** Dorsal view of the bones of the foot showing the origins of the intrinsic muscles (*striped*) and the insertions of the intrinsic and extrinsic muscles (*black*). (Modified from Hollinshead WH. *Anatomy for surgeons*, 3rd ed. Vol 3. Philadelphia: Harper & Row, 1982.)

### Inverters and Everters.

The peroneus brevis is the primary everter of the foot (see Fig. 80-5). The peroneus longus inserts mainly into the base of the first metatarsal on the plantar aspect having passed around the lateral border of the cuboid. It acts primarily to plantar flex the great ray and everts the ankle as a secondary function. Both peroneal muscles arise from the fibula and pass behind the lateral malleolus. The brevis inserts into the base of the fifth metatarsal.

The tibialis posterior, the deepest muscle in the flexor compartment, is the principal inverter of the foot (see Fig. 80-3). In this function it is substantially assisted by the tibialis anterior (see Fig. 80-4).

Many other muscles act to invert and evert the foot at the subtalar and midtarsal joints. Even the tendo Achilles can act to both invert or evert the foot in severe cavus deformity and flatfoot, respectively. As a flatfoot deformity progresses, the muscles acting to invert the foot have less mechanical advantage and those acting to evert the foot have greater mechanical advantage, explaining the rapidly progressive nature of severe flatfoot.

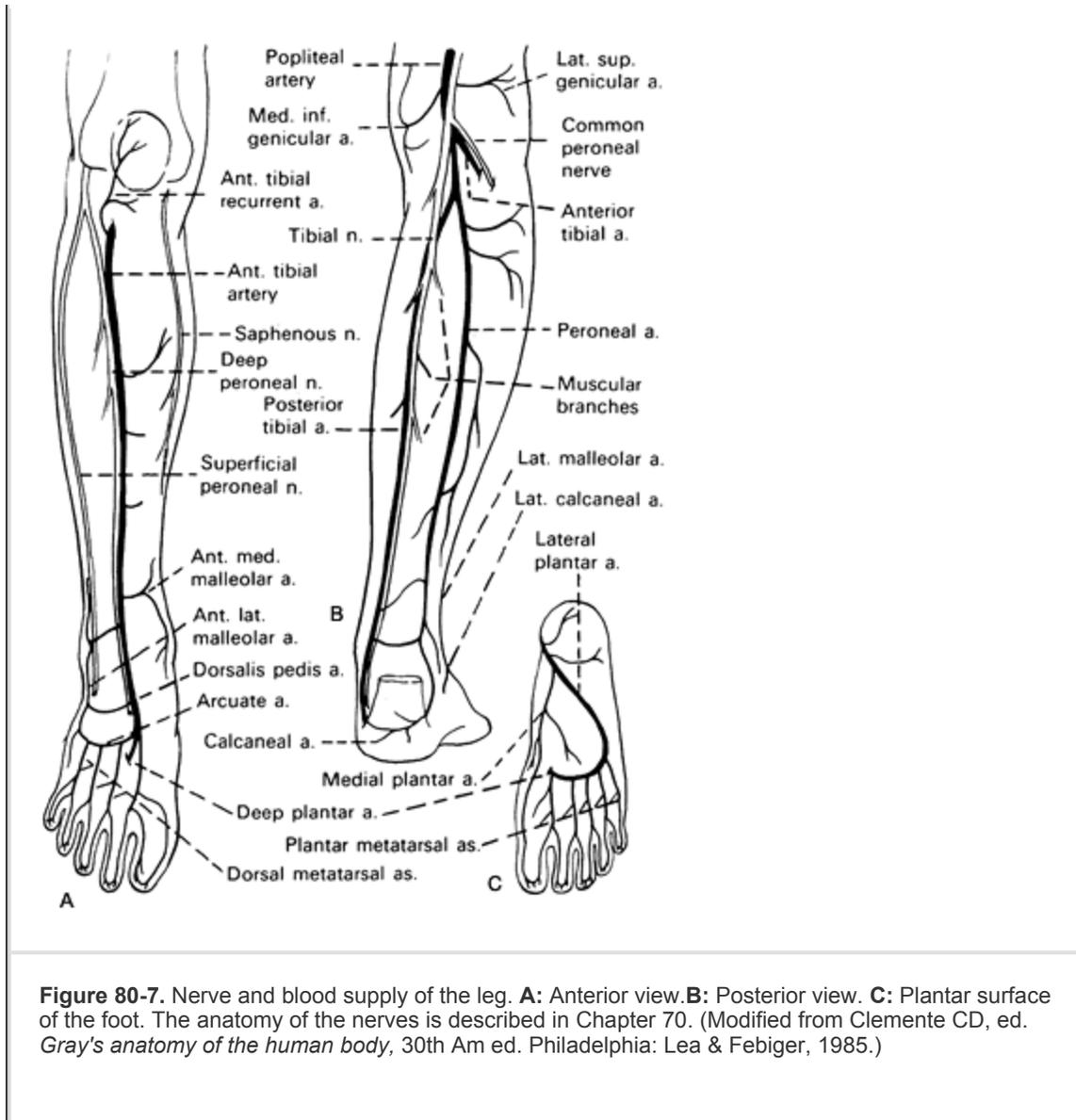
Figure 80-6 illustrates the synovial sheaths of the tendons and retinacula around the ankle joint.

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### Nerve and Blood Supply of the Leg.

Figure 80-7 depicts the major arteries and nerves of the leg (6,8). The anatomy and distribution of the tibial and peroneal nerves are described in detail in Chapter 77. The leg and foot receive their arterial blood supply from the lower portion of the popliteal artery and its two terminal branches, the anterior tibial and posterior tibial arteries. The popliteal artery has two lower branches, the lateral and medial inferior genicular arteries. Both of these vessels terminate in the circumpatellar anastomosis and contribute to the blood supply of the knee and the surrounding ligaments. The anterior tibial artery arises from the posterior tibial artery and passes anteriorly through the superior aperture of the interosseous membrane. It descends to the ankle sitting on the interosseus membrane in the anterior compartment and has the dorsalis pedis artery as its terminal branch.



**Figure 80-7.** Nerve and blood supply of the leg. **A:** Anterior view. **B:** Posterior view. **C:** Plantar surface of the foot. The anatomy of the nerves is described in Chapter 70. (Modified from Clemente CD, ed. *Gray's anatomy of the human body*, 30th Am ed. Philadelphia: Lea & Febiger, 1985.)

The anterior tibial artery gives off (a) the fibular artery before it passes through the interosseus membrane, which supplies the soleus and peroneus longus muscles; (b) the anterior tibial recurrent artery, which terminates in the patellar plexus; (c) numerous muscular branches that supply the muscles of anterior compartment; and (d) the anterior medial and lateral malleolar arteries, which supply the ankle joint. The terminal branch, the dorsalis pedis artery, gives off the lateral and medial tarsal arteries and the arcuate arteries (see Fig. 80-7).

The posterior tibial artery descends in back of the leg as far as the ankle, where it divides into the medial and lateral plantar arteries. It lies between the deep and superficial posterior compartments

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alongside the tibial nerve. Along its course it gives off (a) the large peroneal artery, which gives off numerous muscular branches, nutrient arteries to the tibia and fibula, and

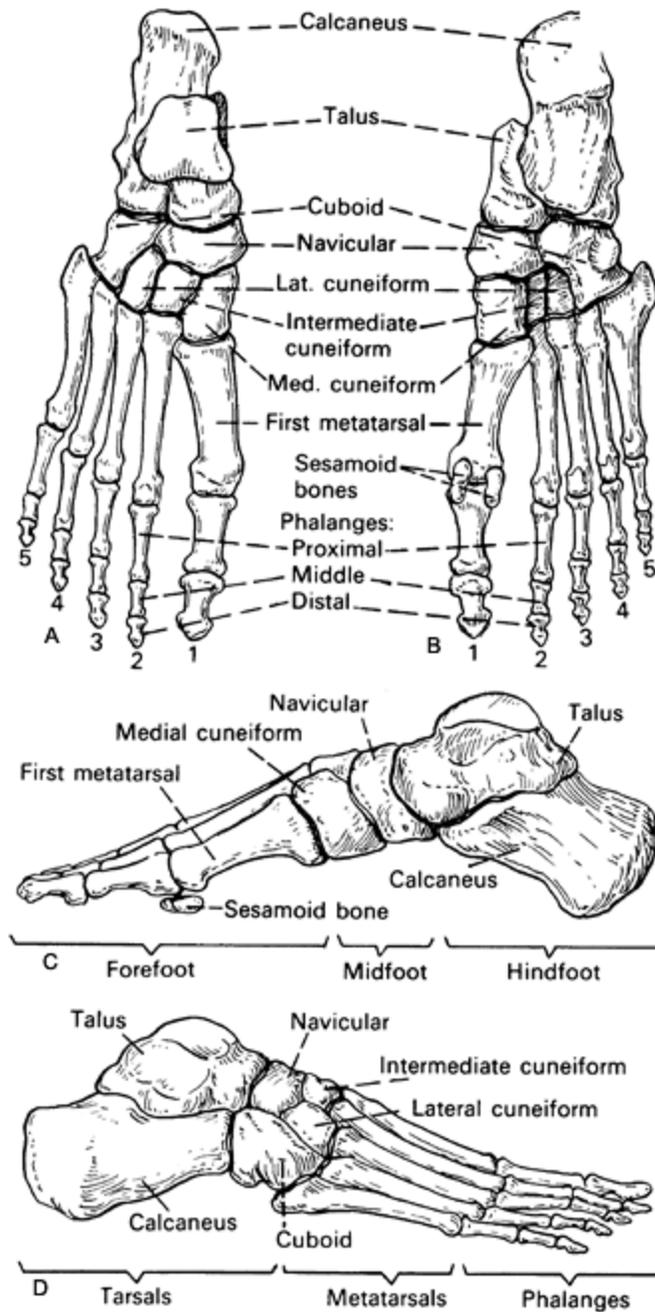
perforating and communicating branches; (b) a large nutrient artery to the tibia; (c) muscular branches to the soleus and deep muscles in the back of the leg; (d) the posterior medial malleolar artery, which contributes to the malleolar arterial network and blood supply to the talus, and several large medial calcaneal arteries.

## ***Anatomy of the Ankle and Foot***

### **Skeleton.**

The foot is an intricate structure composed of 28 articulating bones similar to the bones of the hand and modified for weight-bearing (Fig. 80-8). The bones of the ankle and foot are the tarsals, metatarsals, and phalanges. The tarsal bones differ from the carpal bones of the wrist, but the metatarsals and phalanges are similar to the metacarpals and phalanges of the hand (6,11). The bony skeleton of the foot is divided into the forefoot, the midfoot, and the hindfoot. The metatarsals and phalanges form the forefoot; the navicular, cuboid, and cuneiforms form the midfoot; and the talus and calcaneus form the hindfoot.

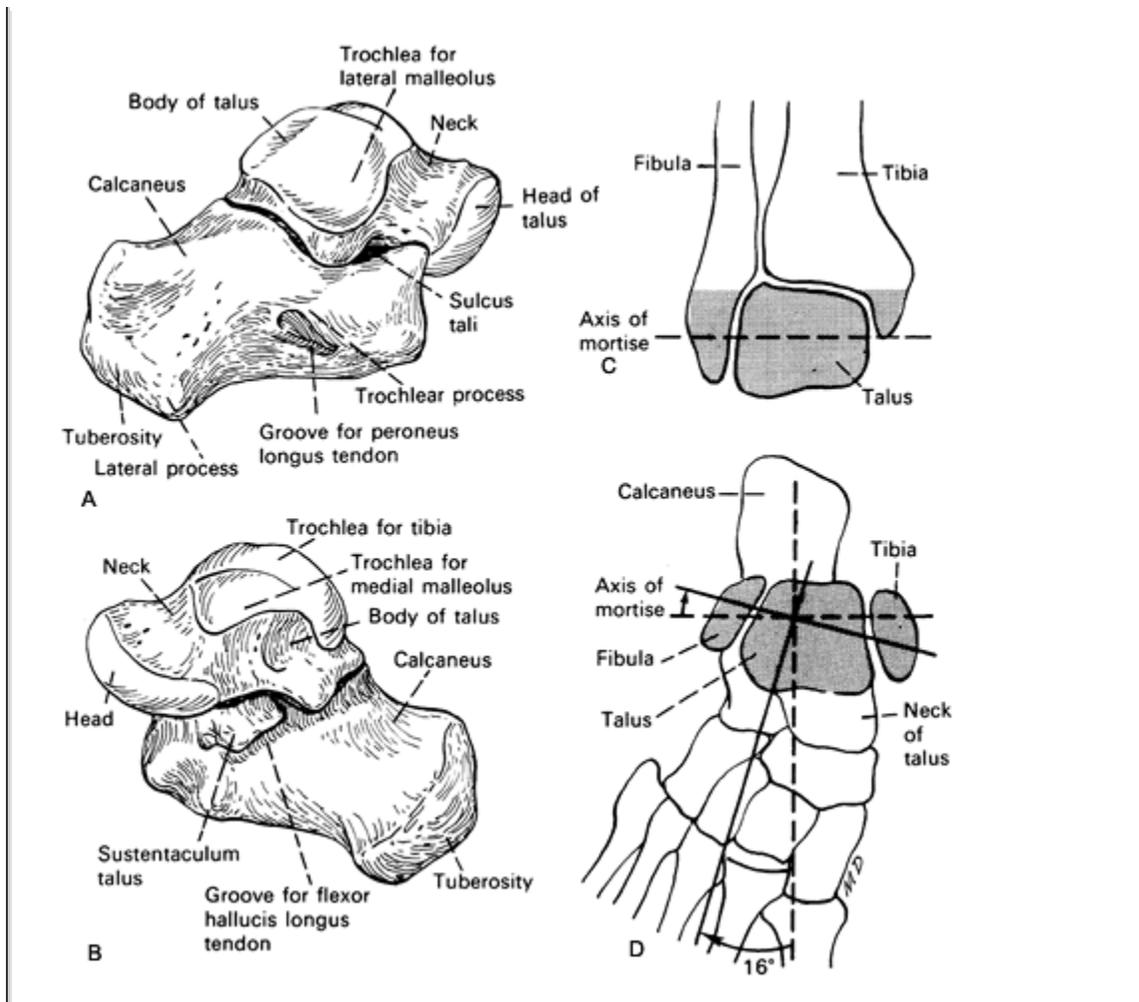




**Figure 80-8.** Bones of the ankle and foot. **A:** Superior surface. **B:** Plantar surface. **C:** Medial view. **D:** Lateral view. The seven bones of the hindfoot and midfoot, which constitute the tarsus, are arranged in two rows, with one bone between them. In the posterior row the talus sits on the calcaneus, and in the distal row the cuneiform bones and cuboid lie side by side. The navicular bridges the two rows on the medial side. The talus articulates with tibia and fibula so all force within the foot must pass through the talus. Normally the calcaneus and the heads of the five metatarsals are the weight-bearing points of the foot (**C,D**). The skeleton of the foot has an arch between the calcaneus and metatarsal heads, with the arch being much higher on the medial side (**C**) than on the lateral side (**D**). The calcaneus, the largest bone of the foot, forms the contour of the heel. The calcaneus supports the talus and

transmits the ground reaction force applied to the heel. The calcaneus forms a lever arm for the insertion of the Achilles tendon. The tubercle of the navicular is palpable 3.5 cm anterior to the medial malleolus. Its posterior concave surface articulates with the head of the talus, and its anterior or distal convex surface articulates with the three cuneiform bones. The cuboid articulates with the fourth and fifth metatarsals anteriorly, the lateral cuneiform and navicular bones medially, and the calcaneus posteriorly. The three cuneiforms, together with the cuboid forming the distal row of tarsal bones, are in line with the three medial rays of the foot and articulate with the corresponding metatarsals. The arrangement of the metatarsals and phalanges is similar to the corresponding segments of the hand. (Modified from Hollinshead WH. *Anatomy for surgeons*, 3rd ed. Vol 3. Philadelphia: Harper & Row, 1982.)

The talus has a body, neck, and head (Fig. 80-9) (8,12). Most of the body, the large trochlea, articulates with the tibia and fibula, together forming the ankle joint. The talus is hard to palpate. The calcaneus is the largest tarsal bone and forms the heel. It supports the talus and articulates with the cuboid laterally. Various parts of the calcaneus are palpable. The sustentaculum tali, a finger's breadth below the tip of the medial malleolus, supports the talus and can be identified as a buttress projecting medially from the calcaneus. Both the medial and lateral walls as well as the tuberosity can be clearly felt. The sinus tarsi is a depression between the body of the talus, the neck of the talus, and the calcaneus opening laterally just anterior and inferior to the lateral malleolus (13).



**Figure 80-9.** Anatomy of the right talus and calcaneus showing their relationship to the tibia and fibula, to other bones of the tarsus, and to the proximal ends of the metatarsals. **A:** Lateral view. **B:** Medial view. The talus has a body, a neck, and a head. **C:** The superior aspect of the large trochlea tali and both sides of the body articulate with the tibia and fibula, together forming the ankle mortise. The tibia contacts the entire superior aspect of the talus, with the medial malleolus extending one-third of the way down the medial aspect of the talus. The lateral malleolus covers the lateral aspect of the body of the talus. The rounded head of the talus fits into the concavity of the navicular bone. The inferior surface of the neck forms the roof of the tarsal canal, the floor being formed by the calcaneus. The tarsal canal separates the nonarticular portions of the talus and calcaneus. The talar neck is situated between the head and trochlea and fits closely between the two malleoli. The axis of rotation of the ankle is oblique to both the long axis of the foot and tibia. **D:** From above, the talus is wedge shaped, with the anterior portion wider than the posterior portion. The longitudinal axis of the joint is perpendicular to the axis of the mortise and forms an external "toe-out" of 16 degrees. (**A** and **B** modified from Clemente CD, ed. *Gray's anatomy of the human body*, 30th Am ed. Philadelphia: Lea & Febiger, 1985, with permission. **C** and **D** modified from Cailliet R. *Foot and ankle pain*, 2nd ed. Philadelphia: FA Davis, 1983.)

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The navicular is a disk-shaped bone, identifiable by a tubercle that is 3.5 cm anterior to the medial malleolus, level with the sustentaculum tali. It can be identified by following the tibialis posterior tendon distally. It articulates with the talus proximally and the medial and

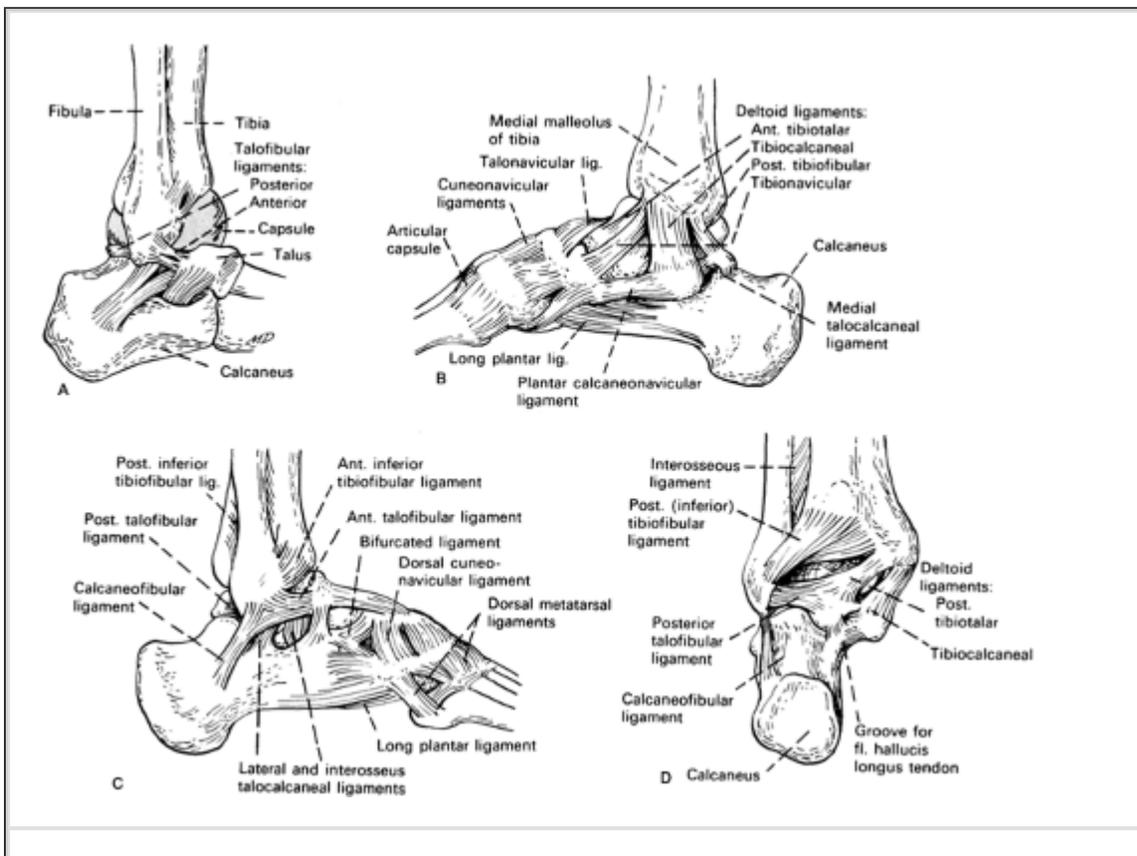
middle cuneiforms distally. The three cuneiforms articulate with the medial three metatarsals. The cuboid articulates with the lateral two metatarsals and is palpable just proximal to the prominent tuberosity of the fifth metatarsal.

## Joints

### **ANKLE JOINT.**

The ankle joint is a hinge, uniaxial, or ginglymus joint (6,12). It is formed above by the lower end of the tibia and the medial malleolus and the lateral malleolus of the fibula. The mortise articulates with the talus on its convex proximal surface and the flat medial and lateral facets. A cast of the ankle mortise duplicates all contours of the articular surface of the talar body, and hence is one of the most constrained joints of the body (6). A good fit is maintained throughout the whole range of plantar flexion and dorsiflexion. No lateral play or accessory motion occurs in any position. The distance between the malleoli does not change in dorsiflexion, although a small amount of lateral rotation of the fibular malleolus is permitted by the obliquity of the tibiofibular interosseous ligament, accommodating the wider anterior talus during full dorsiflexion (7).

The bones are connected loosely by the articular capsule. The medial deltoid ligament complex and lateral collateral ligament complex provide stability to the ankle joint (Fig. 80-10) (8). Part of the medial deltoid ligament and the lateral calcaneofibular ligament stabilizes the subtalar joint (14). The deltoid ligament inserts into the spring ligament stabilizing the talonavicular joint.



**Figure 80-10.** Anatomy of the capsule and ligaments of the right ankle joint. **A:** Lateral view: The articular capsule surrounds the joint, attaching above to the borders of the articular surface of the tibia and malleoli and below to the talus around its articular surface. **B:** Medial view: The medial collateral "deltoid" ligament fans out in a triangular shape from medial malleolus, attaching into the navicular anteriorly and the calcaneus and talus posteriorly. The deltoid ligament has superficial and deep portions. The superficial anterior portion is the tibionavicular ligament. The superficial posterior portion is the tibiocalcaneal ligament inserting into the sustentaculum tali. The anterior and posterior tibiotalar ligament inserts into the talus and forms the deep portion of the deltoid ligament. The deltoid ligament is covered by the tendons of the tibialis posterior and flexor digitorum longus. **C:** Lateral view: The lateral collateral ligament consists of three discrete bands. The short anterior talofibular ligament arises from the anterior margin of the lateral malleolus and inserts onto the lateral aspect of the talar neck. The posterior talofibular ligament, stronger and deeper than the anterior ligament, runs almost horizontally from the posteromedial aspect of the lateral malleolus to insert in a prominent tubercle on the posterior surface of the talus, lateral to the flexor hallucis longus tendon. The calcaneofibular ligament, the strongest of the three, is a narrow rounded cord passing from the apex of the lateral malleolus to a tubercle on the lateral surface of the calcaneus. **D:** This posterior view of the ankle joint showing the posterior inferior tibiofibular, posterior talofibular, posterior tibiotalar, and tibiocalcaneal ligaments. (Modified from Clemente CD, ed. *Gray's anatomy of the human body*, 30th Am ed. Philadelphia: Lea & Febiger, 1985.)

The articular capsule surrounds the joint. It inserts superiorly on the articular border of the tibia and malleoli and inserts inferiorly on the talar articular surface (see Fig. 80-10A). The anterior and posterior capsule is thin.

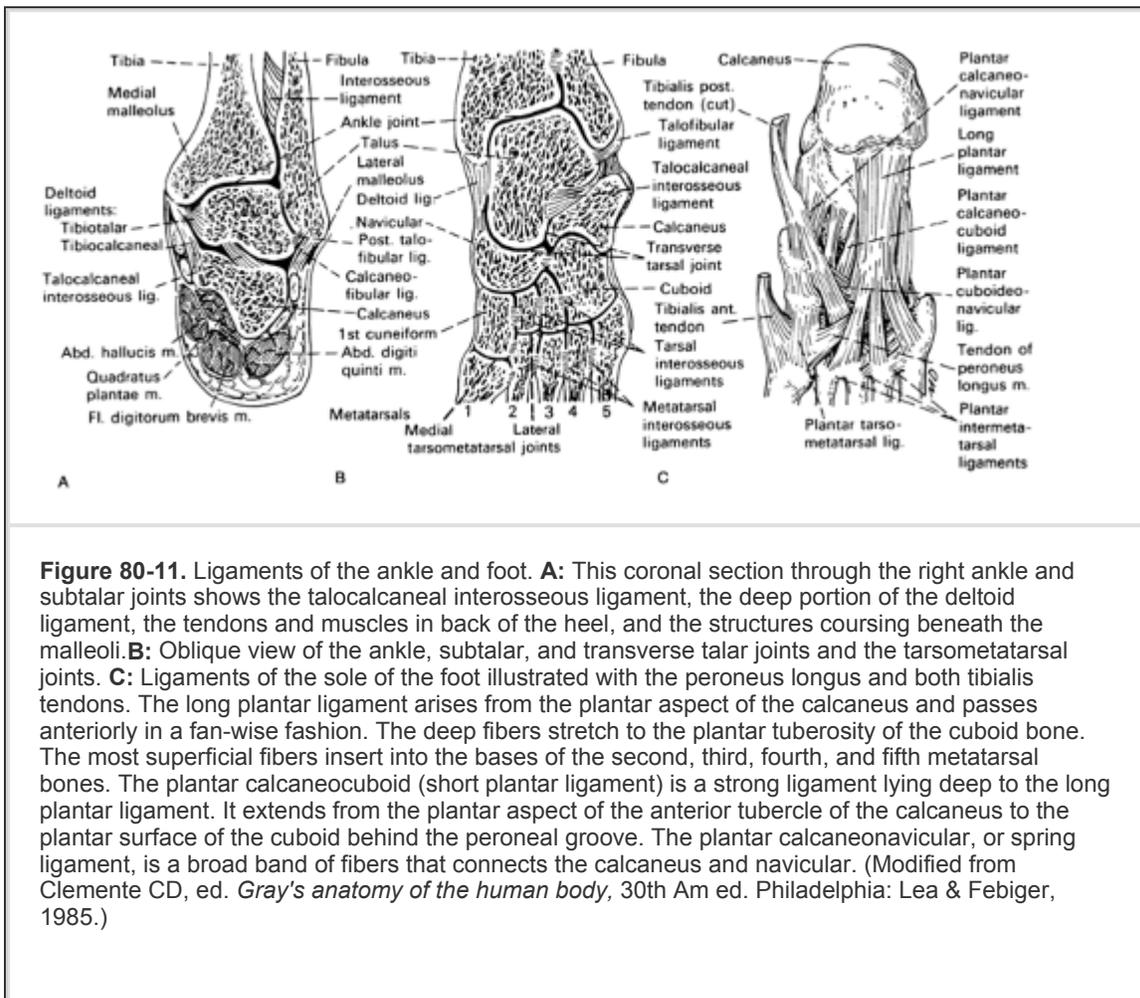
The collateral ligaments provide side-to-side stability to the ankle (see Fig. 80-10B, Fig. 80-10C). Inversion and eversion injuries may rupture the lateral or medial collateral ligaments or fracture the malleoli. In a young adult, fracture dislocation includes rupture of the deltoid ligament, disruption of the distal tibiofibular syndesmosis, and fracture of the fibula just above the joint (15). Occasionally, the medial malleolus may be avulsed without injury to the deltoid ligament. The lateral ligaments rupture during an inversion sprain, the most common form of ankle sprain. The anterior talofibular ligament is ruptured first in the plantar flexed position. The interosseous ligament running between the talus and the calcaneus aids the stability of the subtalar joint (see Fig. 80-10C). The posterior fibers of the deltoid ligament prevent excessive dorsiflexion, whereas the anterior talofibular ligament prevents excessive plantar flexion (see Fig. 80-10B, Fig. 80-10D).

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### **INTERTARSAL JOINTS.**

Movements at the ankle joint are limited mainly to plantar flexion and dorsiflexion. Inversion, eversion, forefoot abduction and adduction, and the combined movements of supination (inversion and abduction) and pronation (eversion and adduction) occur at the other joints (8,10). Most of this motion occurs throughout the subtalar joint, the talonavicular joint, and the calcaneocuboid joint. The motions of these joints are closely tied, with the talonavicular joint allowing the most combined motion. Because three of the arches of the foot involve these joints, they are under particular strain during weight-bearing. The plantar ligaments of these joints are particularly strong (8). The plantar surface of the foot has strong intertarsal ligaments that bind the bones together and help to prevent collapse of the arch. The arch is further maintained by the short muscles of the

foot, the plantar aponeurosis, and the long tendons passing into the sole of the foot from the leg (Fig. 80-11C) (7). The posterior tibial tendon and the peroneus longus muscle have particular roles in maintaining the arch of the foot.



The subtalar joint allows inversion and eversion of the heel and lies between the calcaneus and talus with two or three facets within the joint. The transverse tarsal joint links the hindfoot and midfoot. This joint allows inversion and eversion of the forefoot, forefoot adduction and abduction, and a small amount of forefoot flexion and extension (6). The talonavicular and calcaneocuboid joints together form the transverse tarsal joint. Independent movements are not possible in any of these joints (8). The subtalar joint and the lateral and medial components of the transverse tarsal joint are enclosed by an independent fibrous capsule lined by synovial membrane (Fig. 80-11).

Multiple ligaments stabilize the midtarsal joints (see Fig. 80-11B). The cervical ligament is located in the sinus tarsi and is attached to the neck of the talus and the upper surface of the calcaneus (8). One limb of the bifurcate ligament, the dorsal calcaneonavicular ligament, arises anterior in the sinus and connects the calcaneus and navicular. The other limb, the dorsal calcaneocuboid ligament, connects the calcaneus and cuboid bones. The plantar calcaneocuboid ligament (the short plantar ligament) maintains the calcaneocuboid

joint during weight-bearing.

The long plantar ligament (see Fig. 80-11C) arises from the plantar surface of the calcaneus anterior to the calcaneal tuberosity. Its deep fibers insert on the plantar surface of the cuboid wall, and the superficial fibers continue to the bases of the second, third, fourth, and fifth metatarsal bones. These fibers form the roof on the groove on the plantar surface of the cuboid, making a tunnel for the tendon of the peroneus longus muscle. This ligament reinforces the lateral longitudinal arch (4,5,8).

Other intertarsal joints are found between the navicular and cuneiform bones, the cuboid and cuneiform bones, and among the cuneiforms (6). These can all form one continuous joint cavity, although the navicular cuneiform and cuboid to lateral cuneiform joints can be separate. These joints are supported by weaker dorsal interosseous ligaments and stronger plantar interosseous ligaments. The cuneiforms are supported by the weak transverse dorsal intercuneiform ligaments and by the stronger plantar intercuneiform ligaments.

### ***JOINTS OF THE MIDFOOT AND FOREFOOT.***

The tarsometatarsal joints lie between the three cuneiforms and cuboid bones proximally and the bases of the five metatarsal bones distally. These joints are strengthened by the dorsal and plantar tarsometatarsal ligaments and by interosseous ligaments between the metatarsals and between the cuneiforms (see Fig. 80-11B).

The bases of the metatarsal bones are connected by the dorsal plantar and interosseous intermetatarsal ligaments. These help stabilize the midfoot and are ruptured in a Lisfranc midfoot fracture dislocation. The heads of the metatarsal bones are interconnected on their plantar aspects by the deep transverse

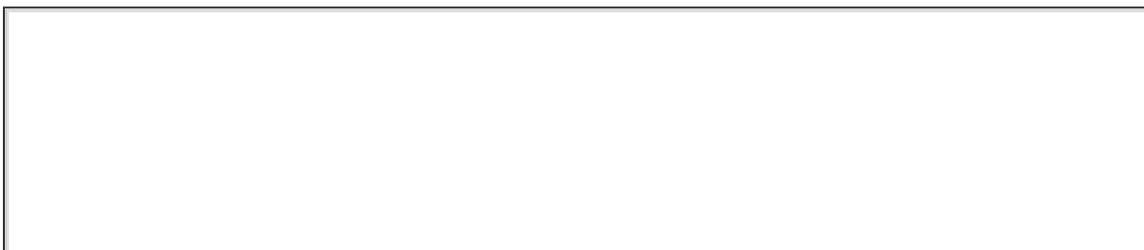
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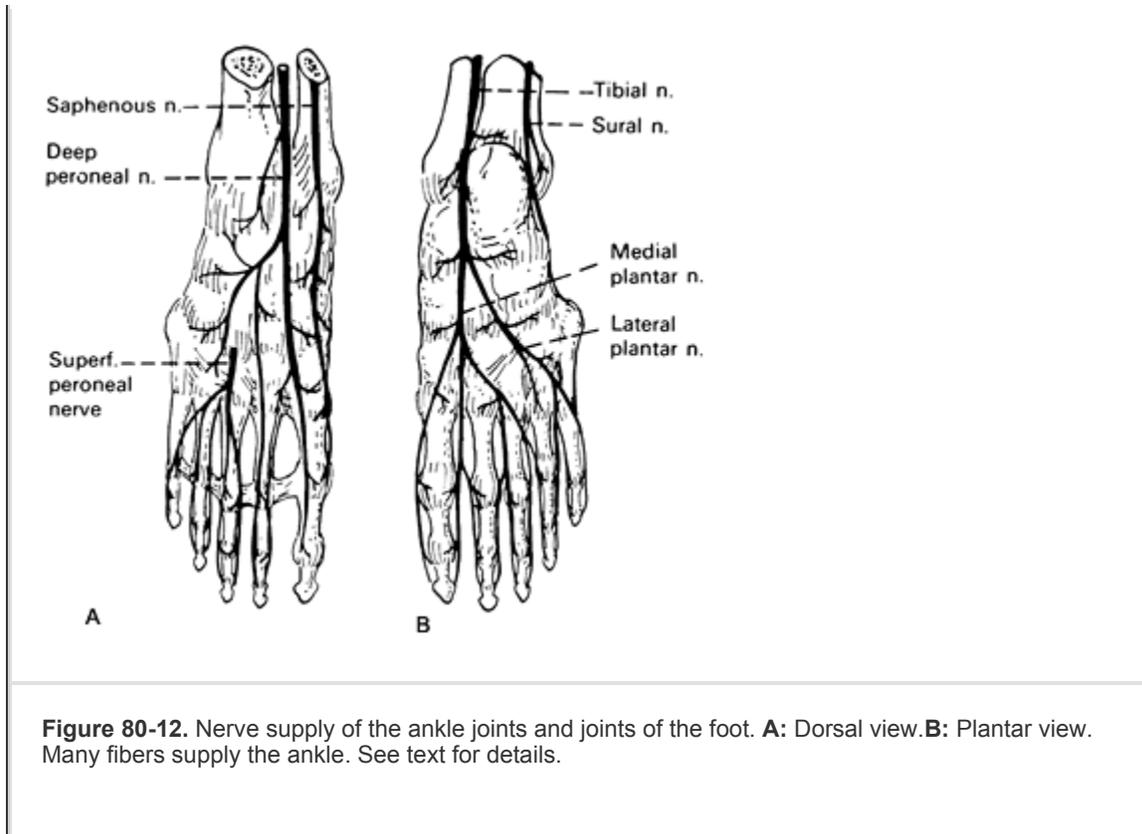
metatarsal ligament. Some fibers of this ligament attach to the base of the proximal phalanx and the metatarsal heads. The range of extension is greater in these joints than the range of flexion, although movement is fairly minimal.

The MP joints are strengthened by the plantar and collateral ligaments. The anatomy of the interphalangeal (IP) joint corresponds to that in the hand (5,8).

### ***Nerve and Blood Supply of the Joints of the Ankle and Foot.***

Figure 80-12 shows the nerve supply of the foot and ankle. The ankle joint is supplied by the deep peroneal, tibial, and saphenous nerves (5,14). The intertarsal joints are supplied by the superficial and deep peroneal nerves (15). The saphenous nerve supplies the joints on the medial border of the foot. The lateral and medial plantar nerves have branches to the plantar aspects of the joints.



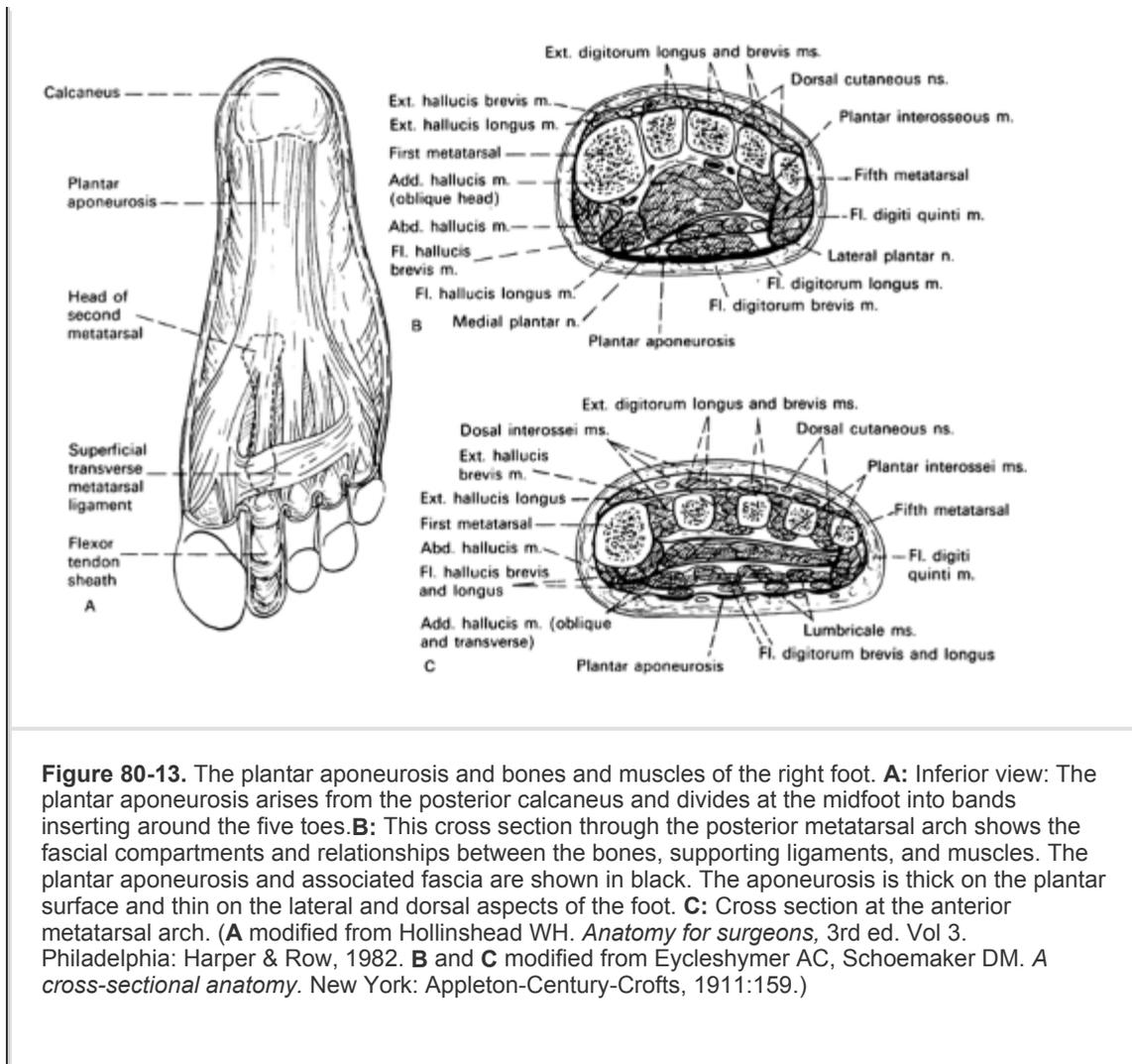


The blood vessels supplying the ankle joint are the malleolar branches of the anterior tibial and peroneal arteries. The other joints of the foot are supplied by the dorsalis pedis artery and its branches, the medial and lateral plantar arteries, and the plantar arch.

### ***Fascia and Intrinsic Muscles of the Foot***

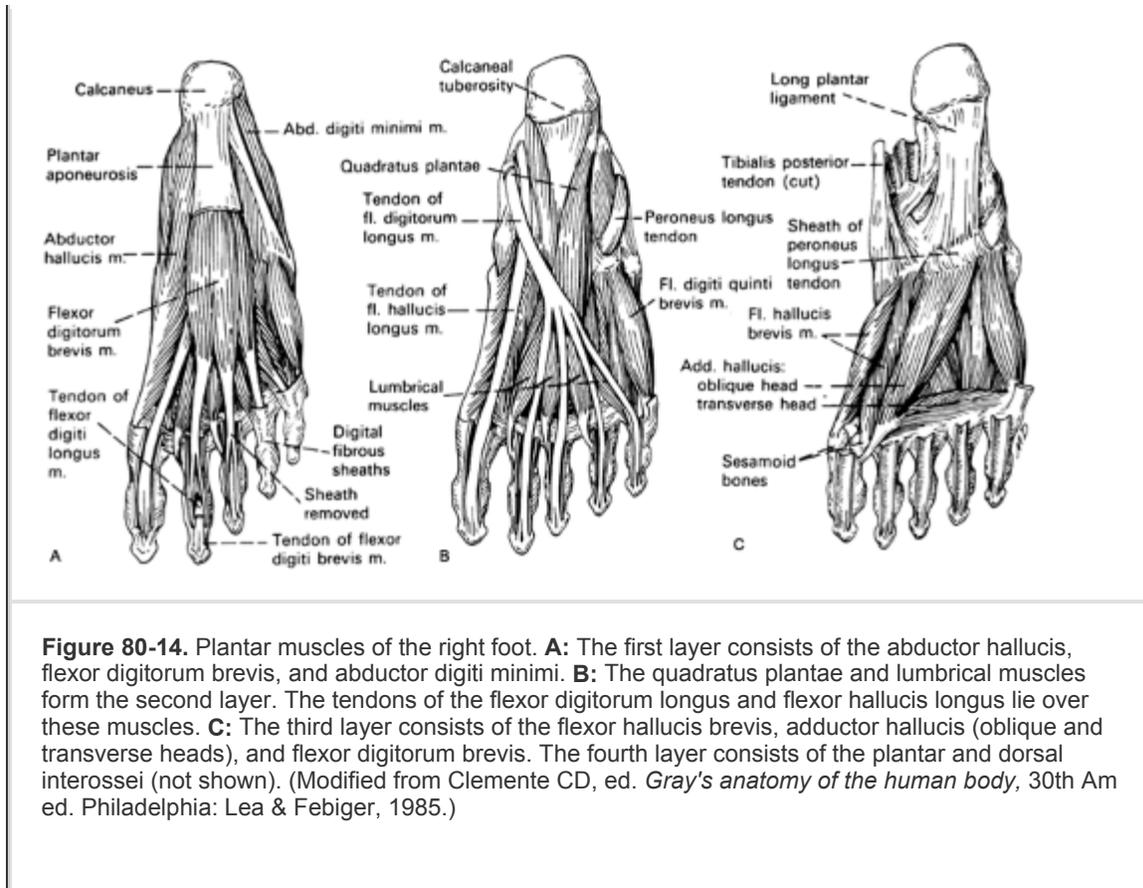
#### **Plantar Aponeurosis and Plantar Fascia.**

The superficial fascia forms a tough thick padding over the sole of the foot. The fascia is thin on the dorsum of the foot (4,5,8). The plantar aponeurosis is attached posteriorly to the calcaneus and fans out anteriorly toward the toes (Fig. 80-13). It sends fibers to the skin forming septa within the sole of the foot (4,5,8). The sides of the aponeurosis continue with intermuscular septa that separate the intrinsic muscles of the first and fifth digits from a central compartment containing the flexor tendons and the lumbricals. Additional sagittal septa over the metatarsal heads distally connect the plantar aponeurosis to the deep transverse metatarsal ligament. The tunnels formed between the septa, the plantar fascia, and the metatarsal heads alternately contain the flexor tendons or the lumbricals and digital vessels and nerves. The lumbricals, digital vessels, and nerves are protected from compression by the metatarsal heads.

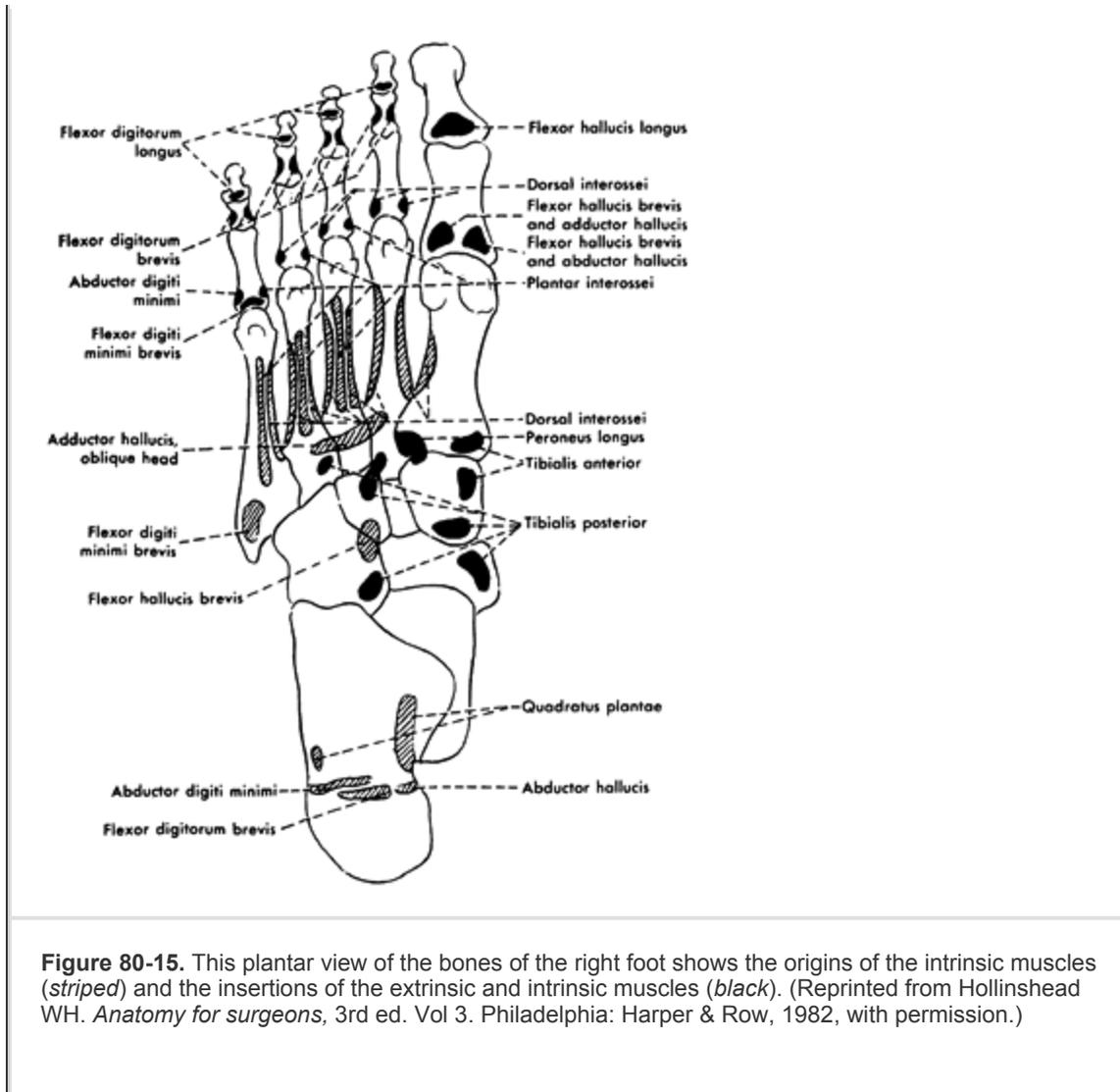


### Intrinsic Muscles.

Figure 80-14 depicts the intrinsic muscles of the plantar aspect of the foot. Figure 80-15 shows the origins of the intrinsic muscles and the insertions of the intrinsic and extrinsic muscles. Figure 80-16 illustrates the muscles of the dorsum of the foot and the origins of the intrinsic muscles. The flexor digitorum brevis and extensor digitorum brevis act to flex and extend the toes when the long flexors are ineffective at extremes of plantar flexion and dorsiflexion. The lumbricals act to flex the MP joints and extend the IP joints and are weak in claw toe deformity. The interossei assist the lumbricals and have a minimal role in moving the toes in abduction and adduction.



**Figure 80-14.** Plantar muscles of the right foot. **A:** The first layer consists of the abductor hallucis, flexor digitorum brevis, and abductor digiti minimi. **B:** The quadratus plantae and lumbrical muscles form the second layer. The tendons of the flexor digitorum longus and flexor hallucis longus lie over these muscles. **C:** The third layer consists of the flexor hallucis brevis, adductor hallucis (oblique and transverse heads), and flexor digitorum brevis. The fourth layer consists of the plantar and dorsal interossei (not shown). (Modified from Clemente CD, ed. *Gray's anatomy of the human body*, 30th Am ed. Philadelphia: Lea & Febiger, 1985.)



**Figure 80-15.** This plantar view of the bones of the right foot shows the origins of the intrinsic muscles (*striped*) and the insertions of the extrinsic and intrinsic muscles (*black*). (Reprinted from Hollinshead WH. *Anatomy for surgeons*, 3rd ed. Vol 3. Philadelphia: Harper & Row, 1982, with permission.)

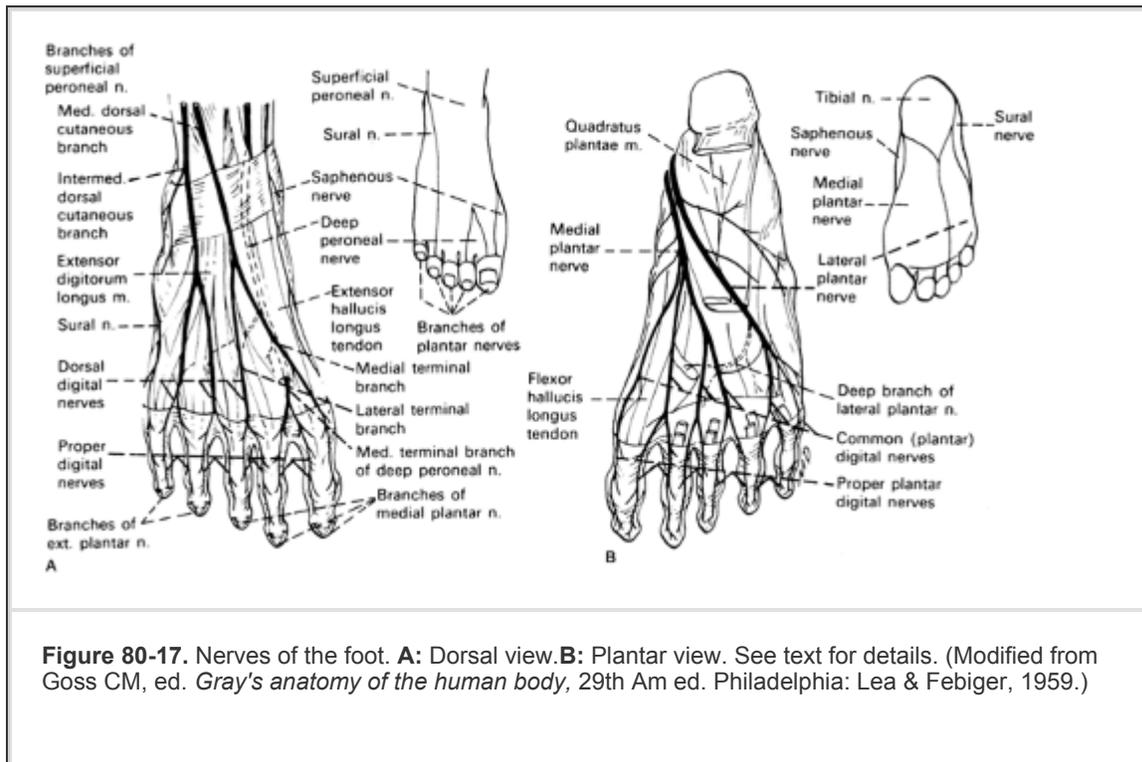
### ***Nerve and Blood Supply of the Foot.***

Figure 80-17 depicts the nerve supply of the foot. Cutaneous sensation of the sole is supplied by the medial and lateral plantar nerves and by the medial calcaneal branch of the tibial nerve. A strip of the lateral side of the foot is supplied by the lateral dorsal cutaneous branch of the sural nerve, itself a branch of the tibial nerve. The saphenous nerve supplies a thin part of the skin and fascia on the medial aspect of the midfoot. Motor innervation of the intrinsic muscles is primarily from the L-5 and S-1 segments through the medial and lateral plantar nerves (see Table 80-3). Most of the cutaneous innervation of the dorsum of the foot lies within the distribution of the superficial peroneal nerve medial and lateral branches. A twig from the deep peroneal nerve supplies adjacent sides of the first interdigital cleft. The saphenous

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nerve supplies the skin along the medial side of the foot, and the sural nerve supplies the skin along the lateral edge of the foot. (The segmental nerve supply to the skin, muscles,

and bones of the foot is depicted in Fig. 75-20, and the peripheral nerve supply is shown in Fig. 75-21.)



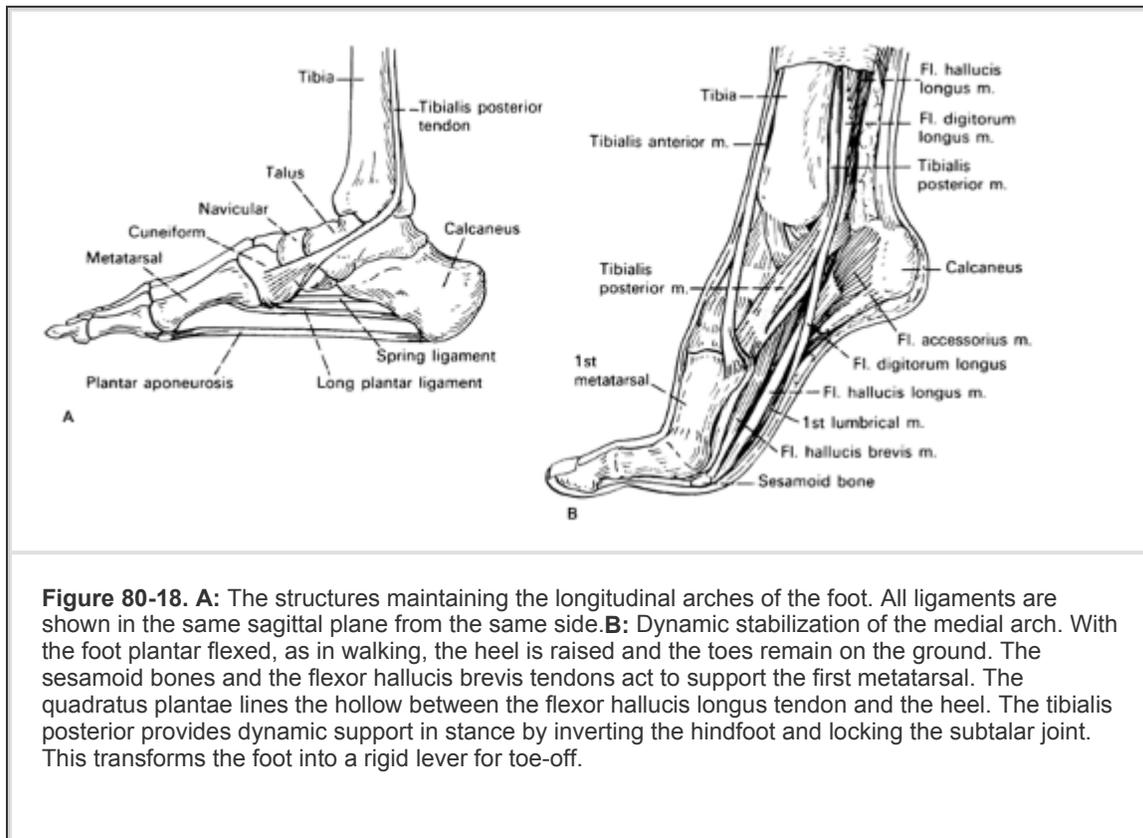
**Figure 80-17.** Nerves of the foot. **A:** Dorsal view. **B:** Plantar view. See text for details. (Modified from Goss CM, ed. *Gray's anatomy of the human body*, 29th Am ed. Philadelphia: Lea & Febiger, 1959.)

Blood reaches the foot by terminal branches of the anterior and posterior tibial arteries. Many anastomoses exist between these vessels (see Fig. 80-7). The dorsalis pedis artery and its branches supply the dorsum of the foot as the terminal branch of the anterior tibial artery. The plantar surface is supplied by the medial and lateral plantar arteries arising from the posterior tibial artery. The dorsalis pedis artery gives off medial and lateral metatarsal arteries, supplying the front part of the ankle joint. It anastomoses with the first tarsal and deep plantar arteries, the arcuate artery, and the plantar arch (see Fig. 80-7). These in turn give off vessels to the first through fifth plantar metatarsals. Each plantar metatarsal artery gives off two digital arteries, which supply the dorsal and plantar aspects of the joints of adjacent toes.

### **Arches of the Foot.**

The foot has four arches, two longitudinal and two transverse. The medial and lateral longitudinal arches are formed by the wedge-shaped bones, which together with their ligamentous support form the arches (Fig. 80-18). The plantar aponeurosis acts as a bowstring or tie rod, as do the long and short plantar and spring ligaments. The medial arch is dome shaped and is higher than the lateral arch (see Fig. 80-8). The posterior transverse or midtarsal arch is formed by the navicular, the three cuneiforms, the cuboid, and the bases of the metatarsal bones. This arch is maintained by ligaments and tendons binding the metatarsal bases. The integrity of these plantar ligaments maintains the arch (16). The anterior metatarsal arch formed by the metatarsal heads is maintained by the deep

transverse metatarsal ligaments.



**Figure 80-18. A:** The structures maintaining the longitudinal arches of the foot. All ligaments are shown in the same sagittal plane from the same side. **B:** Dynamic stabilization of the medial arch. With the foot plantar flexed, as in walking, the heel is raised and the toes remain on the ground. The sesamoid bones and the flexor hallucis brevis tendons act to support the first metatarsal. The quadratus plantae lines the hollow between the flexor hallucis longus tendon and the heel. The tibialis posterior provides dynamic support in stance by inverting the hindfoot and locking the subtalar joint. This transforms the foot into a rigid lever for toe-off.

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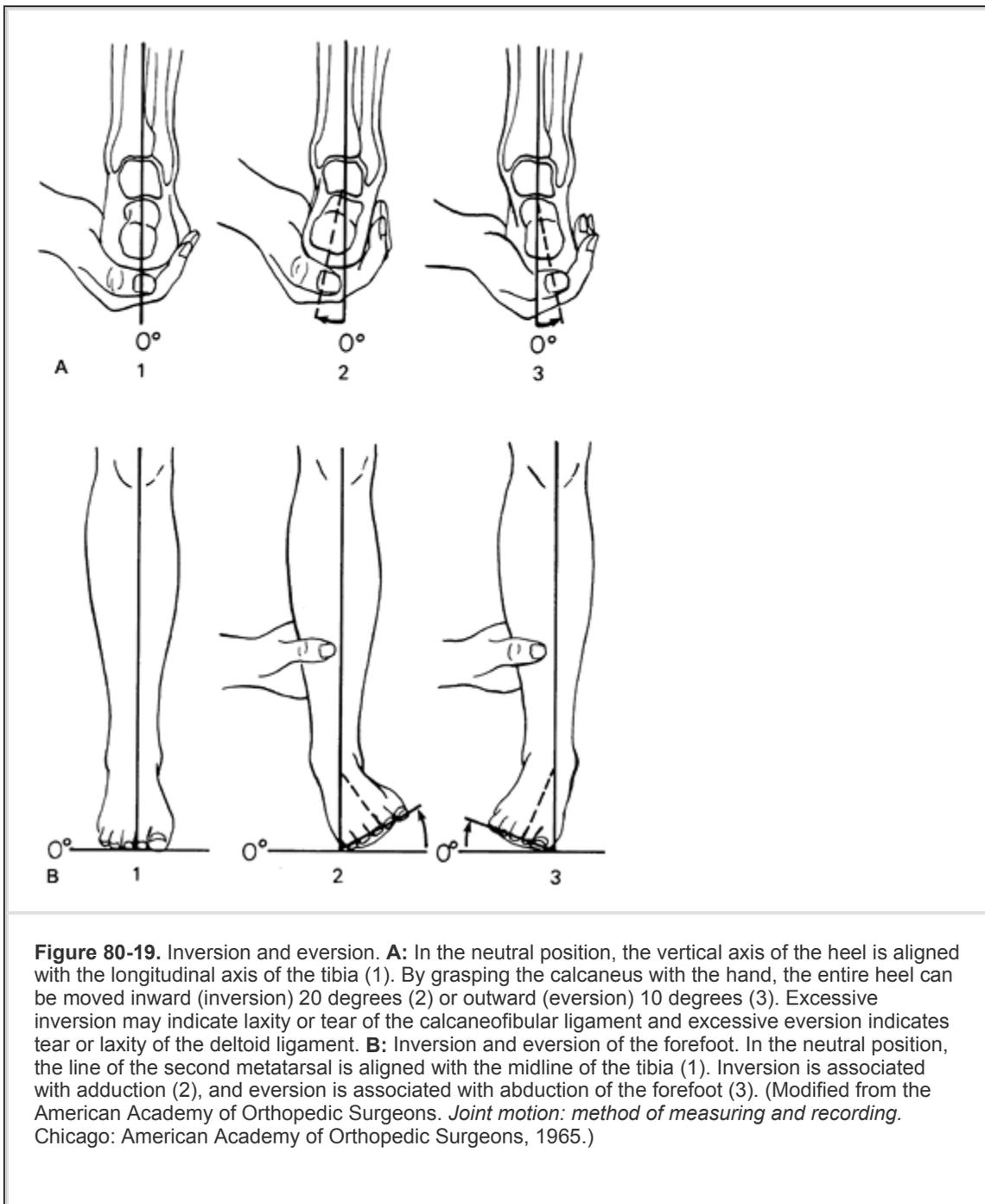
## Movement and Biomechanics of the Foot

### *Movement.*

In the neutral or anatomic position, the foot forms a 90-degree angle with the tibia (6). Plantar flexion increases and dorsiflexion decreases this angle. This motion occurs mainly at the ankle joint and partially at the midtarsal joint. The total range of motion of the ankle joint in the sagittal plane is approximately 45 degrees but varies widely (17). Ten to 20 degrees of this range of motion are in dorsiflexion, and the remaining 25 to 35 degrees are in plantar flexion. The dorsiflexion range is increased with knee flexion as the gastrocnemius muscle passes behind both the knee and hip. The axis of the ankle joint slopes posteriorly and inferiorly on the lateral side (6,8,16,17). As a result, the foot adducts during plantar flexion and abducts during dorsiflexion. Toeing in and out can also be produced by tibial rotation (9,18).

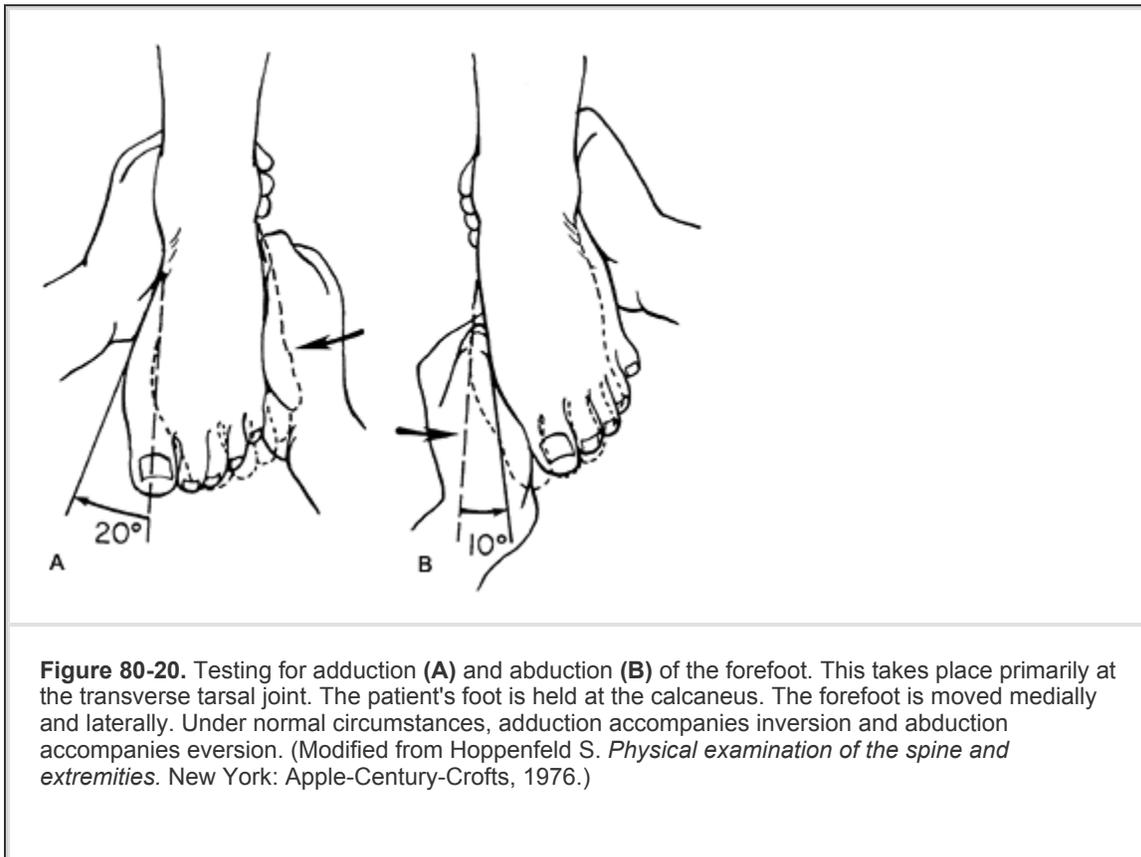
Inversion and eversion turn the sole of the foot medially and laterally, respectively (6,13) (Fig. 80-19). This side-to-side rotation of the foot occurs at the subtalar and transverse tarsal joints around an anterior posterior axis deviating from the sagittal plane. During inversion the heel deviates medially; during eversion it deviates laterally (see Fig. 80-19A). In addition, this motion involves the forefoot, and its deviation is gauged by the line of the

second metatarsal in relation to the tibia (see Fig. 80-19B). Because the axis of inversion and eversion is not strictly in the sagittal plane, the foot adducts during inversion and abducts during eversion through the transverse tarsal joint.



These movements displace the metatarsals in relation to one another and involve the transverse tarsal joint and the joints distal to it (16,17). The foot cannot be adducted without inverting, nor can it abduct independent of eversion. In the neutral position, the heads of the metatarsals are in the same horizontal plane. Adduction associated with

inversion elevates the head of the first metatarsal and depresses the head of the fifth metatarsal, whereas abduction associated with eversion has the opposite effect (Fig. 80-20).



### **Biomechanics.**

The foot adapts to uneven ground and allows the center of gravity of the body to be positioned over the center of support. The fit and construction of shoes affect shock absorption and the support of the foot. Footwear available today is designed specifically for such activities as sports, aerobics, walking, running, and dancing and provides the support, fit, control, shock absorption, and in some cases, splinting necessary for the specific activity. Wearing a shoe that is not designed for a vigorous form of activity can be a source of pain.

Foot biomechanics analyzes the alignment and magnitude of forces acting on the foot. The foot has 26 bones, 19 muscles,

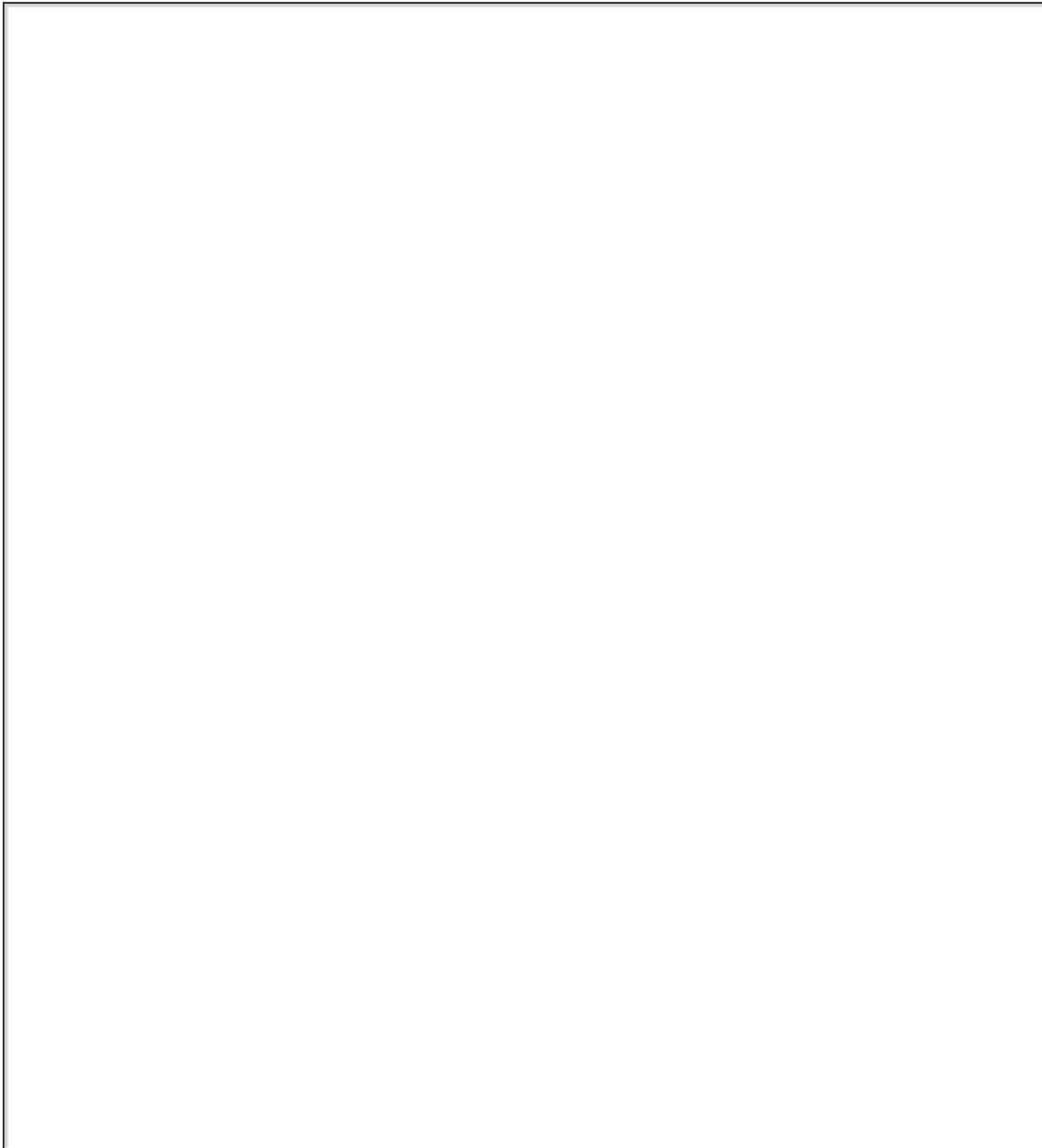
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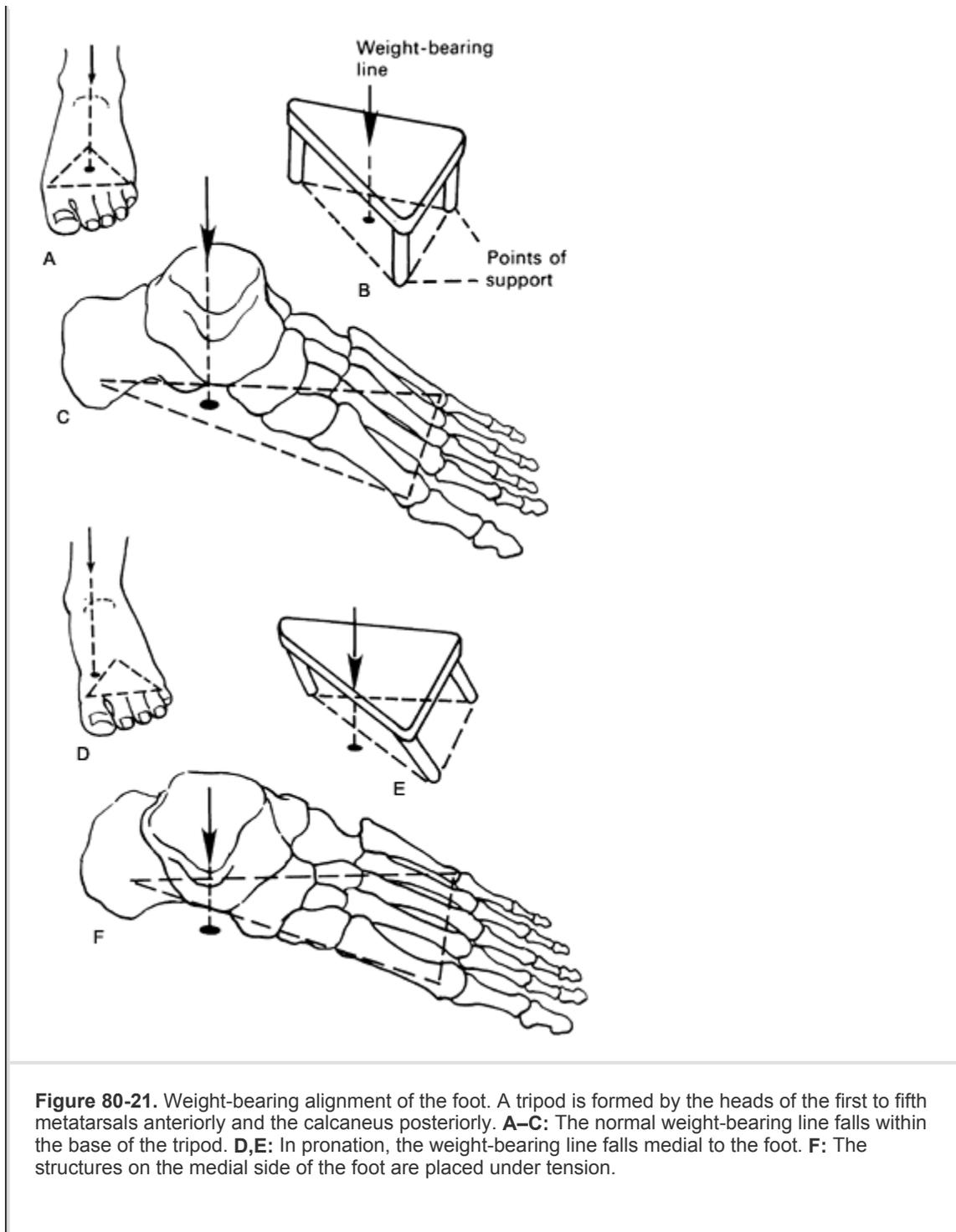
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and 107 ligaments forming four arches (medial and lateral longitudinal and posterior and anterior transverse) (14). The shape of the foot relates to the supporting ligaments, muscle forces, and loading environment. Foot alignment during weight-bearing determines the loading environment to which the foot is subjected. The alignment of the foot is determined by the shape of bony structures, ligamentous tension, coordination of the musculotendinous

units, and alignment of the leg in general.

The foot can be thought of as a tripod, with the os calcis providing one point of support and the heads of the fifth to first metatarsals providing the other two points of support (Fig. 80-21). The weight-bearing line normally passes through the ankle joint into this tripod area. If the weight-bearing line passes outside the area, problems arise. For example, in a pronated foot, the weight-bearing line falls medial to the foot and the hindfoot goes into eversion. Structures on the medial side of the foot are placed in tension. When the weight-bearing line falls laterally in a supinated foot, the ankle becomes inverted and overloads the lateral ligaments and the lateral border of the foot. Medial knee pain can occur in a supinated (or cavus) foot by causing overload of the medial side of the knee. Thus, abnormal foot biomechanics in an active individual can eventually lead to local or more widespread discomfort (6,16,18,19).





**Figure 80-21.** Weight-bearing alignment of the foot. A tripod is formed by the heads of the first to fifth metatarsals anteriorly and the calcaneus posteriorly. **A–C:** The normal weight-bearing line falls within the base of the tripod. **D,E:** In pronation, the weight-bearing line falls medial to the foot. **F:** The structures on the medial side of the foot are placed under tension.