Anatomy of the Ankle and Foot

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The ankle and foot complex at times must be mobile and at other times must be quite stable. The bony, ligamentous, and muscular structures of the ankle and foot are presented with respect to their mobility and stability functions. Innervation and vascular supply are discussed. Normal anatomy provides a basis and a reference point for discussion of dysfunction of the ankle and foot.

Key Words: *Anatomy; Ankle; Foot; Joints; Lower extremity, ankle and foot.*

Unlike some joints that exhibit mainly functional mobility or functional stability, the ankle (talocrural) and foot joints form a complex, which at times is mobile and at other times is stable. This article represents a review of the ankle and foot anatomy, which provides a basis for understanding this duality of function. A strong foundation in anatomy will also enhance the understanding of the consequences and compensations of hypermobility and hypomobility and the accurate evaluation and treatment of ankle and foot disorders.

Because the shape of foot bones provides the basis of structural stability of the foot, the osteology and its anatomical significance will be presented first, followed by the added stability and mobility functions of the soft tissues.

GENERAL OSTEOLOGY AND FOOT SHAPE

The 26 bones of each foot, in addition to the tibia and fibula, are constructed such that they form a series of arches in the foot. These 26 bones—7 tarsals (comprising the calcaneus; talus; navicular; cuboid; and medial, intermediate, and lateral cuneiforms), 5 metatarsals, and 14 phalanges—normally interlock to form medial and lateral longitudinal arches between the calcaneus and the metatarsal heads (Fig. 1)[1,2] and a less well-defined transverse arch located just posterior to the metatarsal heads (Fig. 2).[2] Kapandji reported that the normal medial longitudinal arch is 15 to 18 mm from the ground at the level of the navicular, which is the keystone of the arch, whereas the lower lateral longitudinal arch is normally 3 to 5 mm from the ground at the level of the cuboid.[3] Within a normal transverse arch, the angle formed between the metatarsal and the ground in the sagittal plane is 18 to 25 degrees, 15 degrees, 10 degrees, 8 degrees, and 5 degrees from toes 1 to 5, respectively.[3] The formation of these arches allows the support of the body weight with the least expenditure of anatomical material[1] and provides protection for the nerves and vascular supply on the plantar aspect of the foot. An excessively high arch or low arch can result in a variety of dysfunctions in the foot and more distant segments as forces from the foot are transferred to more proximal joints (see article by Tiberio in this issue).

The bones that form these arches are passively interlocked by the action of the plantar aponeurosis (plantar fascia), long and short plantar ligaments, and the plantar calcaneonavicular (spring) ligament. The plantar aponeurosis is a thick band that spans the plantar foot from the calcaneal tuberosities to blend with the skin, flexor tendon sheaths, and transverse metatarsal ligaments, thus forming a series of arches through which the flexor digitorum longus and flexor digitorum brevis muscles pass to the toes. The aponeurosis forms strong intermuscular septa between lateral, intermediate, and medial plantar muscle groups and is continuous with the dorsal fascia of the foot and flexor retinaculum of the medial ankle.[1]

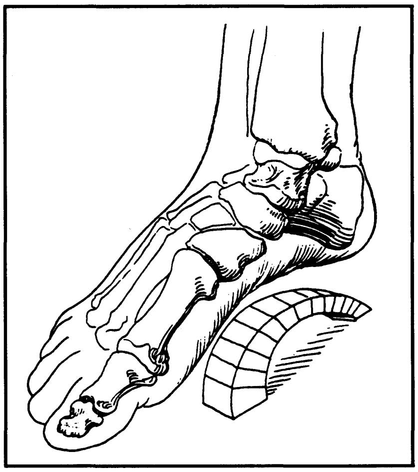

Fig. 1. Longitudinal arch of the foot. (Reprinted with permission from Hoppenfeld S, *Physical Examination of the Spine and Extremities*, New York, NY, Appleton-Century-Crofts, 1976.)

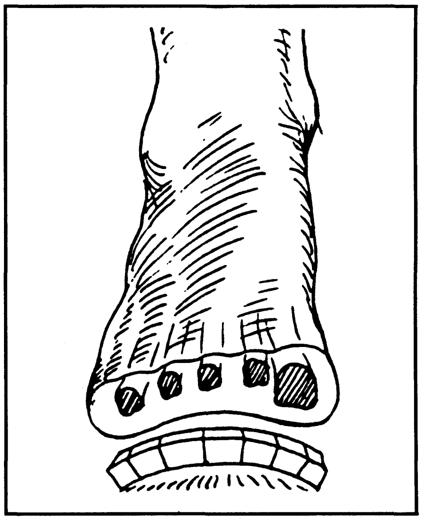

Fig. 2. Transverse arch of the foot. (Reprinted with permission from Hoppenfeld S, *Physical Examination of the Spine and Extremities*, New York, NY, Appleton-Century-Crofts, 1976.)

The long plantar ligament extends from the plantar calcaneus, anterior to the tuberosity, and the plantar cuboid to the bases of the third, fourth, fifth, and occasionally the second metatarsals. The short plantar ligament, deeper and dorsal to the long plantar ligament, courses from the calcaneal tuberosity and area anterior to it to the proximal

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surface of the plantar aspect of the cuboid. The plantar calcaneonavicular ligament extends from the sustentaculum tali of the calcaneus to the plantar surface of the navicular bone.

These ligaments tighten as weight is borne on the foot. The plantar aponeurosis in particular becomes "tight" as the metatarsophalangeal (MTP) joints extend, as in the terminal stance phase of gait. At this time, the aponeurosis is pulled distal to the MTP joints, becoming tight and preventing collapse of the longitudinal arch (Fig. 3).[4,5]

ANKLE AND FOOT JOINTS

Discussion of each joint will include the shapes of relevant bones and articular surfaces, joint ligaments, and joint musculature, with muscular innervation. The shape of articular surfaces is particularly applicable to evaluation of the components of joint motion, such as glides, rolls, and spins, and intervention involving joint mobilization. Because ligaments serve to guide and check excessive joint motion, the ligamentous fiber direction is the key to determining which motions are guided and limited. Table 1 is a summary of important ankle ligaments, their fiber directions, and the motions they limit.

The ankle joint consists of a bony fit between the talus and the tibia proximally and medially (internally) and the talus and the fibula laterally (externally). The dorsal surface of the talus (trochlea) is convex anteroposteriorly and convex-concave-convex from medial to lateral, and the medial surface is slightly concave. These surfaces contact reciprocally shaped areas of the tibia. The lateral aspect of the talus, which is relatively flat, articulates with a reciprocally shaped articular surface on the distal fibula. The proximal surface of the trochlea is slightly wider anteriorly (usually 4–5 mm) than posteriorly.[6,7] The distal tibiofibular joint, involving a convex distal fibula with a concave distal tibia, adds critical stability to the ankle joint. The width between malleoli is greater anteriorly than posteriorly,[6] which results in a snug fit between the trochlea and malleoli in plantar flexion and dorsiflexion.[1]

Strong ligaments, the anterior and posterior tibiofibular and the interosseous ligaments, tightly bind the distal tibiofibular joint. This joint and at times the cuboideonavicular joint are the only joints of the ankle and foot complex that are syndesmosis joints, fibrous joints bound by ligaments but with no synovial membrane. The remaining joints are synovial. The ankle joint has greater ligamentous strength medially, with the continuous and extensive deltoid ligament (Fig. 4), than laterally. The lateral collateral ligament is composed of three separate bands (Figs. 5, 6). Knowing the bony attachments of ligaments, usually indicated in the name of the ligament, and the direction of ligament fibers (fiber direction) will reveal the motions limited when the ligament is tight (Tab. 1).

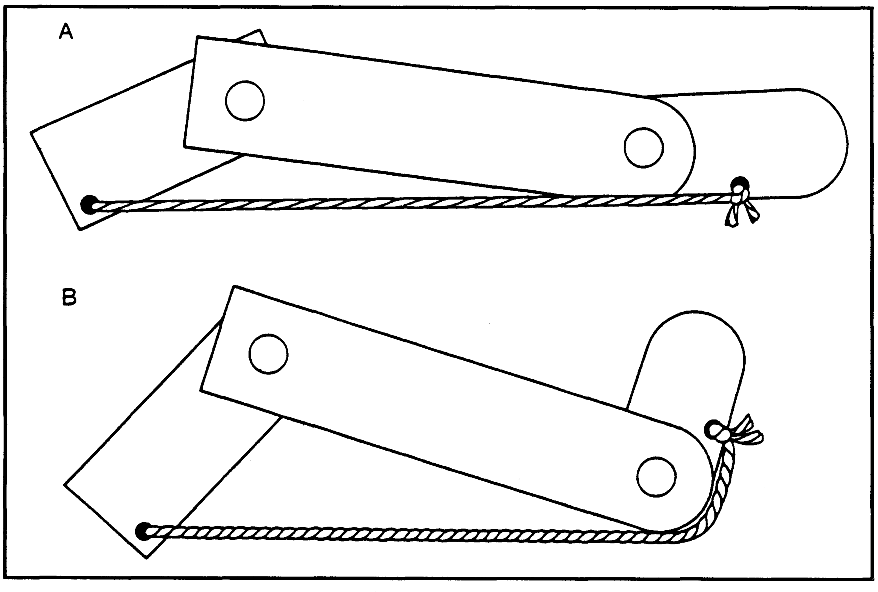

Fig. 3. Functional role of the plantar aponeurosis in raising arch of foot while locking the joints and making a single unit from multiple individual bones and joints. (Reprinted with permission from Frankel YH, Nordin M [eds], *Basic Biomechanics of the Skeletal System*, Philadelphia, PA, Lea & Febiger, 1980.)

Three separate muscular compartments act on the ankle joint: 1) anterior, 2) posterior, and 3) lateral. The anterior and posterior compartments are separated by the tibia, fibula, and interosseous membrane between the two bones. The lateral compartment is separated from the other two compartments by strong fascial sheaths called *intermuscular septa*, which extend from the fibula to the superficial extent of the muscle.

Because the axes of motion for the ankle, subtalar, and midtarsal joints are oblique in three planes, each of these joints will have some component of motion in each plane, that is, dorsiflexion-plantar flexion (sagittal plane), inversion-eversion (frontal plane), and abduction-adduction (horizontal plane). With reference to the main ankle motions, however, anterior compartment muscles cross the ankle anteriorly and act as dorsiflexors, whereas the muscles of the lateral and posterior compartments cross the ankle posteriorly and become plantar flexors. Because no muscles attach to the talus, none of these muscles act exclusively on the ankle.

The anterior compartment muscles originate in general from the anterior surfaces of the tibia, fibula, interosseous membrane, and anterior peroneal intermuscular septum to insert onto the medial and plantar portions of the first cuneiform and first metatarsal (tibialis anterior muscle), the base of the distal phalanx of the hallux (extensor hallucis longus muscle), the expansion around the proximal phalanx, and the dorsum of the middle phalanx and by lateral slips into the dorsum of the distal phalanx of the lateral four toes (extensor digitorum longus muscle) and the dorsal base of the fifth metatarsal (peroneus tertius muscle) (Fig. 7). All of these muscles enter the foot under the cover of the extensor retinaculum (transverse crural and cruciate crural ligaments) and are innervated by the deep peroneal nerve. Table 2 refers to the most important muscles (prime movers) and other muscles (secondary movers) performing each action.

The posterior compartment has a superficial muscle group that is separated from a deep muscle group by a transversely placed intermuscular septum, the deep transverse fascia of the leg. The superficial group is composed of the gastrocnemius, soleus, and plantaris muscles (Fig. 8). The gastrocnemius muscle arises from two heads on the posterior

TABLE 1
Ankle and Foot Joints and Associated Ligaments

Joint	Associated Ligament	Fiber Direction	Motions Limited
Distal tibiofibular	Anterior tibiofibular	Distolateral	Distal glide of fibula Plantar flexion
	Posterior tibiofibular	Distolateral	Distal glide of fibula Plantar flexion
	Interosseous		Separation of tibia and fibula
Ankle	Deltoid (medial collateral)		
	superficial		
	tibionavicular	Plantar-anterior	Plantar flexion, abduction
	tibiocalcaneal	Plantar, plantar-posterior	Eversion, abduction
	posterior tibiotalar	Plantar-posterior	Dorsiflexion, abduction
	deep		
	anterior tibiotalar	Anterior	Eversion, abduction, plantar flexion
	Lateral or fibular collateral		
	anterior talofibular	Anterior-medial	Plantar flexion Inversion Anterior displacement of foot
	calcaneofibular	Posterior-medial	Inversion Dorsiflexion
	posterior talofibular	Horizontal (lateral)	Dorsiflexion Posterior displacement of foot
	Lateral talocalcaneal	Posterior-medial	Inversion Dorsiflexion
	Anterior capsule		Plantar flexion
	Posterior capsule		Dorsiflexion
Subtalar	Interosseous talocalcaneal		
	anterior band	Proximal-anterior-lateral	Inversion Joint separation
	posterior band	Proximal-posterior-lateral	Inversion Joint separation
	lateral talocalcaneal	(See ankle)	
	deltoid	(See ankle)	
	lateral collateral	(See ankle)	
	posterior talocalcaneal	Vertical	Dorsiflexion
	medial talocalcaneal	Plantar-anterior	Eversion
	anterior talocalcaneal (cervical ligaments)	Plantar-posterior-lateral	Inversion
Main ligamentous support of longitudinal arches	Long plantar	Anterior, slightly medial	Eversion
	Short plantar	Anterior	Eversion
	Plantar calcaneonavicular	Dorsal-anterior-medial	Eversion
	Plantar aponeurosis	Anterior	Eversion
Midtarsal or transverse	Bifurcated		Joint separation
	medial band	Longitudinal	plantar flexion
	lateral band	Horizontal	inversion
	Dorsal talonavicular	Longitudinal	Plantar flexion of talus on navicular
	Dorsal calcaneocuboid	Longitudinal	Inversion, plantar flexion
	Ligaments supporting the arches		

(Continued)

TABLE 1 *(Continued)*
Ankle and Foot Joints and Associated Ligaments

Joint	Associated Ligament	Fiber Direction	Motions Limited
Intertarsal	Numerous ligaments named by two interconnected bones (dorsal and plantar ligaments)		Joint motion in direction causing ligamentous tightness
	Interosseous ligaments connecting cuneiforms, cuboid, and navicular		Flattening of transverse arch
	Ligaments supporting arches		
Tarsometatarsal	Dorsal, plantar, and interosseous		Joint separation
Intermetatarsal	Dorsal, plantar, and interosseous		Joint separation
	Deep transverse metatarsal		Joint separation Flattening of transverse arch
Metatarsophalangeal	Fibrous capsule		
	dorsally, thin—separated from extensor tendons by bursae		Flexion
	inseparable from deep surface of plantar and collateral ligaments		Extension
	Collateral	Plantar-anterior	Flexion, abduction, or adduction in flexion
	Plantar, grooved for flexor tendons		Extension
Interphalangeal	Collateral		Flexion, abduction, or adduction in flexion
	Plantar		Extension
	Extensor hood replaces dorsal ligaments		Flexion

aspect of the femoral condyles and subjacent capsule of the knee and inserts into the middle area of the posterior surface of the calcaneus. A sesamoid bone, the fabella, may be present in the lateral head of the gastrocnemius muscle. The soleus muscle arises from a large horseshoe-shaped area on the posterior and proximal fibula and tibia to insert with the gastrocnemius muscle into the Achilles tendon (tendo calcaneus). The two heads of the gastrocnemius and soleus muscles are at times referred to as the triceps surae muscle. The plantaris is a diminutive muscle originating from the lateral extension of the linea aspera and oblique popliteal ligament and inserting with a long, slender tendon into the posterior calcaneus, medial to the Achilles tendon.

The deep group of posterior compartment muscles is composed of the popliteus, tibialis posterior, flexor digitorum longus, and flexor hallucis longus muscles (Fig. 9). The popliteus muscle attaches to the proximal medial portion of the posterior tibia and, after separating the lateral collateral ligament of the knee from the lateral meniscus, to the lateral aspect of the lateral femoral condyle. The popliteus muscle is the prime mover for knee medial rotation and is especially important in initial unlocking of a fully extended knee.[8] The other muscles on this deep group arise posteriorly from the same areas as the anterior compartment muscles and insert, in order, onto all tarsals (except the talus) and metatarsals 2, 3, and 4 (tibialis posterior muscle); the bases of distal phalanges 2, 3, 4, and 5 after passing through their respective tendons of the flexor digitorum brevis muscle (flexor digitorum longus muscle); and the base of the distal phalanx of the hallux (flexor hallucis longus muscle). They course in individual fascial compartments to the foot secured by the flexor retinaculum (laciniate ligament). All muscles of the superficial and deep groups are innervated by branches of the tibial nerve.

The lateral compartment is composed of the peroneus longus and peroneus brevis muscles (Fig. 10). Both are innervated by the superficial peroneal nerve, arise from the fibula and intermuscular septa, and pass posterior to the lateral malleolus under the peroneal retinacula. The peroneus longus muscle, more proximal and superficial in origin than the peroneus brevis muscle, traverses the plantar aspect of the foot to attach to the base of the first metatarsal and medial cuneiform. It attaches to the lateral side of both bones and therefore inserts on the opposite side of the attachment sites of the tibialis anterior muscle. At the lateral malleolus and the cuboid, the peroneus longus muscle abruptly

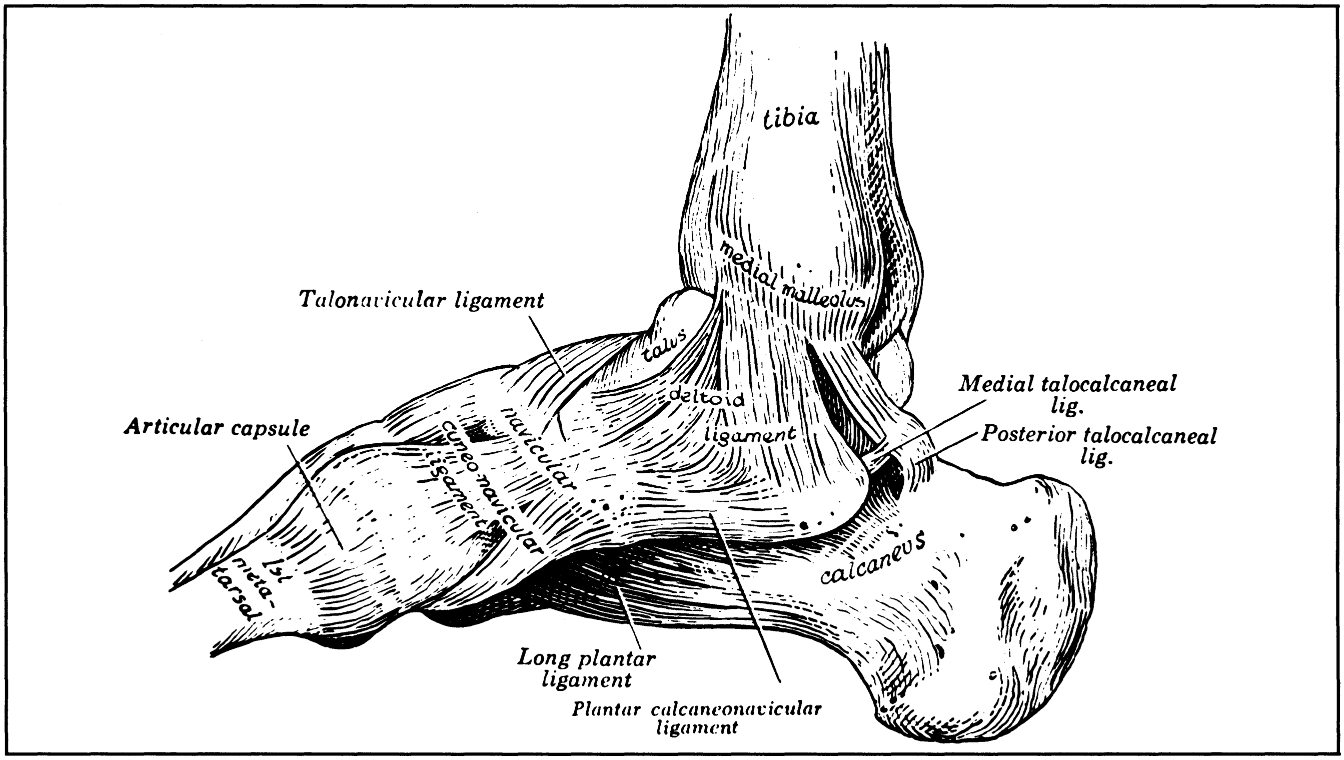

Fig. 4. Medial collateral (deltoid) ligament of the ankle. (Reprinted with permission from Goss CM [ed], *Gray's Anatomy of the Human Body: Twenty-Ninth American Edition*, Philadelphia, PA, Lea & Febiger, 1973.)

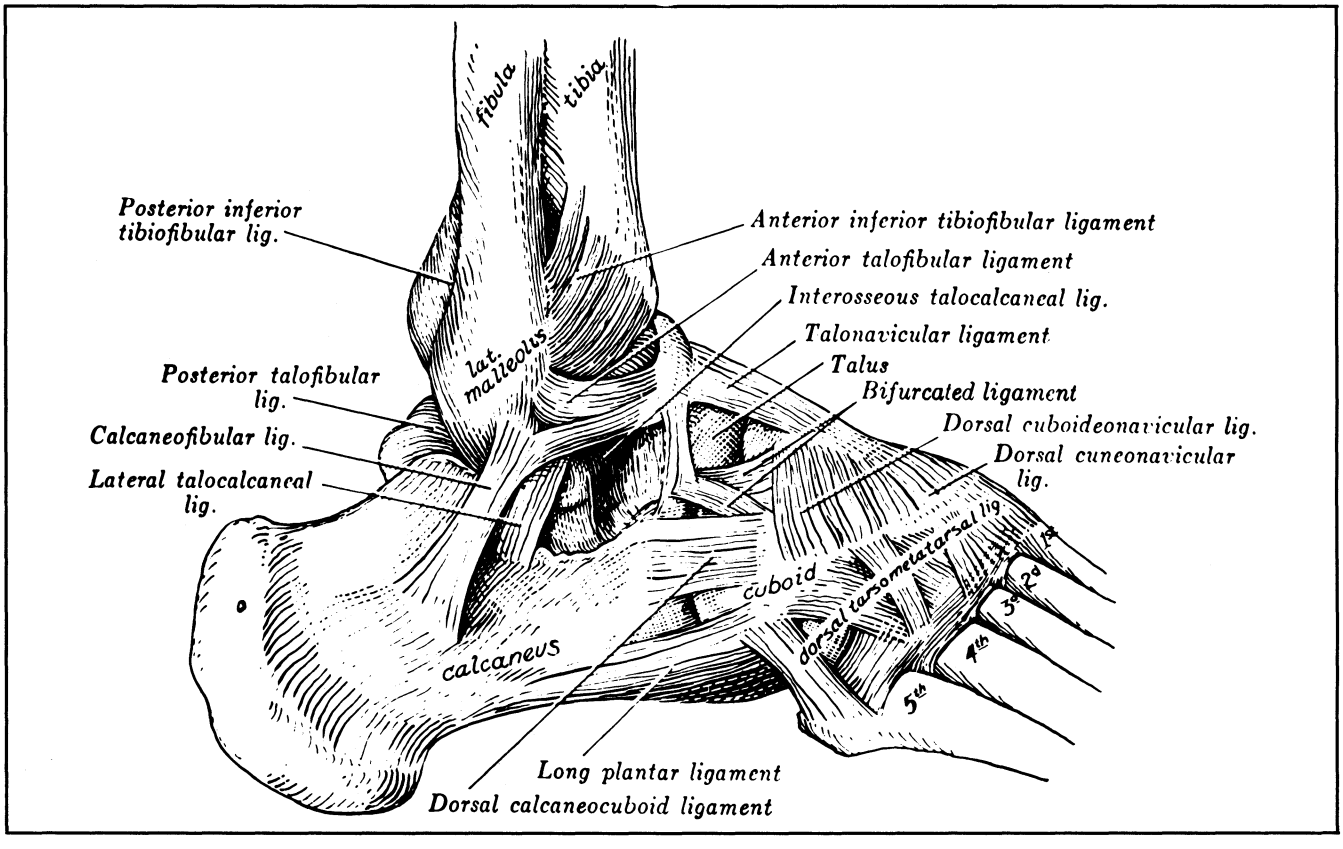

Fig. 5. Lateral collateral ligament of the ankle. (Reprinted with permission from Goss CM [ed], *Gray's Anatomy of the Human Body: Twenty-Ninth American Edition*, Philadelphia, PA, Lea & Febiger, 1973.)

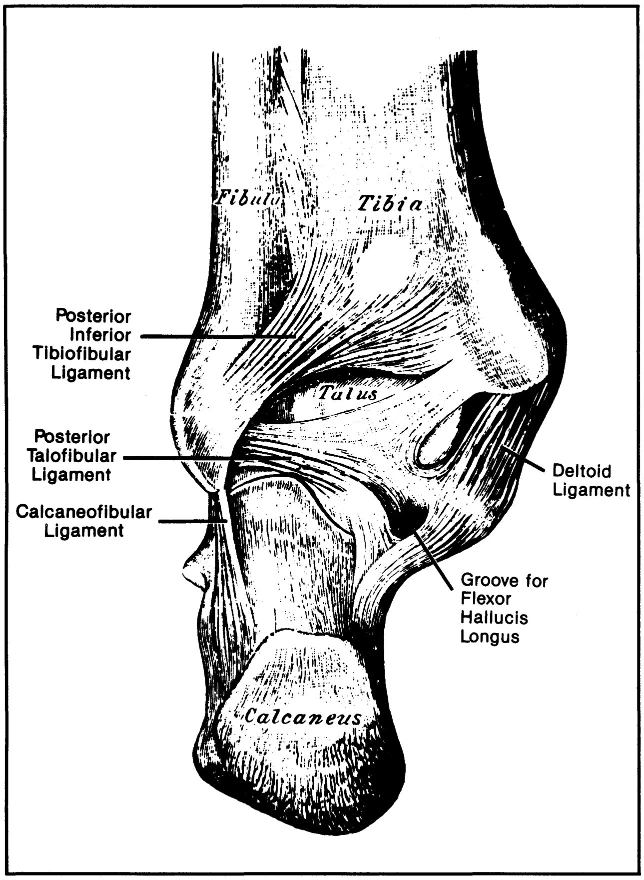

Fig. 6. Lateral collateral and tibiofibular ligaments of the ankle. (Adapted from Goss CM [ed], *Gray's Anatomy of the Human Body: Twenty-Ninth American Edition*, Philadelphia, PA, Lea & Febiger, 1973.)

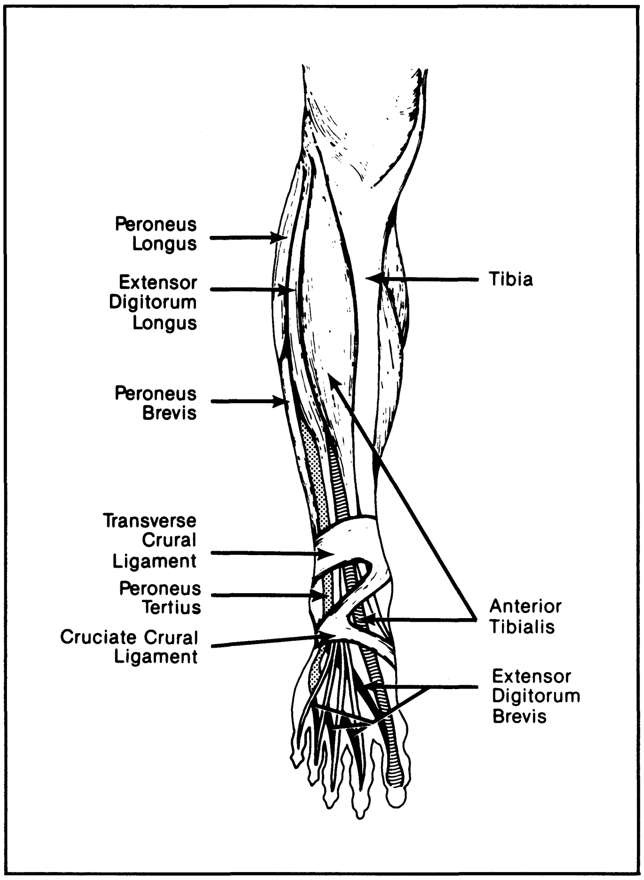

Fig. 7. Anterior compartment of the leg.

changes direction, and the tendon is adaptively thickened at these sites. A protective sesamoid fibrocartilage or bone is usually developed within the tendon at the area of the cuboid. The peroneus brevis muscle takes a direct course to the base of the fifth metatarsal.

Subtalar Joint

The subtalar joint consists of a biconvex posterior calcaneal facet articulating with a biconcave posterior talar facet on the body of the talus, an anteriorly placed biconcave calcaneal facet articulating with a biconvex talar facet on the neck of the talus, and, in some individuals, an additional more anteriorly placed concave calcaneal facet with a convex talar facet. If three facets exist, they are named posterior, middle, and anterior calcaneal or talar facets, whereas if only two facets exist, they become the posterior and anterior calcaneal or talar facets. The anterior medial joint, which is supported by the sustentaculum tali of the calcaneus, includes the talonavicular joint within its capsule. The posterior portion of the subtalar joint has its own joint capsule. Anterior to the posterior facets is a deep groove in the calcaneus (sulcus calcanei). In the intact subtalar joint, it joins a similar depression anterior to the posterior talar facet (sulcus tali) to form a tunnel called the sinus tarsi. Attached to the calcaneus and talus within this groove are the two interosseous ligaments, the thick and strong ligaments that form the chief support of the subtalar joint. The interosseous ligaments are portions of the united capsules of the anterior joint (talocalcaneonavicular joint) and the posterior joint (talocalcaneal joint). The interosseous ligaments as well as other ligaments that support the subtalar joint are listed in Table 1.

Muscles of the anterior, posterior, and lateral compartments act also at the subtalar joint. As with the ankle, motion occurs in a diagonal or oblique plane, with the main motions at the subtalar joint being eversion or inversion (see article by Oatis in this issue). Most posterior compartment muscles and the anterior tibialis muscle are invertors, whereas the lateral compartment muscles, peroneus tertius muscle, and extensor digitorum longus muscle are evertors (Tab. 2). The subtalar motion of the extensor hallucis longus muscle can be inversion or eversion, depending on the angulation of the subtalar axis.[3,9]

Transverse Tarsal Joint

The transverse tarsal or midtarsal joint is actually formed by two joints—the talonavicular and the calcaneocuboid. The talonavicular joint consists of a biconvex talar head contacting a biconcave navicular (scaphoid) bone. In the calcaneocuboid joint, the anterior calcaneus, which is concavo-convex in a dorsoplantar direction and convexo-concave in a lateromedial direction, contacts a reciprocally shaped cuboid bone. This arrangement of the four bones results in an S-shaped appearance of the joint when viewed from above (Fig. 11). The convex head of the talus is directed about 15 degrees medial to

TABLE 2
Ankle and Foot Joints and Muscles Performing Associated Motions

Joint	Motion	Prime Mover	Secondary Mover
Ankle Subtalar Transverse tarsal	Dorsiflexion	Tibialis anterior	Extensor hallucis longus Extensor digitorum longus Peroneus tertius
	Plantar flexion	Gastrocnemius Soleus	Tibialis posterior Flexor digitorum longus Flexor hallucis longus Peroneus longus and peroneus brevis Plantaris
	Inversion (and adduction)	Tibialis posterior	Flexor digitorum longus Flexor hallucis longus Tibialis anterior Extensor hallucis longus
	Eversion (and abduction)	Peroneus longus and peroneus brevis	Peroneus tertius Extensor digitorum longus Extensor hallucis longus
Hallux Metatarsophalangeal (MTP)	Flexion	Flexor hallucis brevis	Flexor hallucis longus Abductor hallucis
	Extension	Extensor hallucis longus	Extensor hallucis brevis
	Abduction	Abductor hallucis	
	Adduction	Adductor hallucis	
Interphalangeal	Flexion	Flexor hallucis longus	
	Extension	Extensor hallucis longus	Dorsal expansion from flexor hallucis brevis, abductor hallucis, and adductor hallucis
Toes 2-5 MTP	Flexion	Flexor digitorum brevis Lumbricals	Flexor digitorum longus Quadratus plantae Lumbricals Plantar interossei (toes 3–5) Flexor digiti minimi brevis
	Extension	Extensor digitorum longus	Extensor digitorum brevis (toes 2–4)
	Abduction	Dorsal interossei (toes 2–4) Abductor digiti minimi (toe 5)	
	Adduction	Plantar interossei (toes 3–5)	
Proximal interphalangeal	Flexion	Flexor digitorum brevis	Flexor digitorum longus Quadratus plantae
	Extension	Lumbricals Interossei Abductor digiti minimi	Extensor digitorum longus-slight
Distal interphalangeal	Flexion	Flexor digitorum longus	Quadratus plantae
	Extension	Lumbricals Interossei Abductor digiti minimi	Extensor digitorum longus-slight

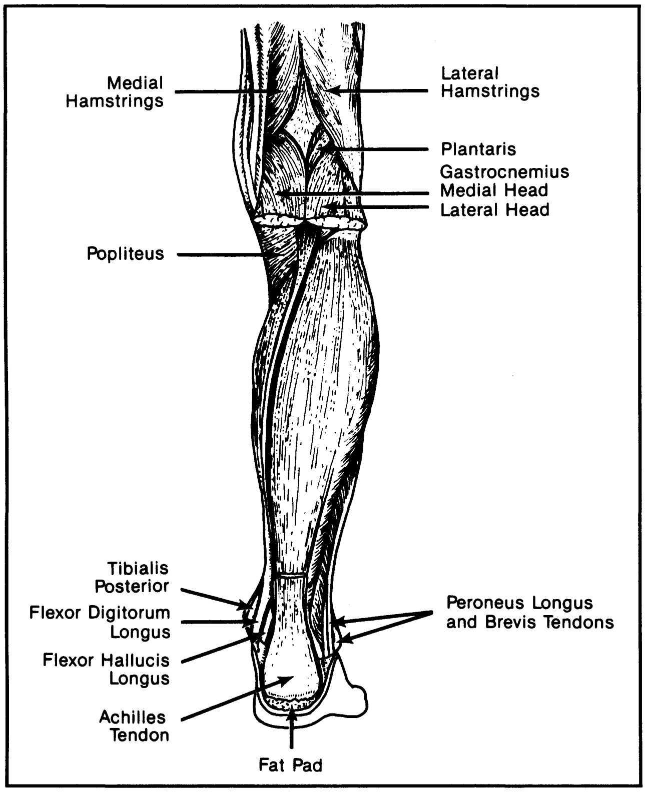

Fig. 8. Superficial muscle layers of posterior compartment of the leg.

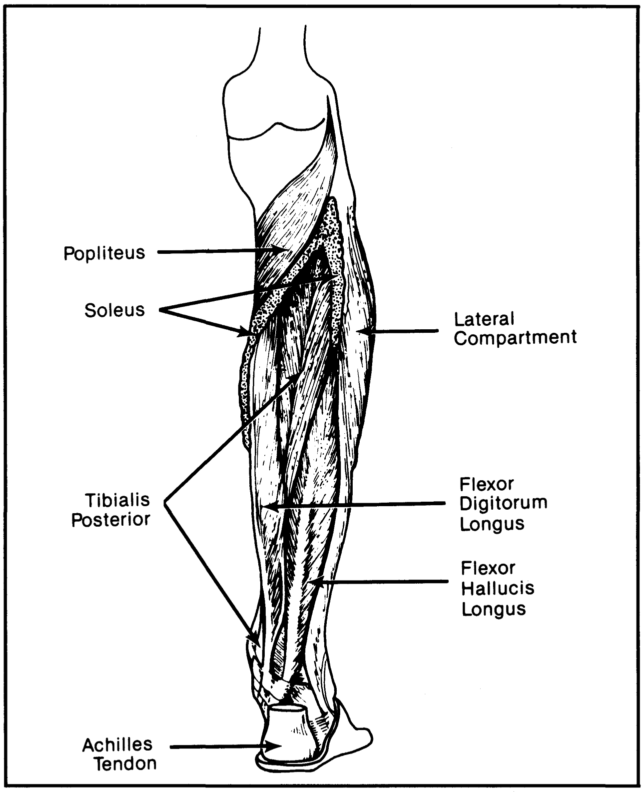

Fig. 9. Deep muscle layer of posterior compartment of the leg.

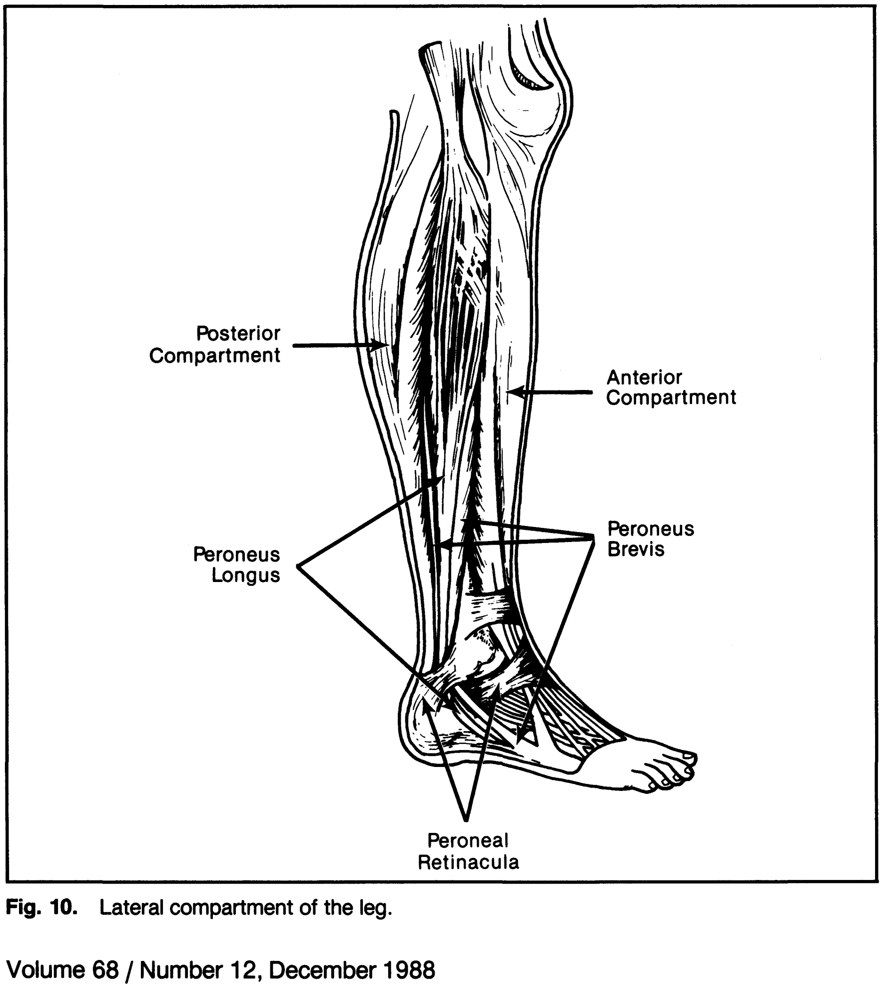

Fig. 10. Lateral compartment of the leg.

the longitudinal axis of the foot and 40 degrees in a plantar direction because of the angulation in the neck of the talus.[10]

Several ligaments provide particular support to this joint complex. The bifurcated ligament spans an area from the anterior dorsal calcaneus to the lateral dorsal navicular (medial band) and to the dorsal cuboid (lateral band). The attachments of other ligaments of this joint are indicated by their names (Tab. 1).

Muscles that cross these joints act around a longitudinal and oblique axis (see article by Oatis in this issue) producing the motions of plantar flexion-dorsiflexion, inversion-eversion, and abduction-adduction. In addition, the tibialis posterior and peroneus longus tendons of insertion cross each other to give a "shoestring" type of support to the transverse tarsal joint. The peroneus longus muscle has the added ability to plantar flex the first metatarsal (first ray), which gives it added importance during terminal stance in gait when body weight is being shifted over the forefoot.

Intertarsal, Tarsometatarsal, Metatarsophalangeal, and Interphalangeal Joints

Intertarsal joints include the three slightly convex navicular facets with the

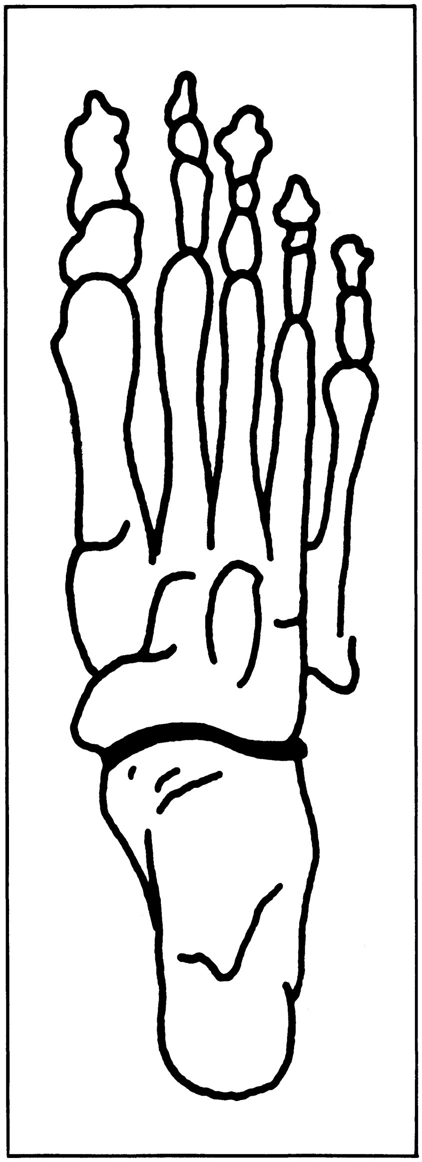

Fig. 11. S-shaped curve in the normal midtarsal joint when viewed superiorly. (Adapted from Frankel VH, Nordin M [eds], *Basic Biomechanics of the Skeletal System*, Philadelphia, PA, Lea & Febiger, 1980.)

three slightly concave facets on the cuneiforms and relatively flat facets between the cuboid and lateral cuneiform and between the cuboid and the lateral navicular. These flat articular surfaces allow gliding motion in many directions between the tarsal bones.

The metatarsal bones are miniature long bones, with each of the five having a proximal flat or slightly concave base and a distal rounded head. The tarsometatarsal joints consist of the articulations of the medial cuneiform with the first metatarsal, all three cuneiforms forming stable contact around the second ray, the lateral cuneiform with the third ray, the lateral cuneiform and cuboid contacting the fourth ray, and the cuboid with the fifth ray. The greater bony stability of the second ray is important in the late stance phase of gait, when increased load is transmitted from the ground through the second metatarsal. The tarsometatarsal joints are capable of gliding motion as are the intermetatarsal joints, which consist of articulations between adjacent metatarsal bases. The biconvex metatarsal heads and biconcave proximal phalangeal bases form the MTP joints, which allow plantar flexion and dorsiflexion, abduction and adduction, and the combination of these four motions, circumduction.

Because the hallux has two phalanges and the other toes have three phalanges, the hallux has an interphalangeal (IP) joint, and the other toes have a proximal interphalangeal (PIP) joint and a distal interphalangeal (DIP) joint. The proximal phalanges resemble miniature long bones, the middle phalanges are short and wide, and the distal phalanges are small and wedge shaped. Proximal surfaces of IP joints are convex in a dorsoplantar direction and concave in a mediolateral direction, and distal joint surfaces are reciprocally shaped.

Ligaments in the forefoot consist of numerous plantar, dorsal, and interosseous ligaments, usually named according to their attachment sites. These ligaments and the collateral ligaments, which attach to the medial and lateral sides of the MTP and IP joints, are listed by joint in Table 1.

Motion of the toes occurs as a result of muscle action by extrinsic muscles, those originating proximal to the foot and inserting in the foot, as well as intrinsic muscles, those muscles originating and inserting within the foot (Tab. 2). The plantar intrinsic foot muscles are composed of four layers of muscles.

Muscles of the first layer, just deep or dorsal to the plantar aponeurosis, originate generally from the calcaneal tuberosities, plantar aponeurosis, and intermuscular septa and insert onto the medial base of the proximal phalanx of the hallux (abductor hallucis muscle); the base of the plantar surface of the middle phalanx of toes 2, 3, 4, and 5 (flexor digitorum brevis muscle); and

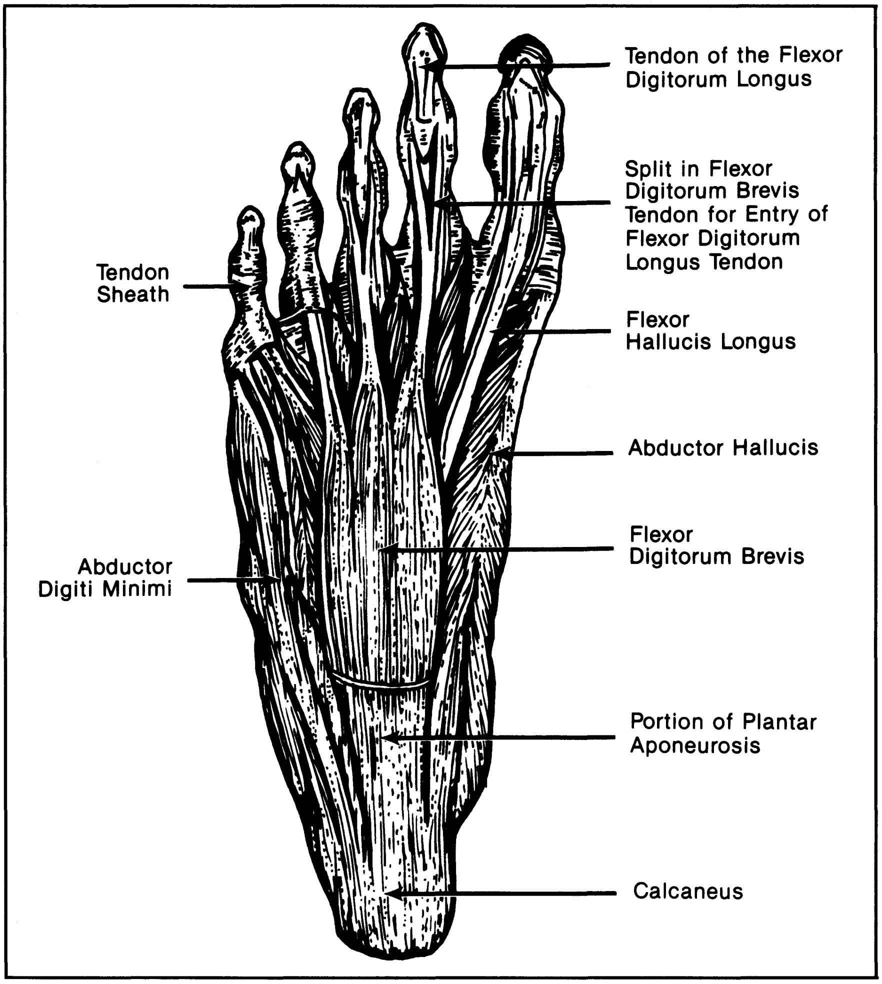

Fig. 12. Superficial (first) layer of muscles on the plantar foot.

the lateral base of the proximal phalanx of toe 5 (abductor digiti minimi muscle) (Fig. 12). These muscles abduct the MTP joints of the hallux and little toe and flex the PIP joints, as their names indicate.

The second layer, deep or dorsal to the first layer, is composed of the tendons of the extrinsic flexor hallucis longus and flexor digitorum longus muscles, the quadratus plantae muscle, and the four lumbrical muscles. The lumbrical muscles attach to their respective flexor digitorum longus tendons and to the tendons of the extensor digitorum longus muscle along the medial side of the MTP of toes 2, 3, 4, and 5 in much the same way as they attach in the hand (Fig. 13). The quadratus plantae muscle connects the plantar surface of the calcaneus and the tendons of the flexor digitorum longus muscle and results in toe flexion without a medial deviation, which the flexor digitorum longus muscle alone would produce.

The third layer of muscles is formed by intrinsic foot muscles, which originate generally from the more anterior tarsals, bases of the metatarsals, and sheath of the peroneus longus muscle to insert onto the base of the proximal phalanx on the medial side of the hallux (medial head of the flexor hallucis brevis muscle) or lateral side of the hallux (lateral head of the flexor hallucis brevis muscle and oblique head of the adductor hallucis muscle), the lateral side of the base of the proximal phalanx of the little toe (flexor digiti minimi brevis muscle), and, in some individuals, the lateral side of the distal half of the fifth metatarsal (opponens digiti minimi muscle) (Fig. 14). The transverse head of the adductor hallucis muscle arises from a different region, the plantar MTP ligaments of toes 3, 4, and 5, and inserts with the oblique head of the adductor hallucis muscle.

The plantar and dorsal interosseus muscles form the fourth layer (Fig. 15). Attachment sites for the interosseus muscles can be determined by recalling the reference line for MTP abduction and adduction, which is the second metatarsal. Plantar interosseus muscles are MTP adductors and therefore insert on the medial surfaces of toes 3, 4, and 5. The hallux has its own adductor. Abduction forces are required on both sides of toe 2 and the lateral sides of toes 3 and 4 because the hallux and minimus both have their own abductors. The three plantar interosseus muscles originate from one metatarsal and insert onto the base of the distal phalanges of the same toes. The four dorsal interosseus muscles arise from two adjacent metatarsals and insert onto toes 2, 3, and 4 as described.

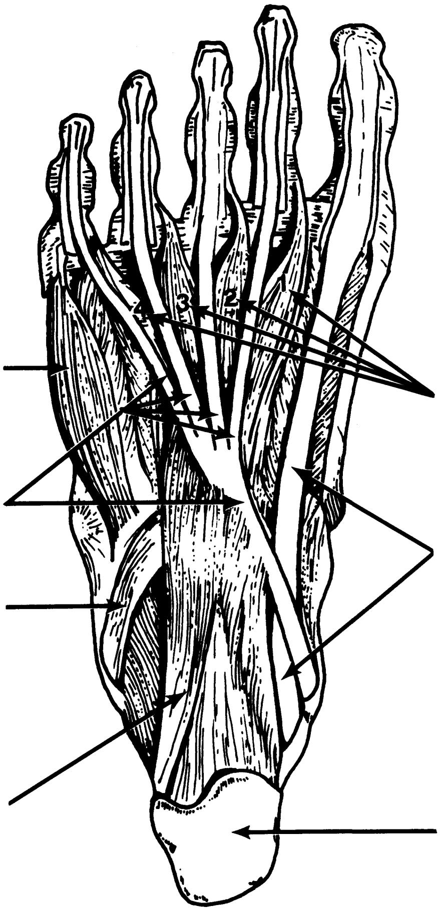

Fig. 13. Second layer of muscles on the plantar foot.

The lumbrical, plantar and dorsal interosseus, and abductor digiti minimi muscles attach additionally by a fibrous expansion to the extensor digitorum longus tendon, forming the extensor hood on the dorsum of the toes (Fig. 16). Through this attachment, these muscles are able to flex the MTP joints and extend the PIP and DIP joints. The expansion from the lumbrical muscles is particularly effective in flexing the MTP joints. Little PIP and DIP extension can be produced by the extensor digitorum longus muscle alone. In some individuals, the hallux may have a similar extensor hood, which would be formed by fibrous attachments to the extensor hallucis longus muscle from the adductor hallucis muscle, abductor hallucis muscle, and both heads of the flexor hallucis brevis muscle.

Innervation to the plantar intrinsic muscles is provided by the medial and lateral plantar nerves, which are branches of the tibial nerve. The medial plantar nerve innervates the flexor digitorum brevis, abductor hallucis, flexor hallucis brevis, and first lumbrical muscles. All other plantar intrinsic muscles are supplied by the lateral plantar nerve.

The only intrinsic muscle that is clearly on the dorsum of the foot is the extensor digitorum brevis. It arises laterally on the dorsal foot, from the distal aspect of the calcaneus, the lateral talocalcaneal ligament, and the cruciate crural ligament. The tendons of insertion attach similarly in toes 2, 3, and 4 onto the lateral aspects of the tendons of the extensor digitorum longus muscle, while the fourth tendon (also known as the extensor hallucis brevis) attaches to the dorsal surface of the base of the proximal phalanx of the hallux. All tendons extend the MTP joints of toes to which they attach and are innervated by the deep peroneal nerve.

Articular Neurology

Joint structures that receive innervation, which are all joint structures except articular cartilage, are supplied by nerves that pass closely to the joint.[10] Innervation has been well documented for the distal tibiofibular joints, supplied by the deep peroneal, tibial, and saphenous nerves, and the ankle joint, supplied by the deep peroneal and tibial nerves.[10]

Dermatomes

Terminal nerve versus dermatomal distribution to the skin can be compared in Figures 17 through 20.

Muscular Representation of Neurologic Levels

Muscles of the ankle and foot are innervated by spinal levels L4 through S3. Muscle groups in the ankle and foot represent the following neurologic levels: dorsiflexors (L4-5), plantar flexors (S1-2), invertors (L4-5), evertors (L5, S1), and foot intrinsics (S2-3).[10]

Individual ankle and foot muscles that are clinically used to test the integrity of motor supply of a neurologic level are the following: tibialis anterior (L4); extensor hallucis longus and extensor digitorum longus (L5); and peroneus longus, peroneus brevis, and gastrocnemius-soleus (S1).[10,11] These same three neurologic levels are tested for sensory integrity at the medial dorsal foot (L4), mid-dorsal foot (L5), and lateral dorsal foot (S1) (Fig. 17).

Vascular Supply to Ankle and Foot

The main arteries of the ankle and foot are the anterior tibial artery, the main artery of the anterior compartment, and the posterior tibial artery, the main artery of the posterior and lateral compartments. These two arteries form at the division of the popliteal artery at the posterior knee and supply the three compartments in addition to sending terminal branches into the foot.

The anterior tibial artery enters the anterior compartment through an opening in the proximal part of the interosseous membrane between the tibia and the fibula (Fig. 21). The branches of the anterior tibial artery supply the anterior compartment and the overlying skin, and some branches pass through the interosseous membrane to anastomose with branches of the posterior tibial artery. The anterior medial and lateral malleolar branches disperse deep to the tendons of the anterior compartment muscles to anastomose with branches of the posterior tibial artery to form the medial and lateral malleolar networks. These malleolar branches may arise instead from the dorsalis pedis artery, the distal continuation of the anterior tibial artery.

The dorsalis pedis passes along the medial side of the dorsum of the foot to the proximal portion of the first metatarsal space and is palpable on the lateral aspect of the extensor hallucis longus tendon at the level of the ankle joint. The tarsal branches course medially and laterally dorsal to the tarsal bones and

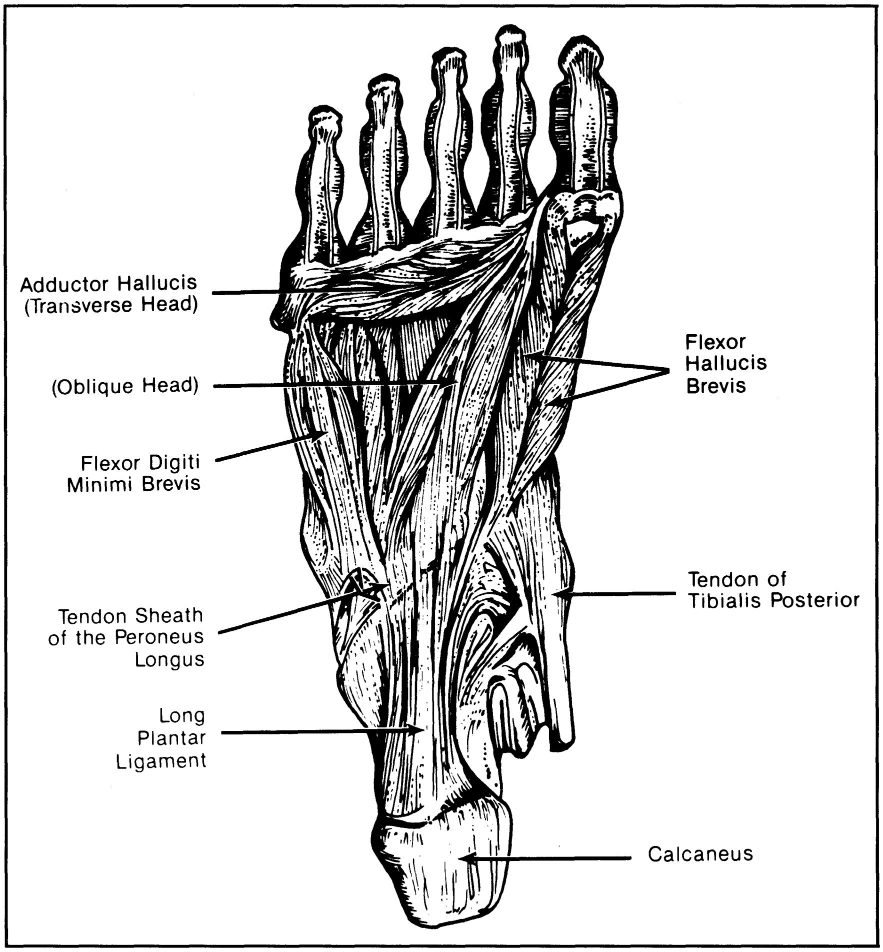

Fig. 14. Third layer of muscles on the plantar foot.

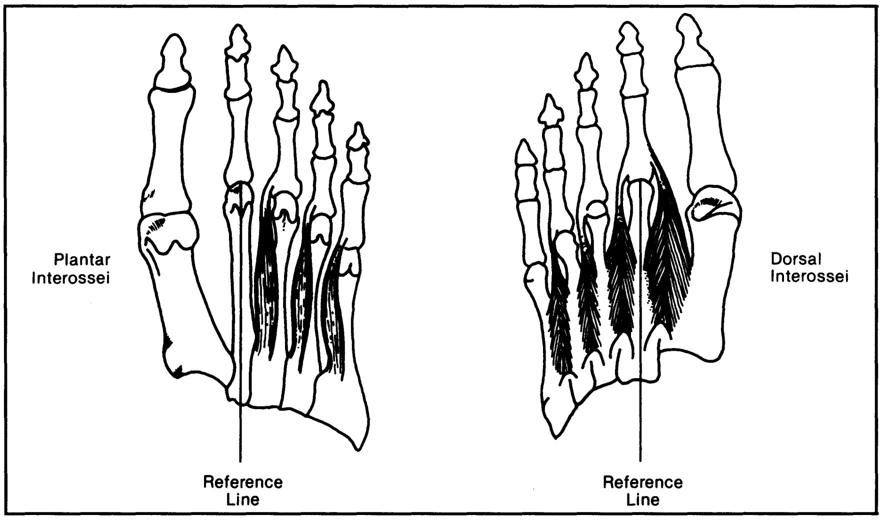

Fig. 15. Fourth layer of muscles on the plantar foot.

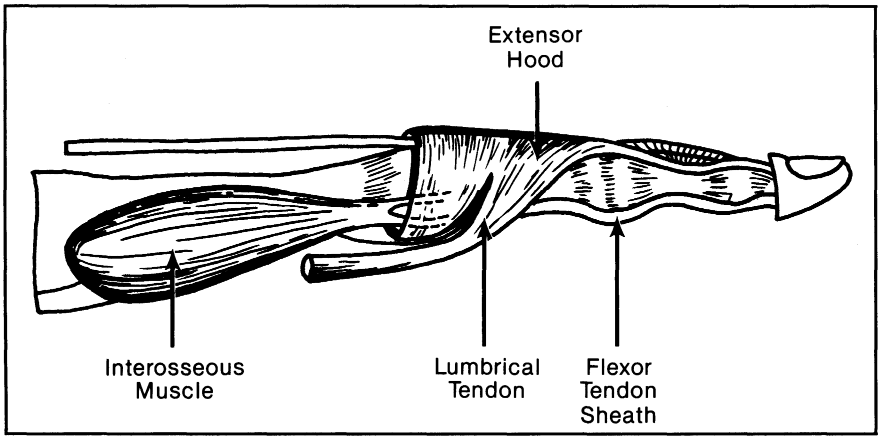

Fig. 16. Extensor hood mechanism of the toes. (Adapted from Frankel VH, Nordin M [eds], *Basic Biomechanics of the Skeletal System*, Philadelphia, PA, Lea & Febiger, 1980.)

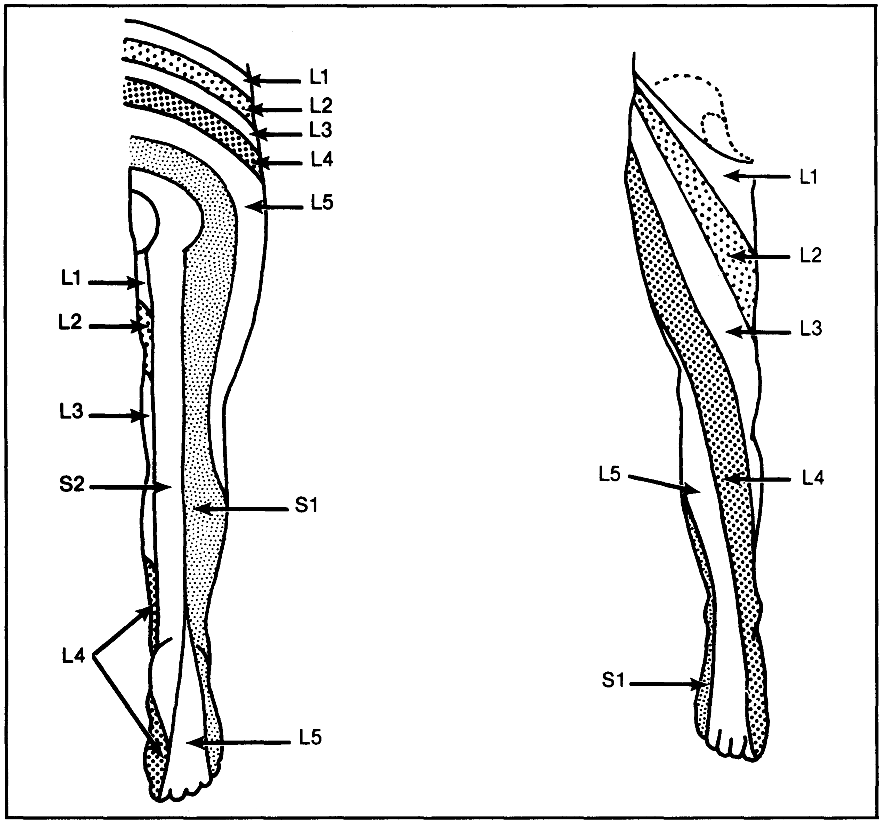

Fig. 17. Dermatomes of the lower extremity.

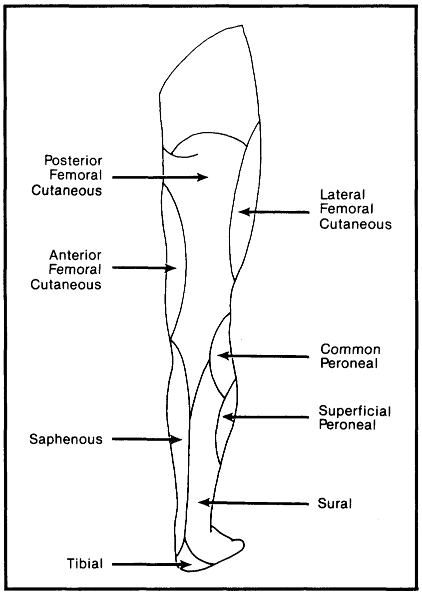

Fig. 18. Cutaneous distribution of terminal nerves in the posterior lower extremity.

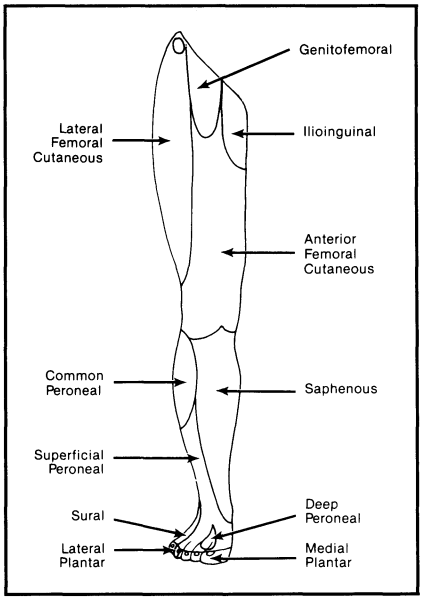

Fig. 19. Cutaneous distribution of terminal nerves in the anterior lower extremity.

add to the malleolar network. The lateral tarsal branch supplies the deep extensor digitorum brevis muscle. The arcuate artery, also a branch of the dorsalis pedis, courses laterally at the level of the bases of the metatarsal bones and sends three metatarsal arteries distally. These metatarsal arteries each divide into dorsal digital arteries and travel distally on the medial and lateral sides of toes 3, 4, and 5 and the lateral side of toe 2. The two terminal branches of the dorsalis pedis are the first dorsal metatarsal artery, which eventually divides to send dorsal digital arteries to both sides of the hallux and the medial part of the second toe, and the deep plantar artery. The deep plantar artery pierces the first dorsal interosseous space to help complete the arterial network of the plantar foot.

The plantar arterial system is formed by the terminal branches of the posterior tibial artery (Fig. 22), which usually divides under the cover of the abductor hallucis muscle to form the medial and lateral plantar arteries. The medial plantar artery travels dorsal to the abductor hallucis and flexor digitorum brevis muscles and then emerges between these muscles to supply the medial plantar aspect of the hallux and partially supply the adjacent sides of toes 1 through 4. The larger lateral plantar artery travels deep to the flexor digitorum brevis muscle toward metatarsal 5 and then forms an arch across the foot at the level of the bases of the metatarsals. The plantar arch is completed as the lateral plantar artery meets the deep plantar artery. Four plantar metatarsal arteries emerge from the arch and, with partial supply from branches from the medial plantar artery, divide into plantar digital arteries, which travel between the toes. The lateral side of the little toe is supplied by

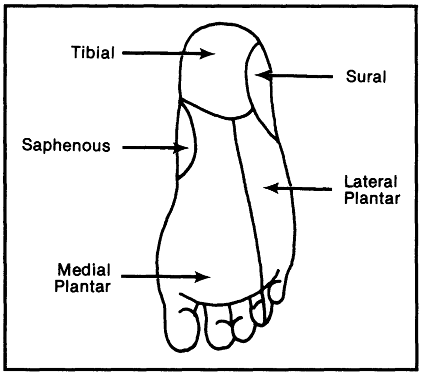

Fig. 20. Cutaneous distribution of terminal nerves in the plantar foot.

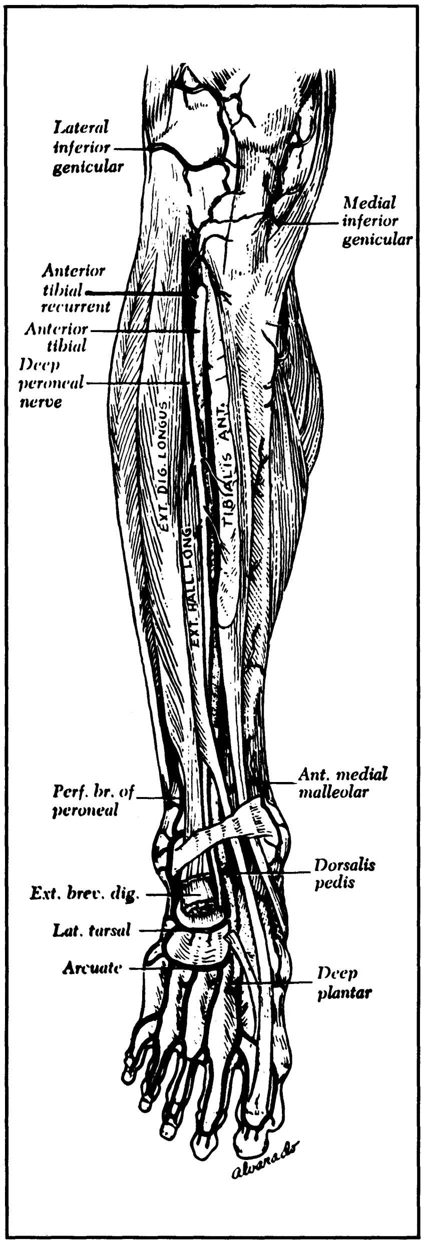

Fig. 21. Vascular supply in the anterior leg and dorsal foot. (Reprinted with permission from Goss CM [ed], *Gray's Anatomy of the Human Body: Twenty-Ninth American Edition*, Philadelphia, PA, Lea & Febiger, 1973.)

a digital branch from the lateral plantar artery itself. Three perforating arteries penetrate the second, third, and fourth interosseous spaces to connect dorsal and plantar metatarsal arteries.

The posterior tibial artery has branches within the leg to supply the posterior and lateral compartments. The large peroneal branch supplies the lateral compartment as well as lateral and posterior calcaneal structures. It also sends branches to the lateral malleolar network. Vascular supply is sent from the posterior tibial artery to the medial malleolar network (posterior medial malleolar artery) to join the peroneal artery in the distal leg (communicating branch) and to the medial heel area (medial calcaneal artery).

Fat Pads

A fat pad superficially cushions all plantar structures. This pad is particularly thick on the heel to dampen the effect of the heel contacting the ground at the heel-strike phase of the gait cycle. The area surrounding the distal Achilles tendon is surrounded with fat as well.

SUMMARY

The anatomical structure of ankle and foot bones, ligaments, muscles; innervation; and vascular supply have been discussed. This review should serve as a basis to discuss functional mobility and stability, static and dynamic biomechanics, and evaluation and treatment of ankle and foot dysfunction.

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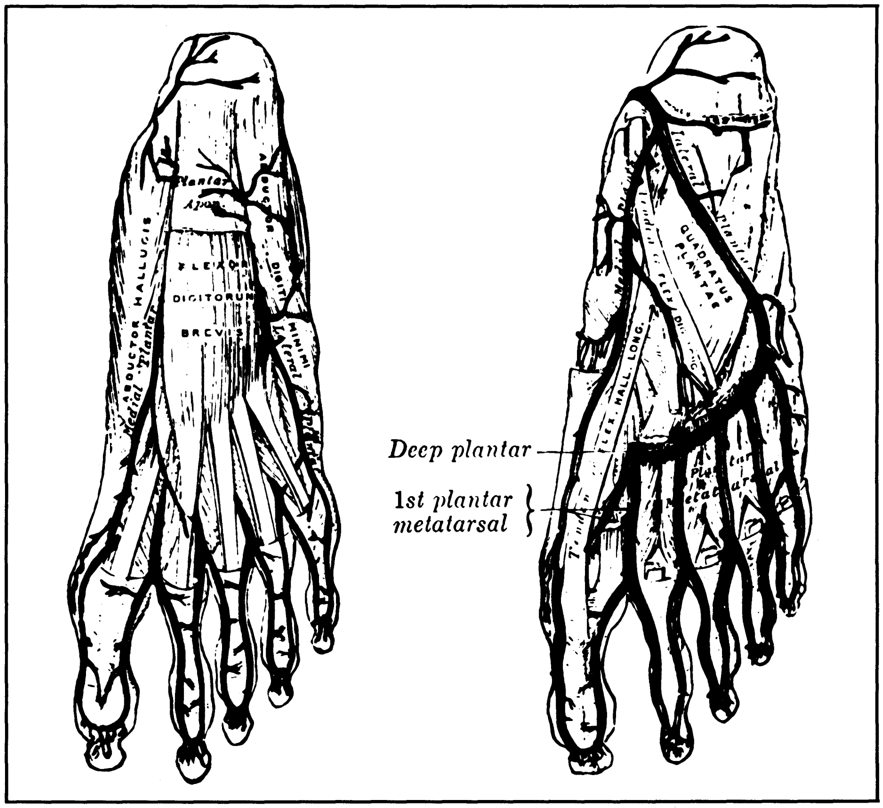

Fig. 22. Vascular supply to the plantar foot. (Reprinted with permission from Goss CM [ed], *Gray's Anatomy of the Human Body: Twenty-Ninth American Edition*, Philadelphia, PA, Lea & Febiger, 1973.)