2

Normal Anatomy of the Forefoot

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LIMB DEVELOPMENT

There are many different types of deformities that may present in the foot. Many congenital deformities can be explained by problems occurring during development of the lower limb.[1] Some of the most common congenital deformities include syndactyly, missing digits, and duplication of digits.[2-4] There are other deformities, however, that may be more difficult to identify, such as missing or abnormal muscles, absent or undersized vessels, and anomalous nerves.[3,5]

The limbs start to appear in the early stages of the embryonic period of development (fourth to eighth intrauterine [IU] week) as condensations of mesenchyme. The upper limb appears a few days before the lower limb. By the end of the embryonic period, the embryo has become distinctly human. Furthermore, all the limbs are formed with all the fingers and toes fully developed (Fig. 2-1). The fetal period (9 weeks IU to birth) is characterized by further growth of the fetus. From the time of birth through the first 6 years of life, the skeleton not only grows in size, with the legs elongating faster than the arms, but undergoes rotational and torsional changes as well.[6] These rotational and torsional changes usually are complete by the sixth year. Skeletal maturity occurs when all growth plates have closed.[7,8]

During the first week of the embryonic period (fourth week IU), small elevations appear on the ventrolateral aspect of the embryo (Fig. 1). These elevations, called limb buds, consist of a mass of mesenchyme covered with ectoderm. During the sixth IU week, the mesenchyme within the center of the limb bud condenses. This mass rapidly undergoes chondrification to form hyaline cartilage, and by the end of the embryonic period ossification has started in most of the long bones of the body. When first formed, the feet are paddle-shaped plates. By the end of the seventh IU week, however, the mesenchymal tissue starts to condense into digital rays and the mesenchyme between the digits eventually degenerates. By the end of this week, the embryo has free movable toes.

Limb rotation occurs between the seventh and eighth IU weeks. It is during this time the embryo takes on the familiar "fetal position." Previous to limb rotation the knees and the elbows are both directed laterad. When rotation occurs, the knee rotates craniad, such that it is now anterior. The elbow rotates in a caudal direction such that it is directed posterior (see Fig. 2-1).

Simultaneously, the mesenchyme immediately surrounding the potential bone develops into a ventral and dorsal mass. These masses eventually form the dorsal and ventral groups of muscles in the limb. The ventral rami of adjacent spinal cord segments grow into these future muscles and form myotomes, some of which persist in the adult.

The arterial supply to the developing lower limb starts as a capillary plexus off the dorsal side of the umbilical artery and the internal iliac artery.[7] The artery formed from this plexus is the *axial artery* and is located in the dorsal aspect of the leg. The axial artery terminates by passing through the sinus tarsi and forming a plantar capillary network. The *femoral artery* forms from the external iliac artery. It descends the limb along the ventral aspect of the thigh and terminates on the dorsum of the foot. During its development, the femoral artery communicates with the axial artery in many locations. Gradually, between the end of the embryonic period and birth, the axial artery

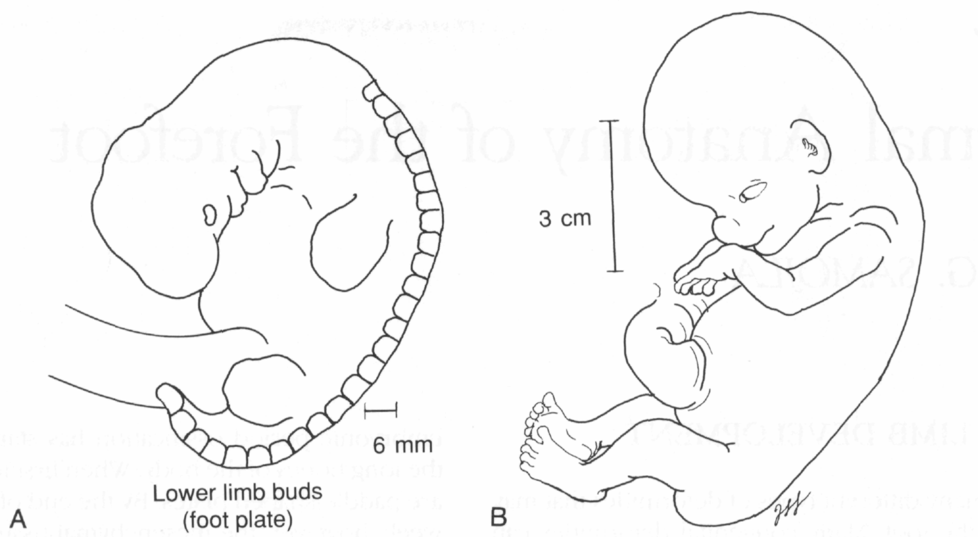


Fig. 2-1. Development of the limbs in the embryo. **(A)** Early embryonic period. The limb buds have formed and the embryo is approximately 6 mm long. **(B)** End of the embryonic period. All the digits have formed, and the limbs have rotated. The embryo is approximately 3 cm long.

degenerates and persists as the popliteal and peroneal arteries.

Skeletal growth is a long process that begins in the seventh IU week and ends as late as 30 years of life. Skeletal growth begins with the appearance of a *primary center of ossification.* All bones that are formed by cartilage have a primary center of ossification. In long bones, primary centers are located in the shaft and appear between the twelfth and fifteenth IU week.[6,7] Short bones, usually develop from a single center of ossification that may appear as late as 5 years after birth.[6,7] *Secondary centers of ossification* are additional centers of ossification. In long bones, secondary centers usually appear in the ends of the bones.

Table 2-1. Ossification Centers for the Bones of the Foot

Bone	Primary Center	Secondary Centers (years)	Fusion (years)
Metatarsals	Shaft 2-4, 9th week IU	Head, 1-2	18-20
	Shaft 1, 10th week IU	Base, 1-2 (head, 10)	18-20
	Shaft 5, 10th week IU	Head, 1-2 (base, 7-10)	18-20
Phalanges	Distal shaft, 9-12 weeks IU	Base, 2-8	18-20
	Proximal shaft, 11-15 weeks IU	Base, 2-8	18-20
	Middle shaft, 15 weeks IU	Base, 2-8	18-20
Calcaneus	3rd month IU	Calcaneal tuberosity, 6-8	14-16
Talus	Body, 6-7 months IU	(lateral tubercle, 8-9 years)	
Cuboid	Birth		
Lateral cuneiform	6 months		
Medial cuneiform	1-2 years		
Intermediate cuneiform	1.5-2 years		
Navicular	2.5-5 years	(tuberosity, 10 years)	
Hallucal sesamoids	7-8 years	(bipartite sesamoids, two centers)	

(Data from Netter,[6] Clemente,[7] Sarrafian,[8] Draves,[9] and Edeiken[10])

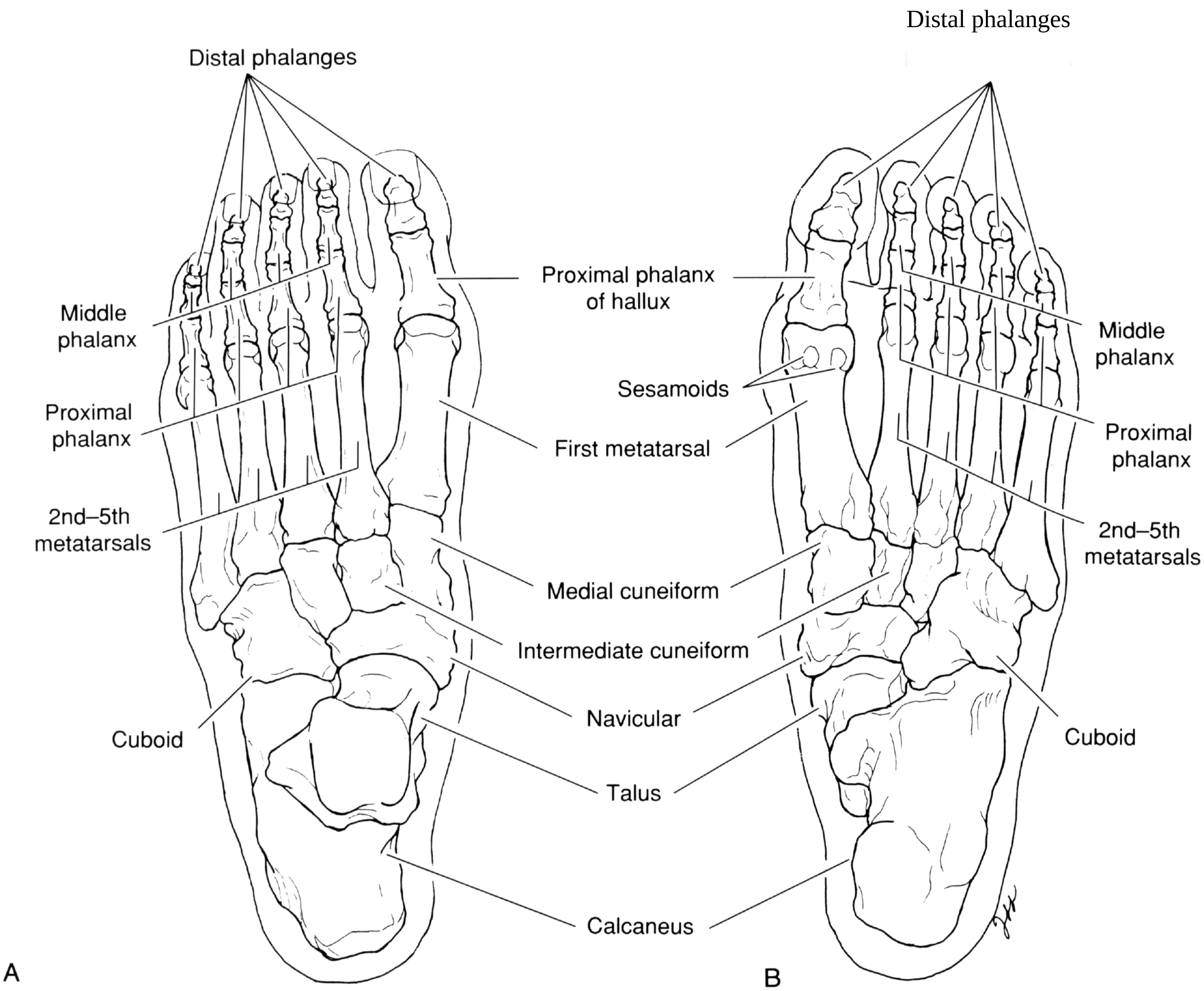


Fig. 2-2. Skeletal structure of the foot. (**A**) Dorsal view. (**B**) Plantar view.

The *growth plate* (epiphyseal plate) is a cartilaginous area between a primary center of ossification and the secondary center of ossification. In long bones, this occurs between the shaft and the ends.

The ossification centers for each bone appear at characteristic locations and times. More important than the exact time of appearance of an ossification center is the order in which these centers appear (Table 2-1).[6-10] As a general rule, the order of fusion of a secondary center to the primary center is opposite to their order of appearance; for example, the last secondary center to appear is the first to fuse to the primary center,

OSTEOLOGY

The main function of the foot is to support the body during locomotion and quiet standing. In anatomic position, the foot is at a right angle to the leg with the feet straight ahead. The "at ease" or neutral stance position is with the foot at a right angle to the leg, but the feet are slightly abducted. In either case, the midline of the foot is through the second metatarsal.

The bones of the foot consist of the calcaneus, talus, navicular, 3 cuneiforms, cuboid, 5 metatarsals, and 14 phalanges. These 26 bones of the foot are divided into the tarsus, metatarsus, and phalanges (Fig. 2-2). The 7

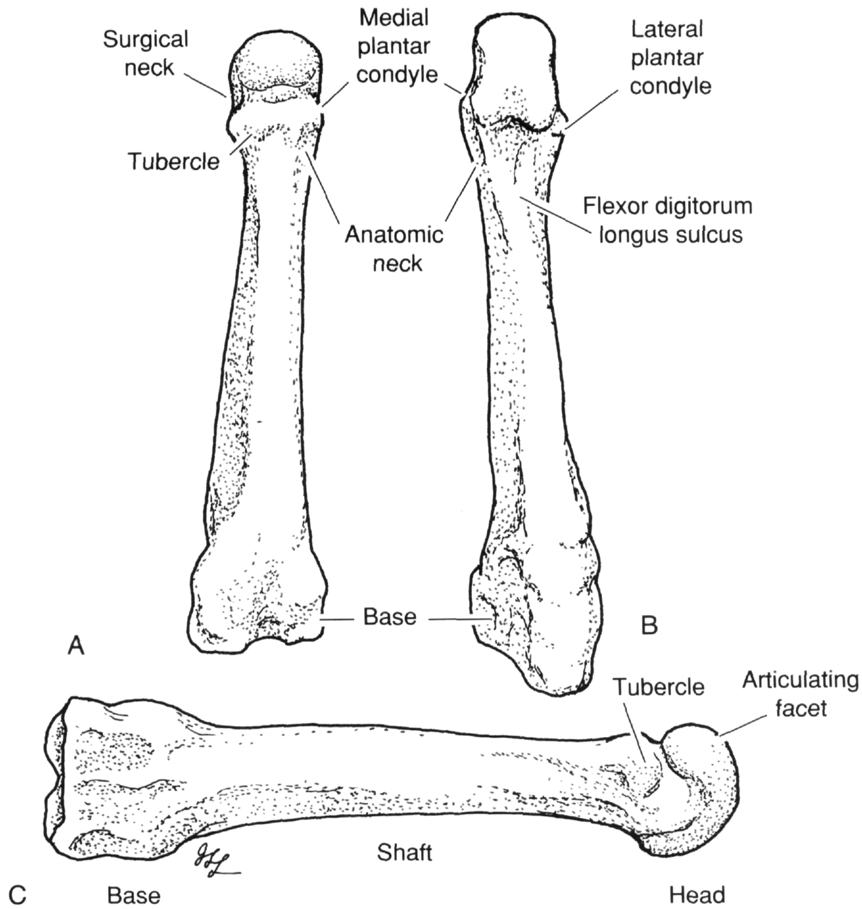


Fig. 2-3. General features of a metatarsal. **(A)** Side view. **(B)** Dorsal view. **(C)** Plantar view.

tarsal bones are short bones that connect the metatarsals to the leg. The 5 metatarsals are weight-bearing bones and provide a foundation for the digits. The phalanges provide the skeletal structure for the digits. Functionally, the bones of the foot can also be grouped into the rearfoot (which consists of the calcaneus and talus), the midfoot (which consists of the navicular, cuboid, and the three cuneiforms), and the forefoot (which consists of the metatarsals and their respective phalanges). The foot bones can also be grouped into a medial or lateral column. The medial column consists of the talus, navicular, the three cuneiforms, the first to third metatarsals, and the respective phalanges. The lateral column consists of the calcaneus, cuboid, the fourth and fifth metatarsals, and the phalanges.

The Metatarsal Bones

General Characteristics

There are a total of five metatarsals, which are numbered from I to V in a medial to lateral fashion. Each metatarsal is a long bone presenting with a base, shaft, and head (Fig. 2-3). The metatarsals extend anteriorly from the foot and are nearly parallel to each other (0°-8°).[11] The first metatarsal is the shortest in absolute length while the second is the longest (see Fig. 2-2). Straus[11] showed that the first metatarsal is approximately 83 percent of the length of the second metatarsal. More commonly, one refers to the protrusion of a metatarsal in the articulated foot (relative length). For example, the second metatarsal protrudes the most distal and is considered to be the longest. Because the fifth metatarsal does not protrude as far as any of the other metatarsals, in the articulated skeleton, it is considered the shortest. The formula most commonly cited referring to the relative length of the metatarsals is 2 (longest) >3>1>4>5 (shortest) (see Fig. 2-2).[8,9]

Base

The base is the most proximal end of the metatarsal and articulates with the tarsus and the other metatarsals (see Fig. 2-3). The base is usually wedge shaped, presenting with five surfaces. The superior and inferior surfaces are rough for the attachment of ligaments. The medial and lateral surfaces present with both flat articular and nonarticular areas. The articular facets are for either the tarsus or metatarsus. The posterior surface is slightly concave and is covered with an articular facet for articulation with the tarsus.

Shaft

When viewed along their dorsal surfaces, the shaft of each metatarsal extends directly anteriorly from the base and tapers distal. The fifth metatarsal shaft differs slightly from the others in that the shaft has a small degree of lateral bowing. When viewed from the side the bone is curved, being convex dorsal and concave plantar (see Fig. 2-3). The shaft of each metatarsal varies in thickness; however, each is roughly pyramidal in section. Further, within each metatarsal there is a degree of torsion between the base and the head of the bone. The amount and direction of the torsion varies among the five metatarsals.[8,11]

Head

The head of a metatarsal presents with a smooth convex facet covered with hyaline cartilage that extends farther on the plantar surface than the dorsal surface (see Fig. 2-3). The plantar surface is characterized by two condyles separated by a small shallow groove for the passage of the flexor tendons. The *lateral plantar condyle* is larger than the *medial plantar condyle.* Both condyles are continuous with the articular surface of the head.

Dorsally, a depression known as the *surgical neck* is present immediately posterior to the articular surface. Posterior to the surgical neck are a *medial* and *lateral tubercle* for the attachment of metatarsophalangeal collateral ligaments. Finally, posterior to these tubercles is another depression known as the *anatomic neck* that represents the point where the primary and secondary centers of ossification have fused.

Development

All the metatarsals develop from two centers of ossification (see Table 2-1).[6-10] The primary centers appear in the shafts of the second, third, and fourth metatarsals before the primary centers in the first and fifth metatarsals. Secondary centers or the epiphysis appear in all the heads of the metatarsals except the first, where the secondary center is located in the base. Occasional centers of ossification appear in the head of the first and in the tuberosity of the fifth metatarsals.

The First Metatarsal

Located on the most medial aspect of the foot, the first metatarsal has two regular articulations, the proximal phalanx distal and the medial cuneiform proximad. On occasion, however, the first metatarsal articulates laterally with the second metatarsal. The first metatarsal is the shortest and broadest, and probably the most mobile metatarsal.

The posterior surface of the base presents with a kidney-shaped facet for articulation with the anterior surface of the medial cuneiform (Fig. 2-4). If there is an articulation between the first and second metatarsal, then there is a small oval facet laterally.

On the base at the junction of the inferior and medial surfaces where the tibialis anterior tendon inserts is a small tubercle. On the opposite side of the base, at the junction of the inferior and lateral surfaces, there is a tuberosity for the insertion of the peroneus longus tendon. The remaining surfaces are rough for the attachment of ligaments.

The head of the first metatarsal is quadrilateral in shape and larger than the lesser metatarsals. It is also unique in that it presents with a ridge or crista that begins on the anterior aspect of the articular cartilage and continues plantarly (see Fig. 2-4). When viewed from above, the beginning of the crista is lateral to the midpoint between the medial and lateral borders of the head. A sagittal plane drawn through the crista is parallel to the lateral surface of the shaft of the metatarsal, but is everted by 13° when compared to the base of the bone.[8,12] During stance, the crista is angulated from the supporting surface by 78°; however, dur-

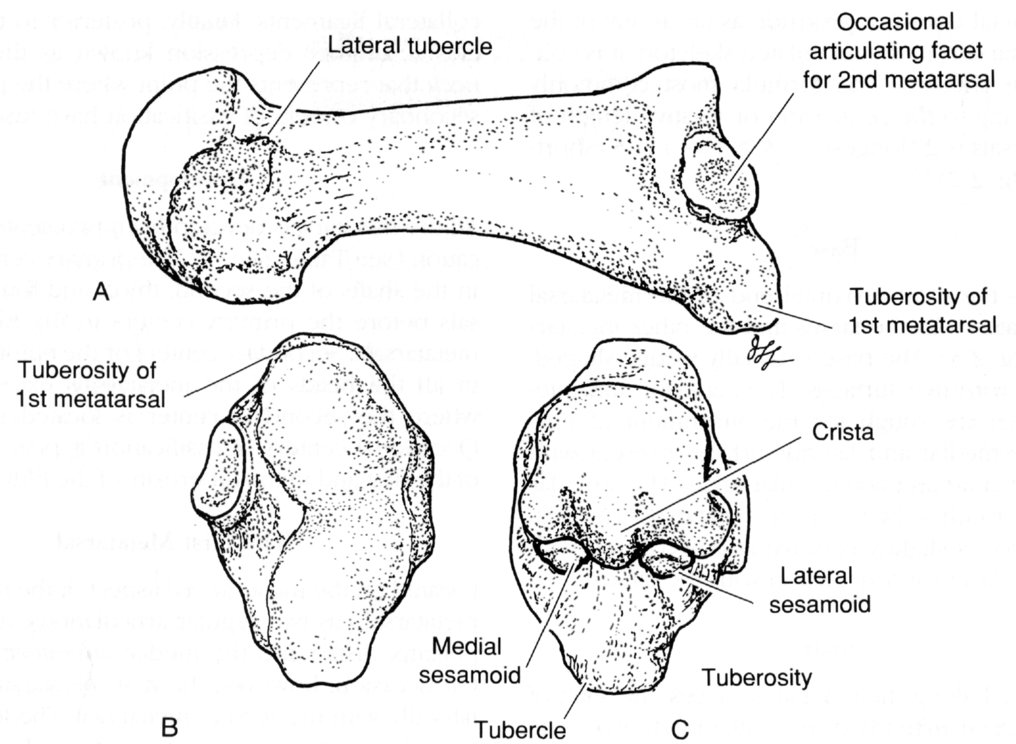


Fig. 2-4. Structural features of the first metatarsal. **(A)** Lateral view. **(B)** Posterior surface of the base. **(C)** Anterior surface of the head. Note sesamoids articulating with the grooves on the plantar condyles.

ing loading of the first metatarsophalangeal joint, the crista becomes perpendicular to the supporting surface such that each sesamoid carries roughly equal weight.[12,13]

On each of the plantar condyles there is a groove for the articulation with the sesamoids. Normally the groove on the medial plantar condyle is larger than the groove on the lateral plantar condyle.[12,13] According to Yoshioka, there are three areas of articulation: on the first metatarsal head; the grooves for articulation with the sesamoids; and the distal-dorsal aspect of the head for articulation with the base of the proximal phalanx.[12]

The Second Metatarsal

The second metatarsal is the longest metatarsal in the foot. It regularly articulates with the proximal phalanx, distal; the second cuneiform, proximad; the first cuneiform, medial; and the third cuneiform and third metatarsal, laterad. Occasionally there is an articulation with the first metatarsal medially. This bone has strong ligamentous attachments to the surrounding bones.

The base is wedge shaped with the base up and apex down. A facet covers the entire posterior surface of the base that is for articulation with the second cuneiform. The medial surface presents with an oval facet at the posterosuperior border for articulation with the medial cuneiform. If there is an articulation between the first and second metatarsal, then there is a small facet anterior to the facet for the cuneiform. The lateral surface has two facets that are separated by a roughened area. Both these facets are divided by a vertical ridge into an anterior and posterior facet. Both the posterior facets articulate with the third cuneiform, while the anterior facets articulate with the base of the third metatarsal. The remaining surfaces are roughened for the attachment of ligaments.

The Third Metatarsal

The third metatarsal articulates with the third cuneiform, proximally; the second metatarsal, medially; the fourth metatarsal, laterally; and the base of the proximal phalanx, distally. The entire posterior surface is covered by a facet that articulates with the anterior surface of the third cuneiform. This surface is triangular in shape with the apex inferior. The medial surface has two facets at the posterior border for articulation with the base of the second metatarsal. These two facets are separated by a thin strip of rough bone. The lateral surface has a single oval facet at the posterosuperior border for articulation with the fourth metatarsal. The remainder of the surfaces are roughened for the attachment of ligaments.

The Fourth Metatarsal

The fourth metatarsal articulates with five bones; the cuboid, proximally; the third cuneiform and metatarsal, medially; the fifth metatarsal, laterally; and the proximal phalanx, distally. This is the only metatarsal that has a rectangular base. The entire posterior surface of the base contains a rectangular facet for articulation with the cuboid. The medial surface presents with a single facet at the posterosuperior border, which is divided into an anterior and a very small posterior facet by a vertical ridge. The anterior facet articulates with the base of the third metatarsal; the small posteriod facet articulates with the third cuneiform; and the lateral surface of the fourth metatarsal has a single facet for the articulation with the fifth metatarsal base.

The Fifth Metatarsal

The fifth metatarsal articulates with three bones: the base of the proximal phalanx, the cuboid, and the fourth metatarsal. The base is pyramidal to triangular in shape with the apex pointing inferolateral. The posterior surface is triangular in shape and is covered with a single articular facet. The apex points laterally and articulates with the cuboid. The distinguishing feature of this metatarsal is a large tuberosity *(styloid process)* found on the lateral surface. The tuberosity is subcutaneous and rough for the attachment of ligaments and muscles. The medial surface presents with a single oval facet for the articulation with the fourth metatarsal base. The remaining surfaces are rough for the attachment of ligaments and muscles.

The Phalanges

General Characteristics

The phalanges are the bones that make up the toes. There are 14 phalanges in the foot: 2 in the hallux and 3 in each of the lesser digits. It is a common occurrence to find the middle and distal phalanges of the fifth digit fused to each other. The phalanges can be divided into rows: proximal, middle, and distal (see Fig. 2-2). Although *very* small, the phalanges are still long bones and consist of a base, body or shaft, and head.

Development

All the phalanges develop from two centers of ossification. The primary centers found in the shafts of distal phalanges are first to appear (see Table 2-1). The proximal phalanges are next to appear, followed by the middle phalanges. The secondary centers or the epiphysis appear in the bases of the phalanges between the second and eighth years, with fusion occurring by 18 years of age. There is great deal of variability in the time and order of appearance of these centers.

Proximal Phalanges

The base of the phalange is concave for articulation with the respective metatarsal head. The body is compressed from side to side, and longitudinally it is slightly convex. The head presents with a trochlear surface for articulation with the middle phalanx. Tubercles are present on the inferior side of the base and dorsal side of the head for the attachment of collateral ligaments.

Middle Phalanges

The first digit or the hallux does not have a middle phalanx. The base of the middle phalanx has a corresponding surface for articulation with the head of the proximal phalanx. The body is broader that the proximal phalanx. The head of the middle phalanges has a trochlear surface for articulation with the base of the distal phalanx. Small tubercles are present on both sides of the head for the attachment of collateral ligaments.

Distal Phalanges

These bones are at the level of the toe nails. The base and the shaft are similar in shape to the middle phalanges. The head of the distal phalanx is characterized by a flattened surface for the support of the toenail and a tuberosity plantarly.

Sesamoids and Accessory Ossicles

Sesamoids are fibrous, cartilaginous, or osseous structures that are almost always contained with a tendon. Anomalous sesamoids frequently present in the joint capsules of the various metatarsophalangeal and interphalangeal joints of the foot. Although the precise functions of sesamoids are uncertain, it has been suggested that they (1) alter the pull of a tendon, (2) decrease friction at articular surfaces, and (3) decrease pressure within a tendon to allow circulation to the tendon.[14-16]

There are only two regular sesamoids in the foot, the *medial (tibial)* and *lateral (fibular) hallucal sesamoid.* Each sesamoid is oval, measuring approximately 10 mm in length and 8.5 mm in width, with the tibial sesamoid being larger and more elongated than the fibular sesamoid.[12,16] These sesamoids are located in the tendon of the flexor hallucis brevis muscle proximal to the metatarsophalangeal joint and articulate only with the head of the first metatarsal. The tibial sesamoid articulates more distal in the head than the fibular sesamoid.[13] It is rather common to see these two sesamoids present as bipartite sesamoids.[16]

Accessory bones differ from sesamoids in that they are not located within tendons.[8,9,15] These are developmental anomalies and represent aberrant ossification centers or an abnormal separation of an ossification center. Many of these bones will have a synovial membrane surrounding it and the adjacent bone, thus forming a regular synovial joint. Accessory bones in the foot are common findings. Located between the dorsal aspects of the bases of the metatarsals, near the tarsus, the *os intermetatarseum* is the third most frequently occurring accessory bone in the foot.[8] It is most commonly found between the first and second metatarsals.[8]

ARTHROLOGY

An *anatomic synovial joint* is defined as a joint that is enclosed within a single synovial membrane.[15] An anatomic synovial joint may be simple, compound, or complex. A simple anatomic joint is the articulation between two bones. The best example of this type of joint is a metatarsophalangeal or an interphalangeal joint. A compound joint is defined as more than two bones enclosed within a single synovial membrane; the best example of this is the greater tarsal joint. In this joint, several of the tarsal bones articulate with one another and the metatarsals; however, because it is enclosed within a single synovial membrane it is considered a single anatomic joint. A complex joint is defined by the presence of a intrasynovial cartilaginous structure of which the knee joint is a good example.

Ligaments that support joints can be *intracapsular, capsular*, or *extracapsular*. Those ligaments that are intracapsular have either one or both of their attachments deep to the joint capsule. Although these ligaments are intracapsular they are still extrasynovial. Most of the ligaments in the forefoot are capsular ligaments; that is, the joint capsule has localized thickenings which are renamed. Extracapsular ligaments are ligaments that support a joint, but they are not typically attached to the joint capsule. The calcaneofibular ligament is an excellent example of an extracapsular ligament.

The Tarsometatarsal Joint

The tarsometatarsal joint is a functional joint composed of three anatomic joints. The bones that form the functional tarsometatarsal joint are all the metatarsal bases, the three cuneiforms, and the cuboid. The tarsi are connected to the metatarsus by dorsal, plantar, and interosseus ligaments.

Dorsal Tarsometatarsal Ligaments

There are eight dorsal ligaments. One ligament attaches from each metatarsal, to each of the respective cuneiforms and cuboid. The remaining three attach from the first cuneiform to the second metatarsal base; the second metatarsal base to the third cuneiform; and from the third cuneiform to the fourth metatarsal base, respectively.

Plantar Tarsometatarsal Ligaments

There are nine plantar ligaments, which attach exactly the same as do the dorsal ligaments with one exception: there is an additional ligament attaching from the first cuneiform to the third metatarsal base.

Interosseus Tarsometatarsal Ligaments

There are only three interosseus ligaments attaching from the roughened areas of the first cuneiform to the second metatarsal base (LisFranc's ligament), from the second metatarsal base to the third cuneiform, and from the third cuneiform to the fourth metatarsal base.[10]

Synovial Membrane

Three different anatomic joints form the functional joint known as the synovial membrane. The *greater tarsal synovial membrane* encloses the cuneonavicular, intercuneiform, the cuneocuboid, the second cuneometatarsal, third cuneometatarsal, and the third cuneiform-fourth metatarsal joints. The *medial tarsometatarsal synovial membrane* encloses the first metatarsal and first cuneiform joint. The *lateral tarsometatarsal synovial membrane* encloses the fourth and fifth metatarsal bases to the cuboid.

Intermetatarsal Joints

The bases of the second to fifth metatarsals are connected by dorsal, plantar, and interosseus intermetatarsal ligaments. The strongest ligaments are the interosseus ligaments, while the weakest ligaments in this group are the dorsal. If present, the first and second metatarsals have only a few weak interosseus fibers attaching to each other. These articulations are enclosed in the greater tarsal, the medial tarsometatarsal, or the lateral tarsometatarsal synovial membrane.

Metatarsophalangeal Joints

The metatarsophalangeal joints are the articulations between the head of a metatarsal and the base of the proximal phalanx. Each metatarsophalangeal joint is a single anatomic joint. However, when all these joints act together they are considered a functional joint. The ligaments supporting the metatarsophalangeal joints are, in general, similar in all five joints (Fig. 2-5). The ligaments are mostly capsular and are best defined on the medial side of the joint. However, because of the hallucal sesamoids the ligaments around the first metatarsophalangeal joint have a slightly different structure.

Lesser Metatarsophalangeal Joints

Fibrous Joint *Capsule*

The fibrous capsule surrounds the entire joint and is thin dorsally. The fibrous capsule is redundant, especially plantarly, to allow flexion and extension of the digits. An extensor expansion dorsal to the capsule provides additional support to the joint.

Medial and Lateral Collateral Metatarsophalangeal Ligaments

Proximally these capsular ligaments are attached to the tubercles on the dorsomedial and dorsolateral aspect of the head of the metatarsal. Distal, they become difficult to distinguish from the joint capsule and attach to the corresponding plantar tubercles on the base of the proximal phalanx.

Plantar Metatarsophalangeal Ligament

The plantar metatarsophalangeal ligament attaches proximally from the head of the metatarsal to the base of the phalanx distally. The ligament extends plantarly from the medial tubercle to the lateral tubercle along the plantar surface of the joint. Some authors describe a part of the ligament that extends from the tubercles to the plantar plate as the *medial* or *lateral metatarsophalangeal suspensory ligament;* in preserved cadaveric dissections, however, these ligaments are very difficult to observe.

Plantar Plate

The plantar plate is a thickening of the plantar metatarsophalangeal ligament. Attached to this structure is the deep transverse metatarsal ligament and the fibrous flexor sheath. The function of the plantar plate is believed to be similar to that of the hallucal sesamoids.

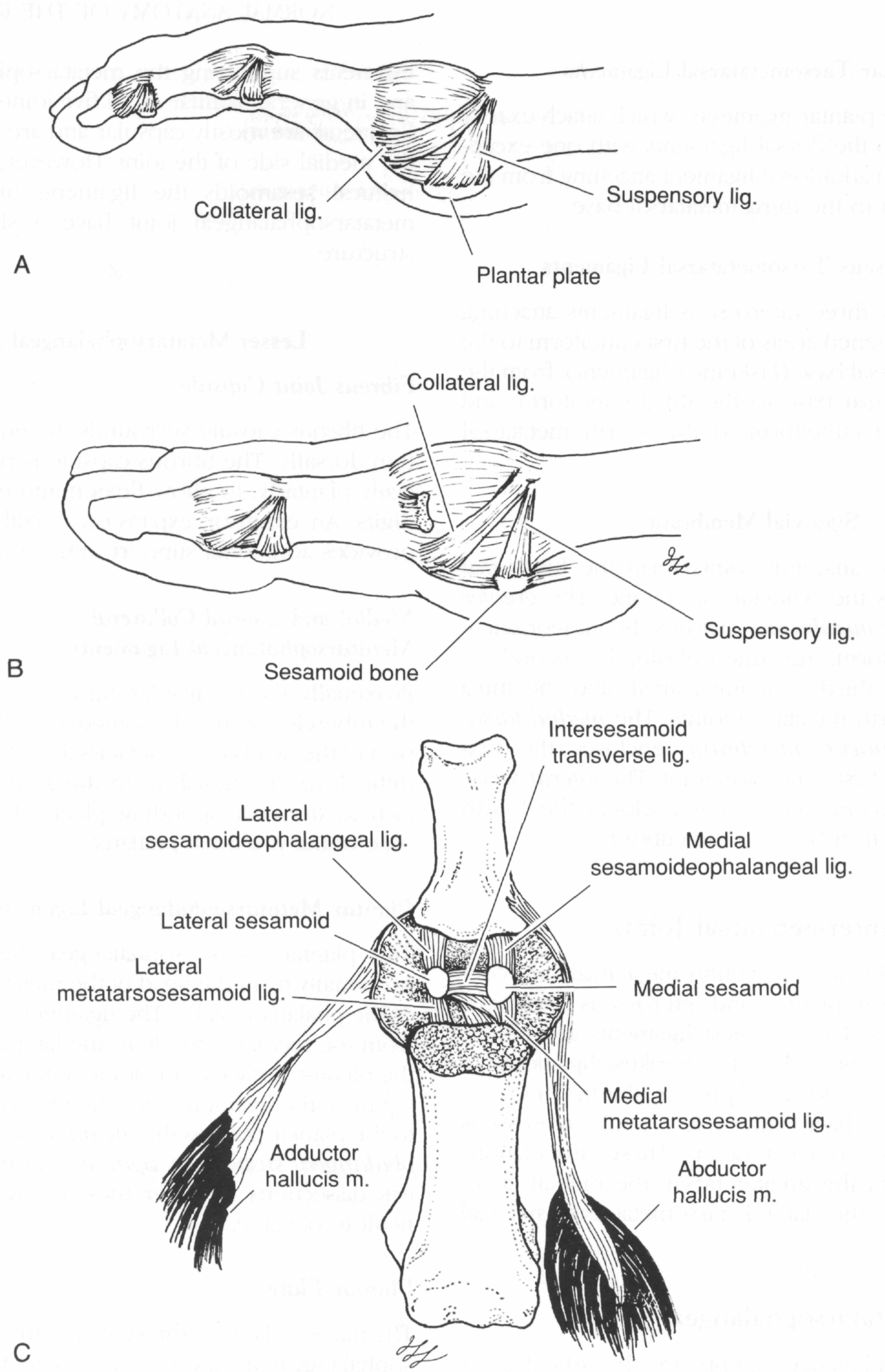


Fig. 2-5. Metatarsophalangeal joint ligaments. **(A)** Medial view of a lesser metatarsophalangeal joint. **(B)** Medial view of the first metatarsophalangeal joint. **(C)** Intracapsular view of the sesamoideal ligaments. The head of the first metatarsal has been removed.

Synovial Membrane

Five synovial membranes enclose each metatarsophalangeal joint.

First Metatarsophalangeal Joint

Many ligaments and tendons are described as attaching to the hallucal sesamoids. In dissection, however, it is very difficult to separate the various layers attaching to each sesamoid; all the ligaments and tendons blend into a single fibrous mass that is strongly adherent to each sesamoid.

Fibrous Joint Capsule

Like the lesser metatarsophalangeal joints the fibrous joint capsule surrounds the entire joint, is thin dorsally, and is redundant, especially plantarly. The joint capsule is attached to the sesamoids plantarly.

Plantar Metatarsophalangeal Ligament

This ligament attaches proximally from the head of the metatarsal to the base of the phalanx distally. The ligament extends plantarly from the medial tubercle to the lateral tubercle along the plantar surface of the joint.

Medial and Lateral Metatarsosesamoideal Ligaments

These ligaments, which are actually a part of the plantar metatarsophalangeal ligament that has been renamed, are attached from the metatarsal proximally to the sesamoids distally (Fig. 2-5C).

Medial and Lateral Sesamoideophalangeal Ligaments

These ligaments are also a part of the plantar metatarsophalangeal ligament that has been renamed; they attach from each sesamoid proximally to the plantar aspect of the base of the proximal phalanx (Fig. 2-5C).

Intersesamoid Ligament

The intersesamoid ligament is a small broad ligament; on intracapsular dissection of the joint, the ligamentous fibers are clearly seen extending from the medial to the lateral sesamoid (Fig. 2-5C).

Medial and Lateral Metatarsophalangeal Suspensory Ligaments

This section of the plantar metatarsophalangeal ligament extends from the medial and lateral tubercles to the medial and lateral sesamoids. These ligaments, as compared to the suspensory ligaments of the lesser metatarsophalangeal joints, are easily observed.

Medial and Lateral Collateral Metatarsophalangeal Ligaments

Proximally these ligaments are attached to the tubercles on the dorsomedial and dorsolateral aspect of the head of the metatarsal. The medial collateral metatarsophalangeal ligament at its proximal attachment, however, is clearly intracapsular. Distal, they become difficult to distinguish from the joint capsule and attach to the corresponding plantar tubercles on the base of the proximal phalanx.

Deep Transverse Metatarsal Ligament

This ligament is actually an intermetatarsal ligament, but it is considered here because of its role in metatarsophalangeal joint stability. This ligament is composed of four slips connecting the metatarsal heads to one another; thus, this ligament prevents splaying of the distal end on the metatarsals. The deep transverse metatarsal ligament is found plantarly attaching to the plantar plate. This proximal edge of the ligament is at the level of the most posterior part of the plantar condyles of the metatarsal. The distal edge usually does not extend past the distal end of the metatarsal.

The structure of the deep transverse metatarsal ligament between the first and second metatarsal heads is somewhat controversial. Most texts describe a single ligamentous slip connecting the two heads.[79,15] However, with careful dissection it is easily seen that the ligament connecting the two heads is actually bifurcated into dorsoproximal and plantodistal slips.[8,17] The plantar slip is the most distal part of the ligament and is attached from the plantar plate of the second metatarsophalangeal joint to the lateral sesamoid of the first metatarsophalangeal joint. The dorsal slip is somewhat posterior to the plantar slip and is attached from the plantar plate of the second metatarsophalangeal joint to the dorsolateral aspect of the joint capsule of the first metatarsophalangeal joint. The tendon of the ad-

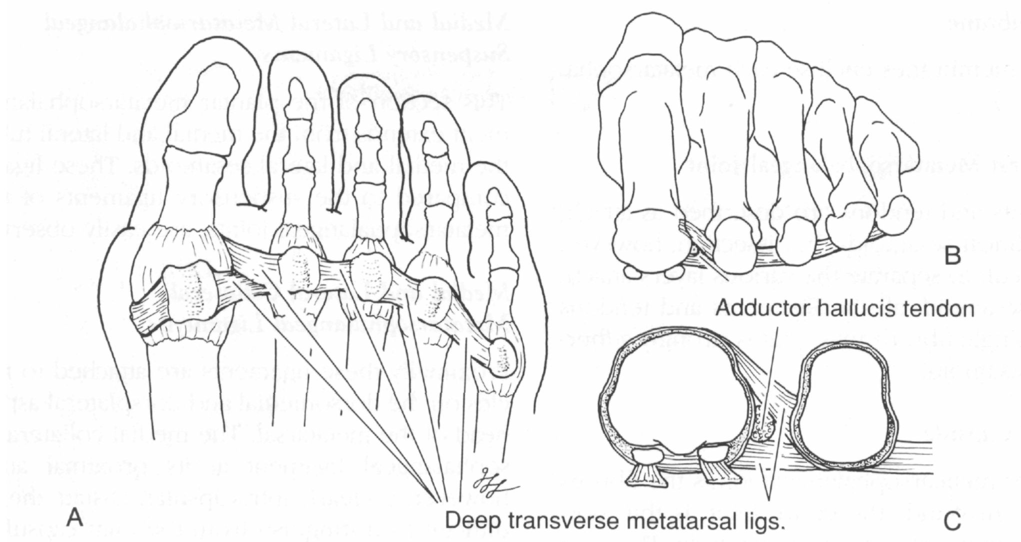


Fig. 2-6. (A-C) Anterior view of the first intermetatarsal space to illustrate the bifurcated nature of the first slip of the deep transverse metatarsal ligament.

ductor hallucis passes between these two slips (Fig. 2-6).

Interphalangeal Joints

There are two groups of interphalangeal joints: the proximal interphalangeal joints, which are the articulations between the base of the middle and the head of the proximal phalanges; and the distal interphalangeal joints, which are the articulations between the head of the middle and the base of the distal phalanges. In the hallux there is only one interphalangeal joint. The ligaments of all the interphalangeal joints are similar to one another and are best observed in the proximal interphalangeal joints.

Fibrous Joint Capsule

Like the metatarsophalangeal joints, the joint capsule is thin dorsally and thickened plantarly. The dorsal side of these joints receive additional support from tendons.

Plantar Interphalangeal Ligaments

This is a thickening of the joint capsule from the medial tubercle to the lateral tubercle across the plantar aspect of the joint. Some authors describe a suspensory ligament appearing on either side of the joint. However, these ligaments can be extremely difficult to observe.

Medial and Lateral Collateral Interphalangeal Ligaments

These capsular ligaments extend from the medial and lateral tubercles on the head of the phalanx to the base of the middle or distal phalanx.

Synovial Cavities

There are nine synovial cavities enclosing the nine interphalangeal joints of the foot.

MYOLOGY

Fascia of the Foot

Over the foot and digits, the superficial fascia is very thin. In lean individuals, the fascia is more fibrous in nature. The cutaneous nerves and superficial veins pass in this layer of fascia. In the toes, the arterial supply is deeply located in this layer. Thick adipose

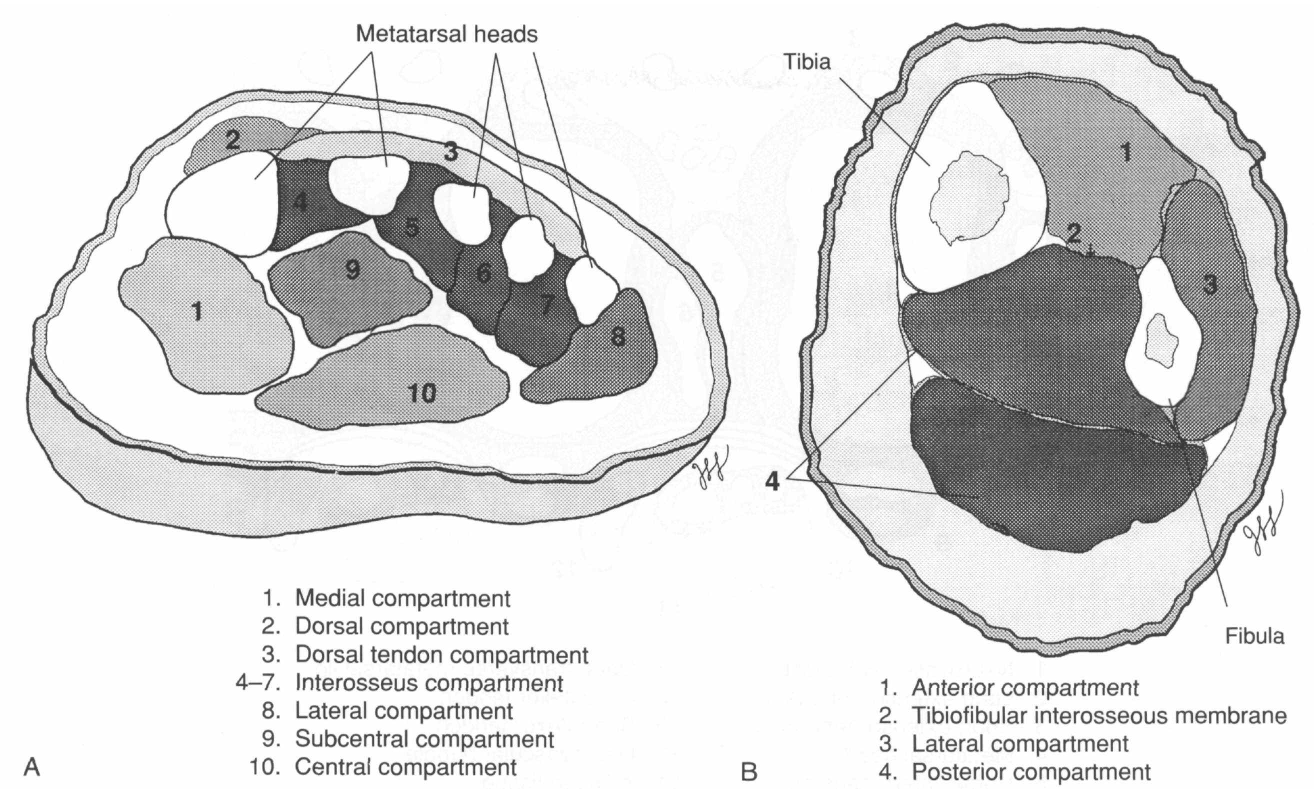
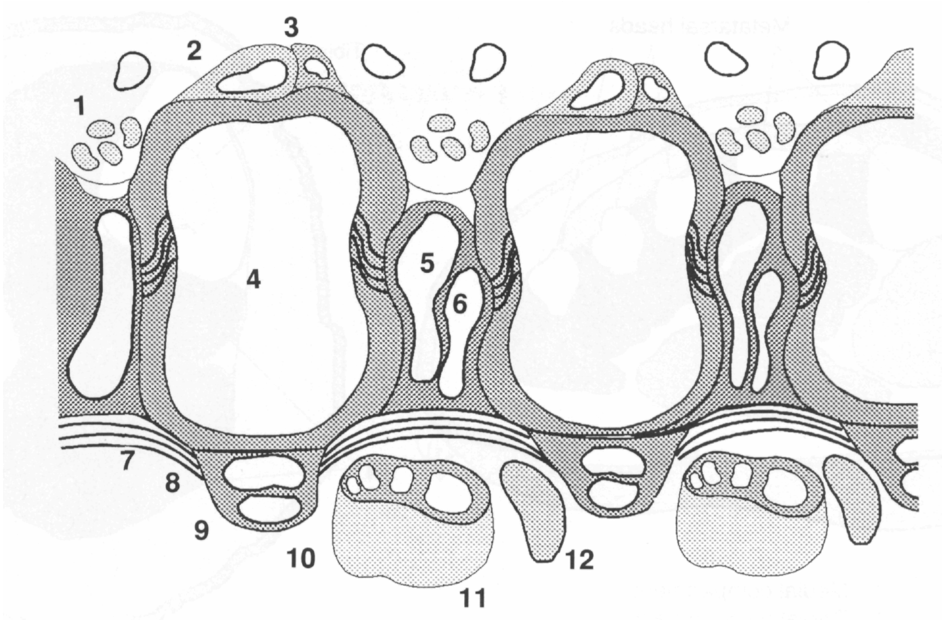


Fig. 2-7. Compartments of the foot and leg. **(A)** Foot. **(B)** Leg.

tissue is present under areas of extreme pressure and stress, such as the ball of the foot and the heel.

The deep fascia of the foot is continuous with the deep fascia of the leg. At the ankle, the fascia becomes thick and organized into transverse bands called retinacula. The *dorsal pedal fascia* is continuous with the plantar fascia and the fascia of the digits. Plantarly, the deep fascia is more complex. *The plantar fascia* is divided into medial, central, and lateral divisions. At the point where two of the divisions meet, the fascia sends thick septa deep into the foot to form compartments (Fig. 2-7A).

The central division of the plantar fascia is that part of the fascia referred to as *the plantar aponeurosis.* It is the thickest and strongest part of the deep fascia. Proximally, the fascia attaches to the calcaneal tuberosity and ends distally by dividing into a superficial and deep strata.[18] The superficial stratum attaches to the skin in the furrow behind the toes. At the level of the metatarsal heads, the deep side of the superficial stratum passes transversely to form the *superficial transverse metatarsal ligament.* The deep stratum divides in five slips, which embrace the metatarsal at the level of the anatomic neck before blending with the deep transverse metatarsal ligament. Proximal to the metatarsal heads, the plantar aponeurosis forms *sagittal septa,* which compartmentalize the tendons and neurovascular bundle to each digit. At the level of the metatarsal heads, the deep fascia is attached to the skin by *vertical fibers.* These vertical fibers, along with the deep transverse metatarsal ligament, form a hollow through which the plantar neurovascular bundle passes (Fig. 2-8).[18,19] The neurovascular bundle is protected inferiorly by fat bodies that extend throughout the weight-bearing areas of the forefoot. These fat bodies act as cushions so that the plantar vessels and nerves are not compressed during weight-bearing.[18] The deep fascia of the digits is continuous with the deep fascia of the foot. The deep fascia of each digit is specialized dorsal to the metatarsophalangeal joint



1. Neurovascular bundle
2. Long extensor tendon
3. Short extensor tendon
4. Metatarsal head
5. Dorsal interroseus m.
6. Plantar interroseus m.
7. Deep transverse metatarsal lig.
8. Long flexor tendon
9. Short flexor tendon
10. Neurovascular bundle
11. Adipose tissue
12. Lumbrical

Fig. 2-8. Anterior view of a lesser metatarsophalangeal joint showing the tendinous, neurovascular, and fascial structures.

and is known as the *extensor expansion.* Distally, the deep fascia covers the tendons and holds them against the phalanges. Plantarly, the deep fascia forms sheaths to tightly hold the flexor tendons against the phalanges. These *flexor sheaths* prevent what is commonly referred to as "bowstringing" of the long and short flexor tendons. In each of the flexor sheaths are short synovial sheaths that allow the tendons to move freely. Several parts of the flexor sheaths are easily identifiable. The thick *annual ligaments* surround the interphalangeal joints, while the thin *cruciate ligaments* help to hold the tendon against the shaft of the phalanx. The deep fascia attaches directly to the medial and lateral sides of the phalanges and the distal part of the distal phalanx.

Extrinsic Muscles of the Foot

The muscles that control the forefoot include both extrinsic and intrinsic muscles. Most of the extrinsic muscles, from the three compartments of the leg, help to control the forefoot (Table 2-2; see also Fig. 2-7B).

Tibialis Anterior Muscle

The tibialis anterior muscle originates from the lateral condyle of the tibia, the upper two-thirds of the lateral surface of the shaft of the tibia, and the adjacent area of the interosseus membrane. The muscle forms a tendon that crosses the ankle joint and is the most medial tendon on the dorsal foot. The tendon inserts into the medioplantar aspect of the first cuneiform and into the

Table 2-2. Vascular and Nerve Supply to the Extrinsic and Intrinsic Muscles of the Foot, Listed According to Their Insertions

Muscle	Innervation	Vascular Supply
Tibialis anterior	Deep peroneal	Anterior tibial
Peroneus longus	Superficial peroneal	Peroneal
Extensor hallucis longus	Deep peroneal	Anterior tibial
Extensor digitorum brevis	Deep peroneal, lateral terminal br.	Dorsalis pedis, lateral tarsal
Flexor hallucis longus	Tibial. lower muscular br.	Peroneal and posterior tibial
Flexor hallucis brevis	Medial plantar. 1st plantar proper digital br.	Medial and lateral plantar"
Abductor hallucis	Medial plantar	Medial plantar
Adductor hallucis	Lateral plantar, deep terminal br.	Lateral plantar"
Extensor digitorum longus	Deep peroneal	Anterior tibial
Extensor digitorum brevis	Deep peroneal, lateral terminal br.	Dorsalis pedis, lateral tarsal
Flexor digitorum longu.s	Tibial. lower muscular branches	Posterior tibial
Flexor digitorum brevis	Lateral plantar	Medial and lateral plantar
1st lumbricale	Medial plantar, 1st common digital br	Medial plantar
1st dorsal interosseus	Lateral plantar, deep terminal br.	1st dorsal metatarsal
	Deep peroneal, 1st interosseus br.	1st plantar metatarsal
2nd dorsal interosseus	Lateral plantar, deep terminal br.	2nd dorsal metatarsal
	Deep peroneal, 2nd interosseus br.	2nd plantar metatarsal
Extensor digitorum longus	Deep peroneal	Anterior tibial
Extensor digitorum brevis	Deep peroneal, lateral terminal br.	Dorsalis pedis, lateral tarsal
Flexor digitorum longus	Tibial. lower muscular br.	Posterior tibial
Flexor digitorum brevis	Lateral plantar	Medial and lateral plantar
2nd lumbricale	Lateral plantar, deep terminal br.	2nd plantar metatarsal
1st plantar interosseus	Lateral plantar, deep terminal br.	2nd plantar metatarsal
	Deep peroneal. 2nd interosseus br.	
3rd dorsal interosseus	Lateral plantar, deep terminal br.	3rd dorsal metatarsal
		3rd plantar metatarsal
Extensor digitorum longus	Deep peroneal	Anterior tibial
Extensor digitorum brevis	Deep peroneal, lateral terminal br.	Dorsalis pedis, lateral tarsal
Flexor digitorum longus	Tibial, lower muscular br.	Posterior tibial
Flexor digitorum brevis	Lateral plantar	Medial and lateral plantar
3rd lumbricale	Lateral plantar, deep terminal br.	3rd plantar metatarsal
2nd plantar interosseus	Lateral plantar, deep terminal br.	3rd plantar metatarsal
4th dorsal interosseus	Lateral plantar, superficial terminal br.	4th dorsal metatarsal
		4th plantar metatarsal
Extensor digitorum longus	Deep peroneal	Anterior tibial
Peroneus tertius	Deep peroneal	Anterior tibial
Flexor digitorum longus	Tibial. lower muscular br.	Posterior tibial
Peroneus brevis	Superficial peroneal	Peroneal
Flexor digitorum brevis	Lateral plantar	Medial and lateral plantar
Abductor digit minimi	Lateral plantar	Lateral plantar
4th lumbricale	Lateral plantar, deep terminal br.	4th plantar metatarsal
Flexor digiti minimi brevis	Lateral plantar, superficial terminal br	4th plantar metatarsal
		Plantar arch
3rd plantar interosseus	Lateral plantar, superficial terminal br	4th plantar metatarsal

Abbreviation: br, branch.
[a] Plantar arch, plantar metatarsal branches of the lateral plantar artery.

tubercle found on the medioplantar aspect of the base of the first metatarsal. Several small slips from the tendon may insert onto the talus or the deep fascia about the foot.

Extensor Hallucis Longus Muscle

The origin of the extensor hallucis longus muscle is deep to the extensor digitorum longus and tibialis anterior muscles. The extensor hallucis longus originates from the middle half of the anterior surface of the fibula and the adjacent interosseus membrane. The muscle ends in a tendon before crossing the ankle joint. It is situated lateral to the tibialis anterior tendon. As the tendon courses distal it crosses from the lateral side of the anterior tibial vessels to the medial side. The tendon inserts into the dorsal surface of the base of the distal phalanx of the hallux. At the level of the first metatarsophalangeal joint a small tendinous slip regularly inserts into the first metatarsophalangeal joint capsule. The tendinous slip is called the *extensor hallucis capsularis* and is present in more than 80% of all cases studied.[20,22]

Extensor Digitorum Longus Muscle

The extensor digitorum longus muscle originates from the lateral tibial condyle, the upper three-fourths of the anterior surface of the fibular shaft, and the adjacent interosseus membrane. This muscle forms a tendon before crossing the ankle joint. On the dorsal aspect of the foot, the tendon of extensor digitorum longus is lateral to the extensor hallucis longus tendon. The dorsalis pedis artery and the deep peroneal nerve are thus situated between these two tendons.

After passing through the inferior extensor retinaculum, the tendon splits into four slips, one to each of the lesser digits. Each tendon slip passes to the metatarsophalangeal joint of the lesser digits and is enclosed by the extensor expansion. Each of the four tendons follows the longitudinal axis of the digit, and at the head of the proximal phalanx each tendon trifurcates into a middle and two collateral slips.[23] The middle slip inserts into the dorsal surface of the base and shaft of the middle phalanx. The two collateral slips (medial and lateral) reunite at the head of the middle phalanx then insert into the dorsal surface of the base of the distal phalanx. At each of the insertions, the tendon splits to wrap around the phalanx. Variations of this muscle include missing tendinous slips or tendons that have joined with the extensor digitorum brevis tendons.

Peroneus Tertius Muscle

The peroneus tertius muscle originates from the distal one-third of the anterior surface of the shaft of the fibula and the adjacent interosseus membrane. The tendon crosses the ankle in the same synovial sheath as the extensor digitorum longus tendons. The peroneus tertius tendon is fan shaped at its insertion into the superior surface of the base and shaft of the fifth metatarsal. There may be an anomalous tendon that passes deep to the tendon of peroneus brevis to insert on the medial aspect of the shaft of the fifth metatarsal.[15]

Peroneus Longus Muscle

The peroneus longus muscle originates from the lateral condyle of the tibia, the upper two-thirds of the lateral surface of the shaft and head of the fibula, and from the deep fascia. During its course at both the angle and the cuboid, the peroneus longus makes a sharp turn. The muscle ends in a tendon that passes posterior to the ankle joint (through the lateral malleolar sulcus just posterior to the peroneus brevis tendon). The tendon passes along the lateral surface of the calcaneus and enters the plantar foot by coursing through the peroneal canal on the plantar surface of the cuboid. Through its course in the plantar foot, the tendon is enclosed within a fibrous sheath. The tendon finally inserts into the lateroplantar surface of the first cuneiform and the tuberosity on the base of the first metatarsal. The tendon of this muscle may fuse to the tendon of the peroneus brevis or insert, in part, to the third or fifth metatarsal base.[15]

Peroneus Brevis Muscle

The peroneus brevis muscle arises from the distal third of the lateral surface of the shaft of the fibula and adjacent deep fascia. The muscle ends in a tendon following the course of the peroneus longus, but is situated anterior to the peroneus longus tendon at the lateral malleolus. Along the lateral surface of the calcaneus, the peroneus brevis tendon courses superior to the peroneus longus tendon. The peroneus brevis tendon inserts onto the tuberosiry of the fifth metatarsal base. The peroneus brevis tendon may be fused to the peroneus longus tendon, or there may be an accessory slip that inserts into the shaft of the fifth metatarsal or into the lateral aspect of the base of the fifth proximal phalanx.[8]

Flexor Hallucis Longus Muscle

The flexor hallicus longus muscle originates from the lower two-thirds (except for the most distal) of the posteriolateral surface of the shaft of the fibula and adjacent interosseus membrane. On the most posterior aspect of the muscle belly, a tendon forms before crossing the ankle joint. The tendon passes through the sulcus on the posterior aspect of the tibia, through the sulcus on the posterior surface of the body of the talus, and beneath the sustentaculum tali. It lies deep to the flexor digitorum longus tendon and often shares a fibrous slip with the tendon called the *knot of Henry*. The tendon of flexor hallucis longus continues through the second layer of the plantar muscles, through a groove formed by the two hallucal sesamoids, and inserts into the plantar surface of the base of the distal phalanx of the hallux.

Flexor Digitorum Longus Muscle

The flexor digitorum longus muscle originates from the posterior surface of the tibia, distal to the popliteal line, but medial to a vertical line. The muscle ends in a tendon that passes through the medial malleolar sulcus posterior to the tibialis posterior tendon. As the muscle continues on its course into the foot, it passes inferior to the sustentaculum tali and into the second layer of plantar muscle. At this point, the tendon is inferior to the tendon of the flexor hallucis longus and receives a fibrous slip from this tendon. Just distal to the knot of Henry, the tendon splits into four slips, one to each of the lesser digits. Each tendinous slip passes through the flexor digitorum brevis tendons and inserts onto the plantar surface of the base and shaft of the distal phalanx. At the level of the cuneonavicular articulations, the tendon of the flexor digitorum longus serves as the insertion and origin for the muscles in the second layer of the foot.

Tibialis Posterior Muscle

The tibialis posterior muscle originates from two heads: a medial head originates from the posterior surface of the tibia lateral to the vertical line and distal to the popliteal line, and a lateral head originates from the medial surface of the fibular shaft. Just lateral to the origin of the muscle is the origin of the flexor hallucis longus. Between these two muscles, passing distal along the crista medialis, the peroneal artery is found. A tendon is formed before it crosses posterior to the ankle joint. The tendon passes deep to the flexor digitorum longus tendon, through the medial malleolar sulcus, and beneath the sustentaculum tali (hence the deltoid ligaments are deep) and the spring ligament. The tendon inserts onto the tuberosity of the navicular and then sends tendinous slips (or expansions) to the sustentaculum tali, all the cuneiforms, the cuboid, and metatarsal bases.[2-4]

Intrinsic Muscles of the Foot

There are 19 intrinsic muscle of the foot. There is only 1 muscle in the dorsal foot, while the plantar foot contains 18 muscles. For ease of description the plantar muscles are divided into four layers, numbered one to four from superficial to deep, respectively. However, a more practical way to group the muscles of the foot is by the compartments formed by the deep fascia. The plantar fascia sends a *medial* and *lateral intermuscular septa* deep into the foot, thus dividing the foot into medial, central, lateral, and interosseus compartments (see Fig. 2-7A and Table 2-2).

Extensor Digitorum Brevis Muscle

The extensor digitorum brevis muscle is located deep to the tendons of the extensor digitorum longus. The nerves and vessels of the dorsal foot are located deep to the tendons of this muscle. The extensor digitorum brevis has an osseous origin from the superior and lateral surfaces of the calcaneus just anterolateral to the calcaneal sulcus. This muscle also originates from the interosseus talocalcaneal ligament and the deep surface of the inferior extensor retinaculum. The muscle forms four distinct muscle bellies, each ending in a tendon. The most medial muscle belly and tendon is often referred to as the *extensor hallucis brevis.* The extensor hallucis brevis tendon inserts into the dorsal aspect of the base of the proximal phalanx of the hallux. The remaining three tendons insert into the lateral side of the extensor digitorum longus tendons of digits two, three, and four. This muscle quite often varies from normal. It is common to find either additional myotendinous units or that tendon slips are absent.

First Layer of Plantar Foot Muscles

Abductor Hallucis Muscle

In a person who is standing the abductor hallucis muscle is seen as a bulge on the medial side of the foot. A tunnel is formed between this muscle and the medial surface of the calcaneus, called the *porta pedis.* This tunnel is continuous with the tarsal tunnel superiorly. The plantar vessels and nerves enter the foot by way of the porta pedis. The abductor hallucis muscle originates from the medial process of the calcaneal tuberosity and from the surrounding deep fascia. The origin from the flexor retinaculum is a strong attachment. The muscle courses distally along the medial side of the foot and ends in a tendon. Occasionally, a strong attachment is found onto the tuberosity of the navicular. The tendon of the abductor hallucis primarily inserts into the medioplantar aspect of the base of the proximal phalanx. Before passing across the medioplantar aspect of the first metatarsophalangeal joint, a tendinous slip attaches to the medial aspect of the medial hallucal sesamoid. Rarely, a second slip occurs that inserts in the second toe. The abductor hallucis muscle also may originate from the flexor hallucis longus.

Flexor Digitorum Brevis Muscle

The flexor digitorum brevis muscle originates from the medial process of the calcaneal tuberosity and the surrounding deep fascia. The muscle passes distal in the center of the foot, dividing into four tendinous slips one to each of the lesser digits. At the level of the base of the proximal phalanx, each flexor digitorum brevis tendon splits in two and reunites at the head of the proximal phalanx. The tendon inserts into the plantar surface of the base and shaft of the middle phalanx. This split allows the flexor digitorum longus tendon to pass. Anomalies of this muscle are relatively infrequent; however, the most common variation occurs in the fifth digit where the tendon may be absent or originate from the flexor digitorum longus.

Abductor Digiti Minimi Muscle

The abductor digiti minimi muscle originates from the lateral margin of the medial process and the entire lateral process of the calcaneal tuberosity and surrounding deep fascia. The muscle may originate, in part, from the tuberosity of the fifth metatarsal. The muscle passes along the plantar aspect of the tuberosity of the fifth metatarsal, then along the lateral side of the foot. The muscle ends in a tendon that inserts (along with the flexor digiti minimi brevis) on the lateral side of the base of the proximal phalanx. There are two variations of this muscle. A separate myotendinous unit, which is attached from the calcaneus to the tuberosity of the fifth metatarsal, is called the *abductor ossis metatarsi quinti muscle*[8] A single myotendinous unit, separate from the abductor digiti minimi, extends from the calcaneal tuberosity to the fifth proximal phalanx and is called the *accessory abductor muscle*[8]

Second Layer of Plantar Foot Muscles

Quadratus Plantae Muscle

The quadratus plantae muscle originates from two heads that are separated by the long plantar ligament. The larger medial head originates from the medial surface of the calcaneus, up to the groove for the flexor hallucis longus. The lateral head originates from the inferior surface of the calcaneus distal to the lateral process of the calcaneal tuberosity. Both heads unite and pass anteriorly to insert into the tendon of the flexor digitorum longus muscle. It is common that these two heads do not unite before insertion. As such, the medial head may insert into the second, third, and fourth digital tendon slips of the flexor digitorum longus muscle. Only rarely is the lateral head absent.[8,15]

Lumbricale Muscles

The first lumbricale muscle is unipennate and originates from the medial side of the first tendon of the flexor digitorum longus. The second, third, and fourth lumbricales are bipennate in structure and originate from the adjacent sides of the long flexor tendons. Each muscle passes distal along the medial side of the metatarsal, but inferior to the deep transverse metatarsal ligament (Fig. 2-8). At the distal edge of the deep transverse metatarsal ligament, the lumbricale tendons make a sharp upward turn. The tendon then inserts into the medial side of the extensor wing part of the extensor expansion at the level of the base of the proximal phalanx. When an anomaly is present it is usually the absence of one of the muscles, most commonly the fourth lumbricale.

Third Layer of Plantar Foot Muscles

Flexor Hallucis Brevis Muscle

The flexor hallucis brevis muscle has a Y-shaped tendinous origin. The lateral origin is from the cuboid (posterior to the peroneal sulcus) and adjacent area of the third cuneiform. The medial origin is from the tendon of the tibialis posterior and the medial intermuscular septum. Both heads of origin converge and pass anteromedial toward the plantar surface of the first metatarsal. The muscle forms a medial and lateral muscle belly. At the level of the anatomic neck of the first metatarsal, each muscle belly head forms a separate tendon containing a sesamoid. The medial tendon contains the tibial hallucal sesamoid and inserts into the medial side of the plantar surface of the base of the proximal phalanx. The lateral tendon contains the fibular hallucal sesamoid and inserts into the lateral aspect of the plantar surface of the base of the proximal phalanx. The two heads form a deep sulcus for the passage of the flexor hallucis longus tendon. A small triangular area is formed by the sesamoids and the muscle. In this space one finds the first plantar metatarsal artery and adipose tissue.[8,24]

Adductor Hallucis Muscle

The adductor hallucis muscle originates from two heads, an oblique and a transverse head. It is the transverse head that is sometimes referred to as the *transverse pedis muscle.* The smaller transverse head originates from the plantar metatarsophalangeal ligaments of the third, fourth, and fifth digits and the deep transverse metatarsal ligament. The oblique head originates from the plantar surfaces of the second, third, and fourth metatarsal bases and the tendinous sheath of the peroneus longus. The oblique head courses anteromedially toward the first intermetatarsal space. At the anatomic neck of the first metatarsal, the oblique head divides into medial and lateral slips. The medial slip inserts directly on the lateral hallucal sesamoid while the lateral slip continues distal to join the transverse head. The conjoined tendon formed by the two heads passes through the bifurcated deep transverse metatarsal ligament and inserts into the inferolateral aspect of the base of the proximal phalanx of the hallux (see Fig. 2-6). Infrequently a separate myotendinous unit, called the *oppenens hallucis muscle*, is sent to the first metatarsal from the oblique head.[15]

Flexor Digiti Minimi Brevis Muscle

The flexor digiti minimi brevis muscle arises from the plantar surface of the base of the fifth metatarsal and from the sheath of the peroneus longus muscle. The muscle passes anteriorly along the lateral aspect of the fifth metatarsal. It inserts into the lateral and inferolateral aspect of the base of the proximal phalanx of the fifth digit, along with the abductor digiti minimi muscle. The oppens digiti quinti is a flat, triangular muscle that has an origin similar to the flexor digiti minimi brevis but an insertion that is on the lateral surface of the fifth metatarsal shaft.

Fourth Layer of Plantar Foot Muscles

Plantar Interossei Muscles

Each of the three plantar interossei muscle originates from the plantar surface of the base and medial surface of a metatarsal shaft. The first plantar interosseus muscle arises from the plantar surface of the base and the medial surface of the shaft of the third metatarsal, the second interosseus muscle from the fourth metatarsal, and the third interosseus muscle from the fifth metatarsal. The muscle passes directly distal ending in a tendon. The tendon of each of the plantar interossei muscles passes superior to the deep transverse metatarsal ligament. Each tendon has an attachment to the extensor expansion and inserts into the medial side of the base of the proximal phalanx of its respective digit.

Dorsal Interossei Muscles

These four bipennate muscles originate from the adjacent sides of the metatarsal shafts. For example, the first dorsal interosseus muscle originates from the lateral side of the shaft of the first metatarsal and the medial side of the shaft of the second metatarsal, and the second dorsal interosseus muscle originates from the lateral side of the shaft of the second metatarsal and the medial side of the shaft of the third metatarsal.

Each muscle ends in a tendon that passes superior to the deep transverse metatarsal ligament. The first dorsal interosseus muscle inserts into the medial side of the base of the second proximal phalanx and extensor expansion. The second, third, and fourth muscles insert into the lateral side of the base of the proximal phalanx and the extensor expansion. There are numerous anomalies of these muscles. Most commonly, the dorsal and plantar interossei are one muscle, or the dorsal interossei muscles spring from only one side of the metatarsal.[8]

Extensor Expansion

The extensor expansions are deep fascial structures encompassing the extensor tendons. There are four extensor expansions, one to each of the lesser digits. The extensor expansion over the fifth digit is not so defined as the other lesser digits. There are contributions to the extensor expansion from both the dorsal muscles and the plantar muscles.

The central structure of the extensor expansion is formed by the extensor digitorum longus tendons (Fig. 2-9). The extensor digitorum brevis, lumbricales, plantar, and dorsal interossei muscles all have an attachment to the expansion. Wrapping around the metatarsophalangeal joint are thick transversely directed fibers called the *extensor sling.* The interossei and extensor digitorum brevis have attachments to the sling before insertion. Thin obliquely directed fibers called the *extensor wing* are attached to the distal edge of the deep transverse metatarsal ligament and to the extensor digitorum longus tendon. Because of the insertion of the lumbricale muscles, the medial side of the extensor wing is better defined than is the lateral side.[25]

NERVE SUPPLY TO THE FOOT

Saphenous Nerve

The saphenous nerve is the continuation of the femoral nerve and is the only nerve in the foot that is not derived from the sciatic nerve. In the leg, the saphenous nerve follows the course of the greater saphenous vein. At the ankle, this nerve divides into anterior and posterior divisions. The posterior division supplies the skin about the medial ankle. The anterior division crosses the ankle joint anterior to the medial malleolus and continues distal along the dorsomedial aspect side of the foot up to the first metatarsophalangeal joint (Fig. 2-10).

Deep Peroneal Nerve

The deep peroneal nerve supplies the muscular innervation to the intrinsic muscles of the dorsal foot. It also contributes to the innervation of the first and second dorsal interossei muscles. The deep peroneal nerve passes into the foot adjacent to the dorsalis pedis ar-

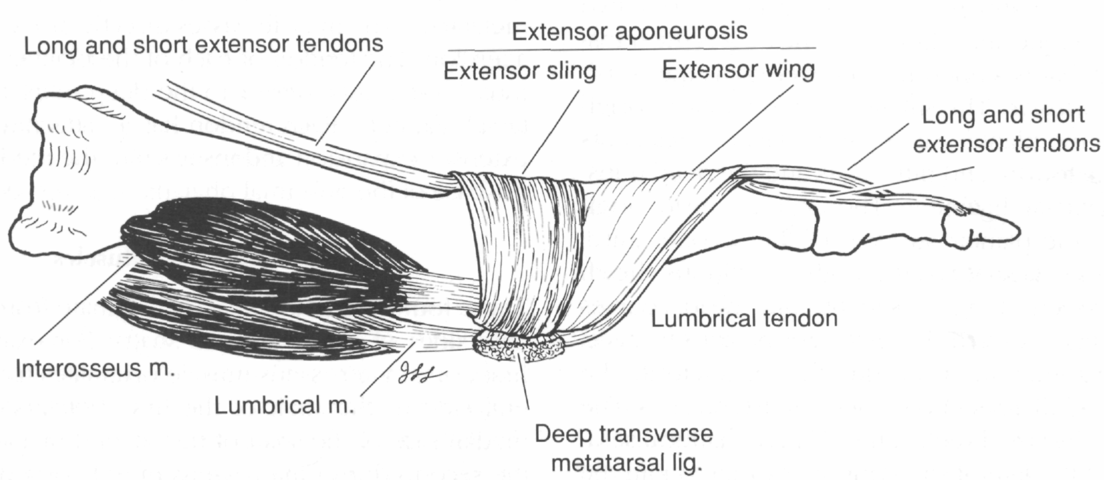


Fig. 2-9. Extensor expansion from the medial side of a lesser metatarsophalangeal joint.

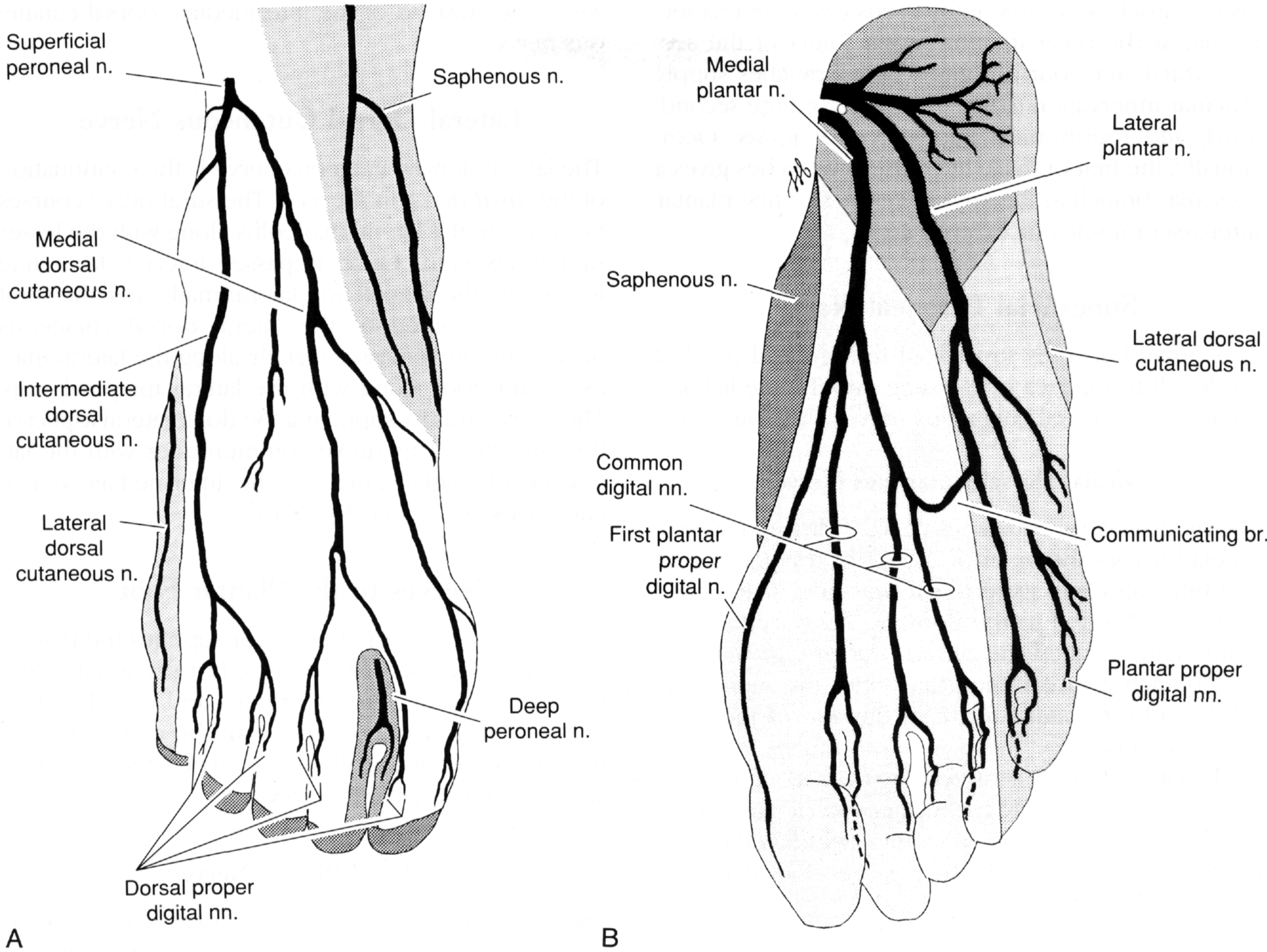


Fig. 2-10. Cutaneous innervation to the foot. **(A)** Dorsal foot. **(B)** Plantar foot.

tery and between the extensor hallucis longus and extensor digitorum longus tendons. The nerve terminates by dividing into a medial and lateral terminal branch.

Medial Terminal Branch

The medial terminal branch follows the course of the dorsalis pedis artery distal. In the first intermetatarsal space, the nerve divides in two dorsal proper digital nerves. Before its termination, a small interosseus branch supplies the first dorsal interosseus muscle and the first metatarsophalangeal joint. The medial terminal branch also has a communicating branch that joins the medial dorsal cutaneous nerve. The dorsal proper digital nerves are the terminal branches of the medial terminal division of the deep peroneal nerve. These nerves supply the adjacent dorsolateral side of the hallux and the dorsomedial side of the second digit (see Fig. 2-10).

Lateral Terminal Branch

Directed anterolaterally, the lateral terminal branch follows the course of the lateral tarsal artery and passes deep to the extensor digitorum brevis muscle. This nerve flattens deep to the extensor digitorum brevis muscle. This enlargement is often referred to as a pseudoganglion. Arising from the pseudoganglion, there is a muscular branch to the extensor digitorum brevis muscle and three interosseus branches that terminate at the metatarsophalangeal joints of the second, third, and fourth digits. These branches supply articular innervation to the intertarsal and the second, third, and fourth metatarsophalangeal joints. Occasionally, the first of these interosseus branches gives a muscular branch to the second dorsal and first plantar interossei muscles (see Table 2-2).

Superficial Peroneal Nerve

This nerve becomes superficial in the distal third of the leg. It terminates by dividing into the medial and intermediate dorsal cutaneous nerves (see Fig. 2-10).

Medial Dorsal Cutaneous Nerve

The medial dorsal cutaneous nerve is directed anteromediad across the anterior aspect of the ankle joint and bifurcates into its terminal branches. The medial branch is directed to the dorsomedial border of the hallux and is called the *medial dorsal digital nerve*. This branch also communicates with the saphenous nerve and the medial terminal division of the deep peroneal nerve.

The lateral branch is directed to the second interosseus space. Just distal to the metatarsophalangeal joint, the dorsal digitial nerve splits into two *dorsal proper digital nerves* that supply the adjacent dorsal sides of the second and third digits.

Intermediate Dorsal Cutaneous Nerve

This branch is smaller than the medial dorsal cutaneous nerve and passes along the dorsolateral aspect of the foot. Throughout its course in the foot, the intermediate dorsal cutaneous nerve is a visible, thin, cordlike structure. This nerve divides into a medial and lateral dorsal digital nerve. The medial dorsal digital nerve supplies dorsal proper digital nerves to the adjacent sides of the third and fourth digits. The lateral dorsal digital nerve supplies dorsal proper digital nerves to the adjacent sides of the fourth and fifth digits. The distribution of the intermediate dorsal cutaneous nerve varies greatly.[8,26] Common variations of this nerve include a branch supplying the dorsolateral aspect of the fifth toe instead of the lateral dorsal cutaneous nerve, or the lateral dorsal cutaneous nerve supplying the adjacent sides of the digits in the fourth web space instead of the intermediate dorsal cutaneous nerve.[8,26]

Lateral Dorsal Cutaneous Nerve

The lateral dorsal cutaneous nerve is the continuation of the *sural nerve* in the foot. The sural nerve courses posterior to the lateral malleolus along with the lesser saphenous vein. Once it passes inferior to a line formed by the medial and lateral malleolus, the sural nerve is renamed to the lateral dorsal cutaneous nerve. The nerve passes distally along the lateral margin of the foot along with the lateral marginal vein. The nerve ends by supplying the dorsolateral aspect of the fifth digit. This nerve communicates with the lateral dorsal digital nerve of the intermediate dorsal cutaneous nerve (see Fig. 2-10).

Nerves to the Plantar Foot

The tibial nerve is the nerve that supplies the plantar foot. The tibial nerve bifurcates, just proximal to the medial malleolus, into the medial and lateral plantar nerves. These nerves course with the plantar vessels behind the medial malleolus between the calcaneus and the abductor hallucis muscle.

Medial Plantar Nerve

The medial plantar nerve is the larger of the two terminal divisions of the tibial nerve. It accompanies the medial plantar vessels (the nerve being situated lateral). After entering the foot, the nerve is directed anteriorly between the flexor digitorum brevis and the abductor hallucis muscles. There are usually several small cutaneous branches that pierce the plantar aponeurosis to supply the skin on the medioplantar aspect of the foot. Two muscular branches supply the abductor hallucis and the flexor digitorum brevis muscles. There are several articular branches, which supply the tarsal joint. *The first plantar proper digital nerve* is the most medial branch and supplies a muscular branch to the flexor hallucis brevis muscle. This nerve ends by supplying cutaneous innervation to the medioplantar aspect of the hallux (see Fig. 2-10).

The medial plantar nerve terminates by dividing into three *common plantar digital branches.* These nerves arise at the level of the bases of the metatarsals.

At this point the nerves are situated deep to the flexor digitorum brevis muscle. Each common digital branch then passes distal to the plantar interosseus spaces one through three. As the branches pass distal they lie in a space between the adjacent flexor tendons, but deep to the plantar aponeurosis. Just before crossing the metatarsophalangeal joint, each common plantar digital nerve emerges from the deep side of the plantar aponeurosis to lie in the superficial fascia. Distal to the metatarsophalangeal joint, each of the common plantar digital nerves branch into two *plantar proper digital nerves* that supply the plantar aspect of the adjacent sides of the first to fourth digits. The first common digital nerve also gives a muscular branch to the first lumbricale. The third common digital nerve also receives a communicating branch from the fourth common plantar digital nerve (a branch from the lateral plantar nerve).

Lateral Plantar Nerve

The lateral plantar nerve is the division of the tibial nerve that supplies most of the intrinsic muscles of the plantar foot (see Table 2-2). This nerve passes with the lateral plantar artery, but is situated medial to the vessels. The nerve courses between the flexor digitorum brevis and the abductor digiti minimi muscles and divides into deep and superficial terminal divisions at the base of the fifth metatarsal. Before its termination, the lateral plantar nerve has several cutaneous branches that pierce the plantar aponeurosis to supply the skin of the lateroplantar foot (see Fig. 2-10). Additional branches before its termination include muscular branches to the quadratus plantae and the abductor digiti minimi muscles and articular branches to the tarsus.

The deep terminal division accompanies the plantar arch and supplies muscular branches to the lumbricales (2, 3, 4), adductor hallucis, plantar interossei (1, 2), and the dorsal interossei (1, 2, 3) muscles.

The superficial terminal division divides into the fourth common digital nerve and a plantar proper digital nerve. The fourth common plantar digital branch passes into the fourth interosseus space and divides into two plantar proper digital nerves. This branch, like the other common plantar nerves, is at first situated deep to the plantar aponeurosis, then at the level of the metatarsophalangeal joint passes into the superficial fascia of the foot. The fourth common digital nerve sends a communicating branch to the third common digital nerve deep to the plantar aponeurosis. The presence of this communicating branch is somewhat variable. For example, Nissen[19] states that the communicating branch is frequently absent, while Jones and Klenerman[27] claim that it was present in each of their specimens. The Jones and Klenerman study indicates that the communicating branch between the two nerves may occur more proximal than previously thought.[27] In general, the communicating branch joins to the third plantar common digital nerve somewhere between the point of bifurcation into its plantar proper digital nerves and midshaft of the fourth metatarsal.

The plantar proper digital branch passes obliquely anterolaterad, supplying the lateral plantar aspect of the fifth digit. Before entering the digit, muscular branches supply the flexor digiti minimi brevis, third plantar interosseus, and fourth dorsal interosseus muscles.

Proper Digital Nerves

Each digit of the foot is supplied by four proper digital nerves: two plantar and two dorsal propers (see Fig. 2-10). These nerves are numbered from 1 to 10 in a medial to lateral fashion. The dorsal proper digital nerves pass along the dorsomedial or dorsolateral aspect of each digit, while the plantar proper digital nerves pass along the plantomedial or plantolateral aspect of each digit.

The level at which the proper digital nerves form varies from the dorsal to the plantar side of the foot. Although the plantar proper digital nerves consistently originate a few millimeters proximal to the web formed by the skin between the digits, the level at which the dorsal proper digital nerves originate varies considerably. The dorsal proper digital nerves can originate as far proximal as the ankle joint or as far distal as the web space. The dorsal proper digital nerves are smaller than the plantar nerve and terminate near the proximal nail fold. The plantar proper digital nerves course to the end of the digits, supplying branches to the lateral and medial borders of the digit and to the distal edge of the nail.[28]

Each dorsal proper digital nerve supplies cutaneous innervation to either the dorsolateral or dorsomedial

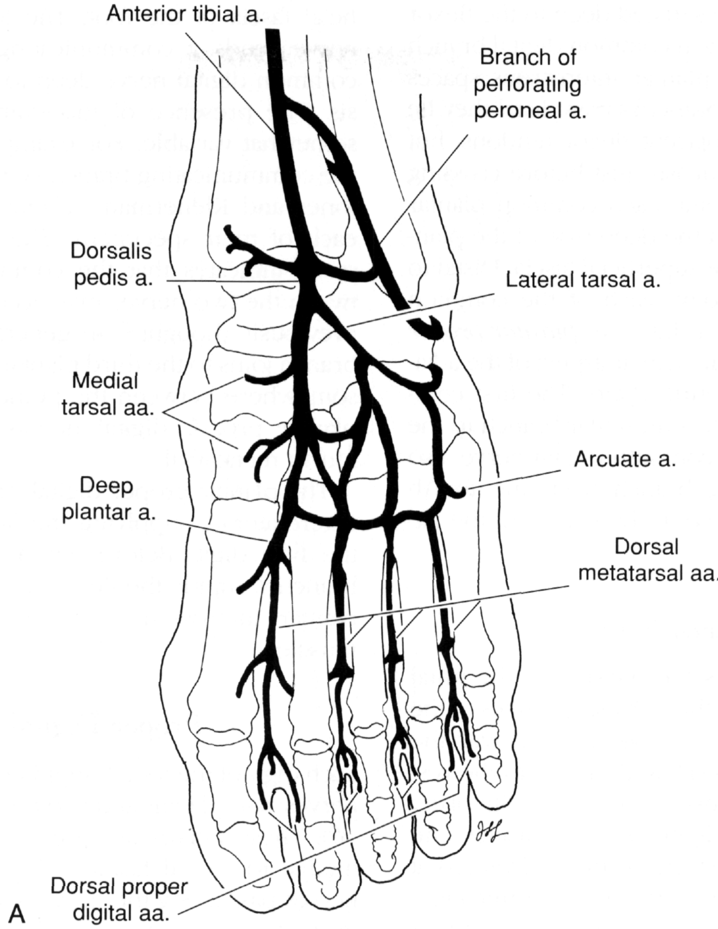


Fig. 2-11. General pattern of the arterial supply to the foot. **(A)** Dorsal foot. *(Figure continues.)*

aspect of the digits, distally to the proximal nail fold. The plantar proper digital nerves supply cutaneous innervation to either the plantomedial or plantolateral aspect of the digits. The plantar proper digital nerves also supply cutaneous innervation to the tips of the digit and the distal aspect of the nail. All proper digital nerves help to provide articular innervation to the interphalangeal joints.

Each proper digital nerve originates from one of the six nerves supplying the foot. Plantarly, the proper digital nerves originate from either the medial or lateral plantar nerve. Dorsally, there is considerable variation to the origin of the digital nerves off the intermediate dorsal cutaneous and the lateral dorsal cutaneous nerve.[26] The two most common variations are that the tenth dorsal proper digital nerve arises from the intermediate dorsal cutaneous or that the eighth and ninth dorsal proper digital nerves arise from the lateral dorsal cutaneous nerve.

VASCULAR SUPPLY

Arterial Supply to the Dorsal Foot

In the now classic study by Huber,[29] the *dorsalispedis artery* and its branches could be superimposed on a general arterial network pattern in 98% of the cases studied (Fig. 2-11). Specifically, there are numerous

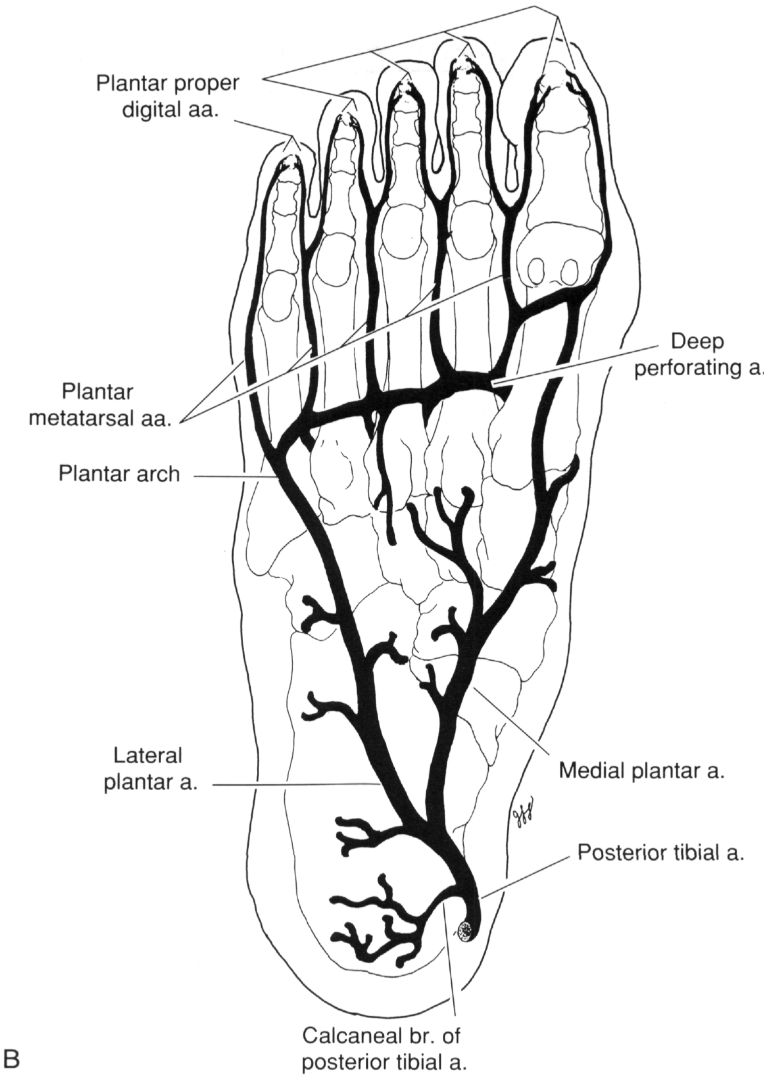


Fig. 2-11 *(Continued).* **(B)** Plantar foot.

variations of the course of the arteries in the foot; however, these variations can be explained as small-caliber or absent vessels or parts of vessels from the general pattern. In 78 percent of the cases studied, the dorsalis pedis artery continued from the anterior tibial artery and at the first metatarsal base, the dorsalis pedis artery bifurcated into its terminal divisions, the first *dorsal metatarsal artery* and the *deep plantar artery*[29] In 12% of the cases, the dorsalis pedis artery was absent or so small as to be considered absent. In these individuals the perforating branch of the peroneal artery supplied the dorsal foot. Only approximately 35 percent of the time does the normal arterial pattern of the foot occur.[8,29] The branches of the dorsalis pedis artery are the lateral tarsal, medial tarsal, arcuate, first dorsal metatarsal, and deep plantar arteries.

Arcuate Artery

The arcuate artery is present in only 54 percent of individuals and when present varies in its point of

	First		Second		Third		Fourth	
Author	Dorsal	Plantar	Dorsal	Plantar	Dorsal	Plantar	Dorsal	Plantar
Adachi	80.9	19.3	36.1	56.5	35.7	57.0	33.9	63.5
Huber	76.5	8.5	55.0	33.5	59.0	23.0	40.5	37.5

[a] Data are percentages of arteries arising from dorsal or plantar arteries, respectively.
(Data from Huber[29] and Adachi.[30])

origin and size. This artery usually branches from the dorsalis pedis artery at the level of the first tarsometatarsal joint; however, it may branch more proximal near the first cuneonavicular articulation.[8,29] When present this artery courses lateral beneath the tendons of the extensor digitorum brevis and anastomoses with the lateral plantar and the lateral tarsal arteries.

Dorsal Metatarsal Arteries

Although the arcuate artery is often described as being the only source of the second, third, and fourth dorsal metatarsal arteries, in fact the plantar arteries can be an important source for these arteries as well.[29] In those individuals in whom the arcuate artery is short or small, the lateral tarsal artery can also give rise to the dorsal metatarsal arteries. Although the medial, most dorsal, metatarsal arteries have their origin from the dorsal arterial network, it is quite common for the lateral, most dorsal, metatarsal arteries to originate from the plantar arteries. The termination of the dorsal metatarsal arteries is usually a bifurcation into the dorsal proper digital arteries; however, the dorsal metatarsal tarsal arteries often continue plantarly to contribute to the formation of the plantar proper digital arteries (see Fig. 2-11).

First Dorsal Metatarsal Artery

This artery usually branches from the dorsalis pedis artery near the base of the first metatarsal. However, the first dorsal metatarsal artery may arise from a plantar artery (8.5 percent, Huber[29]; 19.1 percent, Adachi[30]) or it may be absent (24 percent, Huber[29]). The course of the first dorsal metatarsal artery is distal on the superior surface of the first dorsal interosseus muscle. At the web space the artery ends by bifurcating into two dorsal digital arteries. The two dorsal digital branches supply the adjacent sides of the first and second toe. Before its termination, a dorsal digital branch passes beneath the extensor hallucis longus tendon to the dorsomedial side of the first toe.

The first dorsal metatarsal artery forms an anastomosis with the first plantar metatarsal artery just distal to the deep transverse metatarsal ligament but proximal to the bifurcation into the dorsal digital arteries. The artery forming this communication is the *anterior perforating artery.*

Lesser Dorsal Metatarsal Arteries

The *second, third, and fourth dorsal metatarsal arteries* follows a similar course as the first dorsal metatarsal artery, except within their respective dorsal intermetatarsal spaces. Near the base of each metatarsal the lesser dorsal metatarsal arteries receive a *posterior perforating artery* that forms an anastomosis with the plantar arteries. The origin of the lesser metatarsal arteries differs among them. While the second dorsal metatarsal artery usually originates from the dorsal arterial network, the fourth dorsal metatarsal artery usually originates from the plantar arteries. The fourth dorsal metatarsal artery also differs in that before the bifurcation into the dorsal digital arteries, the fourth dorsal metatarsal artery gives off a dorsal digital branch to the dorsolateral aspect of the fifth digit.

Arterial Supply to the Plantar Foot

The arterial supply to the plantar foot is from the terminal divisions of the posterior tibial artery. The posterior tibial artery bifurcates into the lateral and medial plantar arteries between the medial malleolus and the medial process of the calcaneal tuberosity (distal to the bifurcation of the plantar nerves). Both vessels enter the foot along with the plantar nerves.

Medial Plantar Artery

The medial plantar artery is smaller than the lateral plantar artery. This artery courses between the abductor hallucis and the flexor digitorum brevis muscles, medial to the plantar nerve. It continues to pass distal to the base of the hallux, where it becomes smaller and divides into a superficial and deep branch. The deep branch passes deep to supply the bones in the midfoot. The superficial branch continues along the medioplantar aspect of the hallux. The superficial branch is often referred to as the *medial plantar marginal artery*. Only rarely do these arteries form a superficial plantar arch.[15,28,30] This artery anastomoses with the first dorsal metatarsal artery and the first, second, and third plantar metatarsal arteries.

This artery supplies blood to the following bones of the foot: most of the tarsal bones, the first metatarsal, and the sesamoids. This artery also supplies the abductor hallucis, flexor digitorum brevis, quadratus plantae, first lumbricale, and the flexor hallucis brevis muscles.

Lateral Plantar Artery

The lateral plantar artery is larger than the medial plantar artery. It courses with, but lateral to, the lateral plantar nerve. The artery courses to the lateral side of the foot passing deep to the flexor digitorum brevis and superficial to the quadratus plantae muscles. The artery comes to rest in the septum between the flexor digitorum brevis and the abductor digit! minimi muscles. It rests on the medial side of the base of the metatarsal. As the artery courses anterolateral, it becomes superficial. At the base of the fifth metatarsal the artery turns sharply medial, coursing deep as the *plantar arch.* The plantar arch rests on the bases of the metatarsals and will form an anastomosis with the *deep plantar artery.* The deep plantar artery is situated deep to the oblique head of the adductor hallucis muscle and superficial to the interossei muscles. The artery supplies the flexor digitorum brevis, quadratus plantae, and the abductor digiti minimi muscles as well as some of the tarsal bones.

Plantar Proper Digital Branch

This branch bifurcates from the lateral plantar artery at the base of the fifth metatarsal and crosses to the plantolateral aspect of the fifth metatarsal and digit.

Plantar Arch

The plantar arch has two main groups of branches, the posterior perforating and the plantar metatarsal arteries. From the plantar arch, near the bases of the metatarsals three *posterior perforating arteries* arise that anastomose with the second, third, and fourth dorsal metatarsal arteries (Fig. 2-12). The plantar arch directly supplies the flexor hallucis brevis, flexor digiti

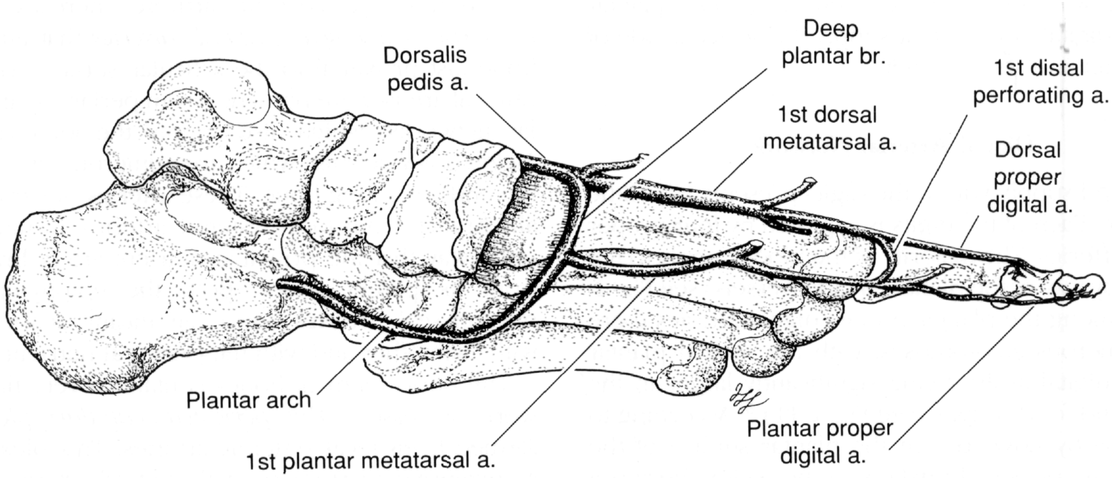


Fig. 2-12. Metatarsal arteries as viewed from the medial side of an intermetatarsal space. Note that the two arteries communicate by way of the anterior and posterior perforating arteries.

minimi brevis, and the oblique head of the adductor hallucis muscles.

There are a total of four plantar metatarsal arteries, each lying along the midline of the shaft of medial four metatarsals.[28] With the exception of the first, each of the plantar metatarsal arteries rests on the plantar surface of the plantar interossei muscles. The artery courses distally to the web space where it divides into two branches to supply the adjacent sides of the digits. These branches are called the plantar proper digital (plantar digital) branches. Before bifurcating, each plantar metatarsal artery anastomoses to the dorsal metatarsal artery via the anterior perforating artery (Fig. 2-12).

The first plantar metatarsal artery follows a different course than the other plantar metatarsal arteries. After branching from the plantar arch, the first plantar artery passes distal deep to the flexor hallucis brevis muscle. At the level of the anatomic neck of the metatarsal, the first plantar metatarsal artery forms a cruciate anastomosis with the medial plantar artery (superficial branch). The first plantar metatarsal artery then emerges from the deep aspect of the muscle in a triangular space formed by the sesamoids and the muscle bellies. The first plantar metatarsal artery then bifurcates (see Fig. 2-11). The branches of the bifurcation pass on either side of the hallucal sesamoids. The medial branch (medial plantar hallucal artery, medial plantar marginal artery) supplies the medioplantar aspect of the hallux. The lateral branch continues distal into the web space where it bifurcates into plantar proper digital arteries that supply the adjacent side of the hallux and second digit.

Digital Arterial Network

The blood supply within the digits presents with little variation. Each of the digits is supplied by four proper digital arteries. The majority of the blood supply to the digit is byway of the plantar arterial vessels (see Fig. 2-12).[28] Among the plantar proper digital arteries there are numerous anastomoses, with the medial plantar proper digital artery being significantly larger in the hallux and fourth digits (see Fig. 2-11).[28] According to the study by Edwards, on the plantar surface of the shaft of the proximal phalanx in the hallux there is a regular, well-formed, transverse communicating artery between the two plantar proper digital arteries. The terminal ends of the proper digital arteries arborize to form a rete around the tuft of the distal phalanx. Again, the plantar proper digital arteries are the major supply to this rete.[28]

Blood Supply to the Bones of the Foot

Bone, like any other structure in the body, has a regular blood supply. The blood supply to a long bone usually enters the bone in several locations (Fig. 2-13). The vessels, after entering the bone, branch into a complicated network of vessels that supply discrete regions of the bone. The arterial supply then drains into venous channels that follow the course of the arteries and then exit the bone.

Typically a long bone is supplied by one or two principal nutrient arteries that enter the bone in the shaft.[15] After entering the bone, the principal nutrient artery bifurcates into descending and ascending branches. These arteries follow a spiraling course as they pass toward the ends of the bone. Each of these arteries sends *medullary arteries* that course to the center of the bone and *cortical arteries* which pass toward the surface of the bone. Finally the principal nutrient artery anastomoses with the arteries supplying the ends of the bone.

The ends of a long bone are covered by hyaline cartilage and are not penetrated by arteries. Therefore, the blood supply to the ends of a bone is by way of arteries that enter near the cartilage. There are usually numerous *epiphyseal (capital) arteries* that enter the bone just proximal to the articular surface. The epiphyseal arteries are branches from periarticular vascular networks, which also supply the joint capsule. *Metaphyseal arteries*, which are numerous, also supply the ends of a long bone. These arteries however usually branch from local systemic arteries, in much the same way that the principal nutrient artery branches from its parent artery. Both the epiphyseal and metaphyseal arteries form significant anastomoses with each other and with the principal nutrient artery.

The periosteum of bones contains a very fine network of vessels. This *periosteal capillary plexus* is formed from local systemic arteries. This plexus has an extensive anastomosis with cortical arteries. In areas where a muscle originates from a bone, the periosteal plexus forms an anastomosis not only with the

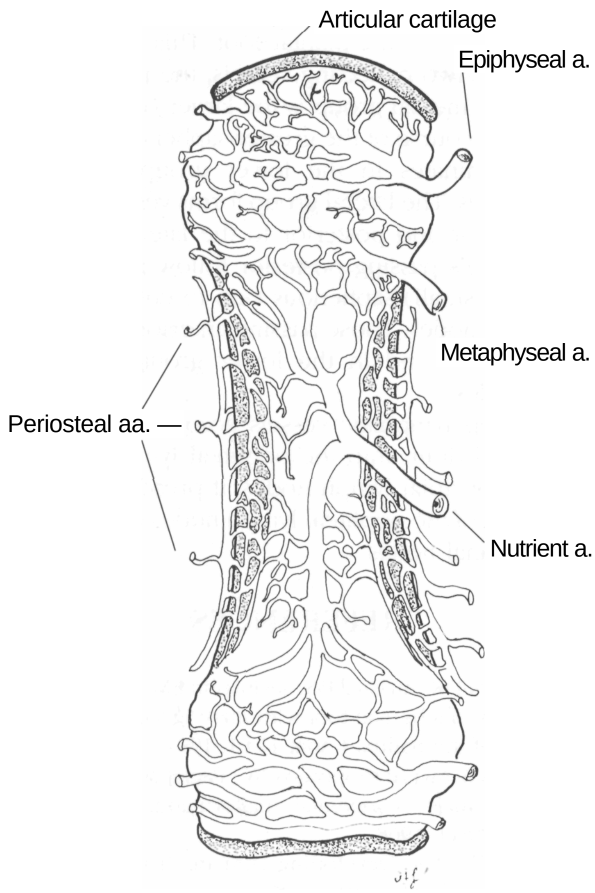


Fig. 2-13. Blood supply to a typical long bone.

cortical branches but with the capillaries of the muscle as well.

First Metatarsal

The first dorsal metatarsal and first plantar metatarsal arteries supply most of the blood to this bone with an inconsistent source from the superficial branch of the medial plantar artery.[31,33] The single principal nutrient artery supplying this bone is most often a branch from the first dorsal metatarsal artery. There are four distal metaphyseal arteries that enter on the dorsal and plantar corners of the head. The dorsal arteries are typically larger than the plantar and supply the dorsal two-thirds of the head; the plantar metaphyseal arteries supply the inferior one-third of the head; and the epiphyseal arteries supply the lateral and medial sides of the metatarsal head.

Sesamoids

The hallucal sesamoids receive their blood from the first plantar metatarsal artery after the anastomosis with the superficial branch of the medial plantar artery. Each sesamoid receives one to three branches. These branches anastomose within the sesamoid.

Lesser Metatarsals

The second through fifth metatarsals receive their blood from both the dorsal and the plantar metatarsal arteries. The principal nutrient artery enters on the lateral surface of the shaft of the lesser metatarsals, except in the fifth metatarsal where the principal nutrient artery enters on the medial surface of the shaft.[34]

Phalanges

The phalanges receive their blood supply mainly from the proper digital arteries. The proximal phalanges receive their blood mostly from the dorsal proper digital arteries; the distal phalanges receive their blood supply predominantly from the plantar proper digital arteries; and the middle phalanges receive their blood supply from both the dorsal and plantar proper digital arteries. In general, the principal nutrient artery enters these bones on the lateral surface, with the exception of the distal phalanges, where it enters the bone plantarly.[9,32] Each bone has numerous tiny metaphyseal and epiphyseal arteries.

Venous Return

Superficial Veins of the Foot

The veins of the lower limb can be divided into a superficial and deep system. The deep veins carry most of the blood back to the heart. However, both the superficial and deep veins contain values that prevent the backflow of blood in the leg.[35]

On the dorsum of the foot, two dorsal digital veins drain each digit. The dorsal digital veins in turn drain into the superficial dorsal metatarsal veins rather than emptying into the deep metatarsal veins. The superficial metatarsal veins end in the *dorsal venous arch.* Proximal to the arch is an irregular venous network that drains into the marginal veins of the foot. On the dorsolateral border of the foot, the *lateral marginal vein* is formed by many small veins from the plantar and dorsal foot. This vein passes posterior to the lateral malleolus and is continuous with the *lesser (small) saphenous vein.* On the medial side of the foot, the *medial marginal vein* is formed by the veins draining the inferomedial and dorsomedial foot. This vein passes anterior to the medial malleolus and is continuous with the *greater saphenous vein.*

Plantarly, in the toe-furrow a small *plantar venous arch* is located in the superficial fascia. This vein joins the medial and lateral marginal veins. The venous arch contains intercapitular veins, which are veins connecting the dorsum of the foot to the plantar foot.

Lymphatics

There are two locations in the lower limb where lymph nodes can be regularly found, the popliteal fossa and just inferior to the inguinal ligament. The popliteal group of lymph nodes receive both deep and superficial vessels. This group contains one to three nodes and is situated deep in the fossa around the politeal vein. On occasion, a lymph node is associated with the anterior tibial vessels just anterior to the interosseus crural membrane.

The second group of lymph nodes are the inguinal lymph nodes. This group has a deep and superficial set of nodes. The *superficial inguinal lymph nodes* are located in the superficial fascia of the anterior thigh inferior to the inguinal ligament. This set of 15 to 20 nodes is divided into two subgroups, an upper group that is parallel to the inguinal ligament and a lower group which is parallel to the femoral vein. It is the lower group of superficial inguinal lymph nodes that receives vessels mostly from the lower limb. These nodes send vessels (efferents) to the *iliac nodes,* which eventually empty into the cisterna chyli. A small group of *deep iliac lymph nodes* is located around the femoral vein (near the inguinal ligament) or in the femoral canal *(lymph node of Cloquet).* These nodes receive deep lymph vessels and have efferents to the iliac lymph nodes.

The lymphatic vessels in the foot consist of a superficial and deep set, corresponding to the superficial and deep veins. Like veins, the lymph vessels have valves, and the superficial system communicates with the deep. The *subcutaneous lymphatic capillary plexus* is most abundant in the plantar foot. This plexus drains into one of two collecting vessels, the medial or the lateral. The medial group is the larger of the two and follows the course of the greater saphenous vein. This group terminates in the lower group of inguinal lymph nodes. The lateral group forms vessels that pass both anterior and posterior to the lateral malleolus. Those vessels passing posterior follow the course of the lesser (small) saphenous vein to enter the popliteal lymph nodes. Those passing anterior join the medial group to end in the lower group of inguinal lymph nodes.

The deep lymphatic vessels accompany the deep vessels and drain into the popliteal lymph nodes or the anterior tibial lymph nodes, if present. The efferent vessels of the popliteal lymph nodes drain into the deep inguinal nodes.

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