Anatomy of the lower limb

Ankle joint, Arches & sole of the foot

Dr. Hayder

Ankle joint

Type & articulation

Ankle joint is a synovial joint of hinge type. Proximal articular surface is formed by the articular facets of the:

- Lower end of the tibia including its medial malleolus
- Lateral malleolus of the fibula
- Inferior transverse tibiofibular ligament

These three together form a deep tibiofibular socket (also called tibiofibular mortise).

Distal articular surface is formed by the articular facet on the upper (trochlear surface), medial (comma-shaped) & lateral (triangular) aspects of the body of the talus.

Joint capsule & capsular ligaments

The fibrous capsule is thickened medially and laterally as the collateral ligaments. The anterior and posterior parts are made up of thin transverse fibers extending anteriorly from the anterior margins of the distal end of the tibia to the upper surface of the talar neck. Posteriorly, the fibers extend from the posterior margin of the distal end of the tibia and the posterior tibiofibular ligament to the posterior surface of the talar body.

The medial collateral (deltoid) ligament is a very strong ligament attached by its apex to the medial malleolus. It radiates to attach at its base to the medial side of the talus, the sustentaculum tali, the medial edge of the spring ligament, the navicular bone and the neck of the talus. In addition to stabilizing the ankle joint, it holds the calcaneum, talus and navicular to each other and suspends the medial longitudinal arch of the foot.

The lateral collateral ligament is weaker than the medial one and consists of 3 bands;

- The anterior talofibular ligament passes from the lateral malleolus to the lateral surface of the talus.
- The calcaneofibular ligament passes from the tip of the lateral malleolus to the lateral surface of the calcaneum.
- The posterior talofibular ligament passes from the lateral malleolus to the posterior tubercle of the talus.

Synovial membrane

The synovial membrane lines the articular capsule but is separated from it anteriorly and posteriorly by pads of fat. It extends upwards between the tibia and fibula for a short distance just to be inferior to the interosseous tibiofibular ligament.

Stabilizing factors

The ankle joint is stable in dorsiflexion and unstable in plantar flexion (because the wider anterior part of trochlea of the talus gets lodged into the articular socket during dorsiflexion, while the posterior narrower aspect moves into the socket during planter flexion).

Other factors include fitness of articular surfaces, strong ligaments & surrounding long tendons.

Blood supply

The arterial anastomosis around the ankle joint is derived from the following arteries;

- **Anteriorly**; the perforating branch of the peroneal artery and the lateral tarsal branch of the dorsalis pedis artery.
- **Posteriorly**; the medial calcaneal branch of the posterior tibial artery and the lateral calcaneal branch of the peroneal artery.
- **Medially**; the medial malleolar rete is formed by the anterior medial malleolar branch of the anterior tibial artery and the posterior medial malleolar branch of the posterior tibial artery.
- **Laterally**; the lateral malleolar rete is formed by the anterior lateral malleolar branch of the anterior tibial artery and the posterior lateral malleolar branch of the peroneal artery.

Nerve supply

Articular branches provided by the tibial and deep peroneal nerves.

Movements

MOVEMENTS OF THE ANKLE JOINT				
Movement	**Muscle**		**Movement**	**Muscle**
Plantar flexion	Gastrocnemius & Soleus (triceps surae) Plantaris Tibialis posterior Flexor hallucis longus Flexor digitorum longus Peroneus longus & brevis		**Dorsiflexion**	anterior Extensor hallucis longus Extensor digitorum longus Peroneus tertius

Dorsiflexion is limited by the tension of tendocalcaneus, the calcaneofibualr ligament and the posterior fibers of the deltoid ligament.

Plantar flexion is limited by the tension of the dorsiflexors, the anterior talofibular ligament and anterior fibers of the deltoid ligament.

Clinical correlation*: ankle is the most commonly injured joint in the lower limb. The excessive stretching and/or tearing of ligaments of the ankle joint is called the ankle sprain. The ankle sprains are usually caused by the falls or twists.*

When the plantar-flexed foot is excessively inverted, the anterior and posterior talofibular and calcaneofibular ligaments are stretched and torn. The anterior talofibular ligament is most commonly torn

When the plantar flexed foot is excessively everted, the deltoid ligament is not torn instead there is an avulsion fracture of medial malleolus. Because the lateral malleolus is longer than the medial malleolus making the range of motion of inversion is wider than the eversion, the inversion sprains are more common than eversion sprains.

Relations

Anterior (from medial to lateral) 1. Tibialis anterior 2. Extensor hallucis longus 3. Anterior tibial artery 4. Deep peroneal nerve 5. Extensor digitorum longus 6. Peroneus tertius

Posterior (From medial to lateral) 1. Tibialis posterior 2. Flexor digitorum longus 3. Posterior tibial artery 4. Posterior tibial nerve 5. Flexor hallucis longus

ARCHES OF THE FOOT

The foot as a mechanical unit performs two major functions:

- It acts as a pliable platform to support the body weight during standing
- It acts as lever to propel the body forward during walking, running & jumping

To fulfill these 2 functions, the foot is designed in the form of segmented arches that distribute the body weight in a way that doesn't fatigue the mechanical unit & also have a spring-like action.

The arches are being built in the form of stone bridge, to easily understand & appreciate the factors maintaining the arches of the foot we will apply the same factors of the engineering device used to support a stone bridge, which are:

1- The stones of the arch should have a **wedge shape** closely packed with the narrow area of the wedge directed inferiorly and the central stone or the **keystone** being the center receiving the stress to be distributed evenly to both pillars of the arch.
2- **Inferior ties (staples)**; by which the lower edges of the stones are tied together to prevent their separation during weight bearing.
3- Tie beam connects the lower ends of the pillars of the arch preventing their separation during weight bearing.
4- Suspending slings support the arch from above.

All of these points are accomplished effectively in the functional three arches of the foot. The medial longitudinal arch is the highest arch. The lateral longitudinal arch is lower. The transverse arch is created by the difference in the height between the medial and lateral longitudinal arches and is really a half-arch that completes the other half of the other foot. Thus, the three arches put together make half a dome and the two feet held together complete the dome.

Transmission & distribution of the body weight

- The body weight is transferred from the vertebral column through sacroiliac joints to the pelvic girdle and from pelvic girdle through the hip joints to the femurs.
- The body weight is transferred from the knee joint to the ankle joint by the tibia. The fibula does not articulate with the femur, though it does not transfer any weight.
- At ankle, the weight is transferred by tibia onto the talus (keystone of the medial longitudinal arch) which in turn distributes the weight evenly between the arch pillars.
- The weight-bearing points of the foot are medial process of the calcaneus posteriorly and six equal pillars anteriorly formed by the heads of four lateral metatarsals and two sesamoid bones underneath the head of the first metatarsal bone.
- To make a practical example, in a person weighing 48 kg, the weight distribution will be as follows:
    - ♦ 24 kg to each foot
    - ♦ 12 kg to the calcaneus posteriorly
    - ♦ 12 kg distributed to the anterior 6 weight-bearing points so that each point bears only 2 kg

The above distribution is maintained effective as long as the arches are effectively supported by the 4 factors mentioned earlier. For each arch, a number of ligaments and muscles help support the bone arrangement of the arch.

FACTORS MAINTAINING FOOT ARCHES INTEGRITY					
Arch	**Forming bones**	Maintaining factors			
		Bone arrangement & keystone	**Inferior ties (staples)**	**The tie beam**	**Suspending slings**
Medial longitudinal arch	Calcaneus, talus, navicular, 3 cuneiforms & the medial 3 metatarsals	- The posterior pillar is the medial calcaneal tubercle - The anterior pillar is the heads of the medial 3 metatarsals (especially the 1st) - The keystone: the head of talus is fitted between the sustentaculum tali & the navicular	Planter ligaments especially the spring ligament (planter calcaneonavicular ligament)	The planter aponeurosis, assisted by the medial parts of flexor digitorum longus & brevis and the tendons of flexor hallucis longus & brevis & abductor hallucis	Tendons of tibialis anterior, flexor hallucis longus & tibialis posterior
Lateral longitudinal arch	Calcaneus, Cuboid & the lateral 2 metatarsals	- The posterior pillar is the calcaneus - The anterior pillar is the heads of metatarsals - The keystone: the cuboid	Short & long planter ligaments and the origin of flexor digiti minimi brevis	The planter aponeurosis assisted by abductor digiti minimi & the lateral parts of flexor digitorum longus & brevis	Tendons of peroneus longus & brevis
Transverse arch	Cuboid, 3 cuneiforms & the bases of all metatarsals	- The lateral pillar is the tuberosity of the 5th metatarsal - The keystone: the middle cuneiform closely wedged with the 2nd metatarsal base between the medial & lateral cuneiforms	Ligaments bind the cuneiforms & metatarsals, interossei muscles & superficial & deep transverse metatarsal ligaments	Tendon of peroneus longus assisted by the tendon of tibialis posterior	Peroneus tertius & peroneus brevis on the lateral side Tibialis anterior of the medial side

Main functions of arches

1. Distribute the body weight to the weight-bearing points of the sole
2. Act as shock absorber during jumping by their spring-like action.
3. The medial longitudinal arch provides a propulsive force during movement.
4. The lateral longitudinal arch functions as a static organ of support during standing erect.
5. The concavity of arches protects the nerves and vessels of the sole.

Clinical correlation:

Flat foot (pes planus): *The flat foot is the commonest of all foot problems. It occurs due to the collapse of medial longitudinal arch. During long periods of standing the plantar aponeurosis and spring ligament are overstretched. As a result, the support of the head of talus is lost and is pushed downward between the calcaneus and the navicular bones. This leads to flattening of the medial longitudinal arch with lateral deviation of the foot.*

Hallux valgus*: In this condition, the big toe is deviated laterally at the metatarsophalangeal joint. It usually occurs due to constant wearing of pointed shoes with high heel. The head of the first metatarsal bone becomes prominent and rubs on the shoe.*

SOLE OF THE FOOT

Skin & superficial fascia

The skin is thick & hairless, and it is firmly attached to the underlying tissues (planter aponeurosis) by fibrous bands. Comparing to the skin of the palm it contains less creases but more sweat glands, these features increase the efficiency of grip of the sole on the ground.

The skin over the major weight-bearing areas of the sole—the heel, lateral margin, and ball of the foot—is very thick. The superficial fascia is thick and dense over the weight-bearing points to provide fibrofatty cushions at these sites (e.g., posterior tubercles of the calcaneus, metatarsal heads, and pulps of the digits.

Cutaneous innervation

The skin of the sole of the foot is supplied by three cutaneous nerves, which are direct or indirect branches from tibial nerve :

1- Medial calcaneal nerve: supplies the skin over the posterior calcaneal tuberosity (over the weight-bearing area).
2- Cutaneous branch of medial planter nerve: supplies the skin over the medial two thirds of the sole & the medial 3 and a half toes.
3- Cutaneous branch of lateral planter nerve: supplies the skin over the lateral one third of the sole & the lateral one and a half toes

Deep fascia

The deep fascia in the region of the sole consists of three parts: central, medial, and lateral. The central part of the deep fascia is very thick and termed **plantar aponeurosis**. The medial and lateral parts are thin and termed medial and lateral plantar fasciae, respectively.

The planter aponeurosis is triangular in shape & occupies the central region of the sole.

- It's apex is attached posteriorly to the medial tubercle of calcaneus.
- The base of the planter aponeurosis near the heads of the metatarsals divides into 5 bands. At the points of division five processes are bound by a transverse fascial fibers.
- Each band of these 5 (opposite to the metatarsophalangeal joints) splits into superficial & deep slips.
- The superficial slip attached to the dermis of the skin & blends with the superficial transverse metatarsal ligaments.
- The deep slip divides into two parts which embrace the flexor tendons & blend with the deep transverse metatarsal ligaments.

Functions of the planter aponeurosis:

1- Firmly fixes the skin of the sole
2- Provides origin to the short muscles of the sole
3- It protects the planter nerves & vessels from compression
4- Helps maintain the longitudinal arches of the foot by acting as tie beam.

Clinical correlation

Planter fasciitis & calcaneal spur*: The plantar aponeurosis is stretched during standing position. Hence, tearing or inflammation (plantar fasciitis) often occurs in individuals who do a great deal of standing or walking. It causes pain and tenderness in the sole of the foot especially underneath the heel during standing. Repeated attacks of the plantar fasciitis lead to ossification in the posterior attachment of the plantar aponeurosis forming a calcaneal spur that becomes apparent on x-ray.*

The deep fascia is further modified in the region distal to the metatarsophalangeal joints into **fibrous flexor sheath** which has a similar arrangement to those of the fingers. They are blind distally and attached by their open bases to the heads of the metatarsals & by closed apices to the bases of the distal phalanges. The sheaths contain the tendons

and their synovial sheaths of the flexor digitorum longus & brevis for the lateral 4 toes & the tendon of flexor hallucis longus only for the big toe.

The deep transverse metatarsal ligaments; these are 4 short flat bands of modified deep fascia, which connect the ligaments & capsules of the adjoining metatarsophalangeal joints. They are related dorsally to the interossei & ventrally to lumbricals.

Muscles of the sole of the foot

MUSCLE LAYERS OF THE SOLE OF THE FOOT		
Layer	**Muscles**	**Features**
First layer	- Flexor digitorum brevis - Abductor hallucis - Abductor digiti minimi	They cover whole of the sole
Second layer	- Flexor digitorum accessories (AKA; quadratus plantae) - Tendons of flexor digitorum longus - Tendon of flexor hallucis longus - 4 lumbricals	Flexor digitorum accessorius and lumbricals are attached to the tendon of flexor digitorum longus
Third layer	- Flexor hallucis brevis - Flexor digiti minimi - Adductor hallucis	They are confined to the metatarsal region of the sole
Fourth layer	- Interossei (3 planter & 4 dorsal) - Tendon of tibialis posterior - Tendon of peroneus longus	They fill up the intermetatarsal spaces

An account of the attachments and actions of the intrinsic muscles of the sole is provided in the table above. However, it is more practical for medical students to recognize certain features that are specific to each muscle, rather than memorizing the details of muscle attachments;

- Regarding the **nerve supply of the intrinsic muscles of the sole**; it is practical to know that the medial plantar nerve supplies only 4 muscles; abductor hallucis, flexor hallucis brevis, flexor digitorum brevis and the first lumbrical. All the other muscles are supplied by the lateral plantar nerve.
- **Flexor digitorum brevis** divides into 4 tendons for the lateral 4 toes. Each of these tendons is perforated by the corresponding tendon of **flexor digitorum longus** creating a **chiasma tendinum** arrangement similar to that of flexor digitorum superficialis and flexor digitorum profundus in the hand.
- **Flexor hallucis longus tendon** runs in a groove on the plantar surface of the head of the 1st metatarsal between the 2 sesamoid bones on that bone.
- **Quadratus plantae** is inserted into the tendon of flexor digitorum longus before it splits into 4 tendons. It assists flexor digitorum longus in flexing the toes by bringing the pull of flexor digitorum longus into line with the toes; hence, its other name, **flexor accessorius**.

Intrinsic muscles of the sole

Muscle	Action
Abductor hallucis	Abducts & flexes the metatarsophalangeal joint of the big toe
Flexor digitorum brevis	Flexes lateral 4 toes at the proximal interphalangeal joints
Flexor digitorum accessorius (quadratus plantae)	Assists flexor digitorum longus tendon in flexing the lateral 4 toes
Lumbricals (4 muscles)	Flexion of metatarsophalangeal joint and extension of interphalangeal joints
Flexor hallucis longus	Flexes the big toe at metatarsophalangeal joint
Adductor hallucis	Adducts great toe at metatarsophalangeal joint
Flexor digiti minimi brevis	Flexes little toe at metatarsophalangeal joint
Dorsal interossei	Abduction of lateral 4 toes
Plantar interossei	Adduction of lateral 3 toes

N.B. Neurovascular planes of the sole: There are two neurovascular planes between the muscle layers of the sole:
A- Superficial neurovascular plane between the first and second layers.
B- Deep neurovascular plane between the third and fourth layers.
In the superficial neurovascular plane lies the trunks of medial and lateral plantar nerves, and the arteries.
In the deep neurovascular plane lies the deep branches of the lateral plantar nerve and artery.

Vessels of the sole

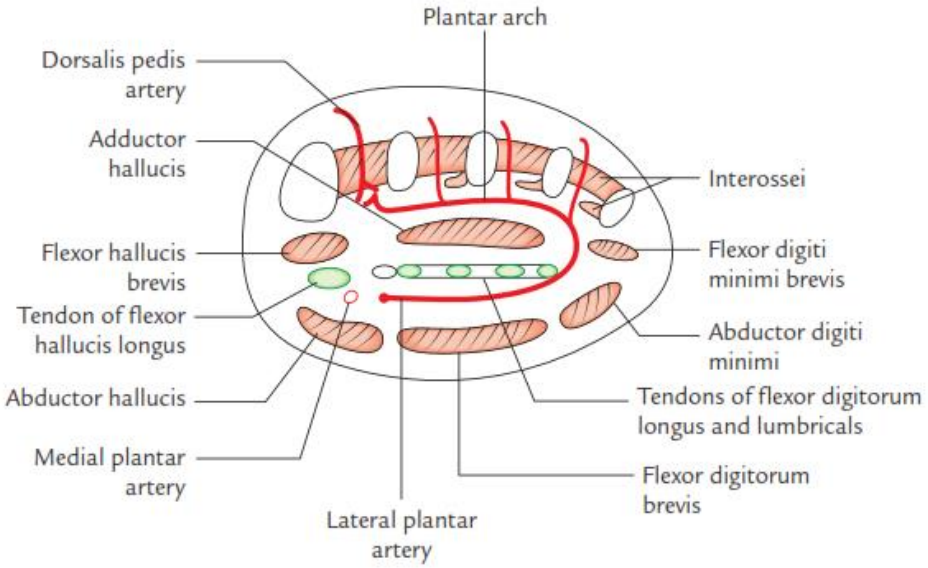
The medial planter artery

This is the smaller terminal branch of the posterior tibial artery. It arises beneath the flexor retinaculum, appears in the sole deep to abductor hallucis accompanied by the medial planter nerve. It terminates on the medial side of big toe.
Branches:

- Medial planter digital artery for the medial side of the big toe.
- Large branch that splits into 3 branches that anastomose with the first 3 metatarsal arteries.

The lateral planter artery

This is the larger terminal branch of the posterior tibial artery. It arises beneath the flexor retinaculum & runs forward towards the base of the 5th metatarsal accompanying the lateral planter nerve. At the base of the 5th metatarsal it curves round forming the **planter arch** & runs medially towards the first intermetatarsal space to join dorsalis pedis artery.



Branches:

- 4 planter metatarsal arteries: pass forward in the intermetatarsal spaces and ends by dividing into pair of proper planter digital arteries to supply the remaining of the toes (lateral 4 and a half toes).
- Each planter metatarsal artery gives off a perforating branch ascend through 2nd, 3rd & 4th intermetatarsal spaces to anastomose with their corresponding dorsal metatarsal arteries from arcuate arteries in the dorsum of the foot.

Nerves of the sole

The medial planter nerve

This is the larger terminal branch of the tibial nerve, it runs with the medial planter artery between abductor hallucis & flexor digitorum brevis muscles giving the following branches:

- **Muscular branches** supply abductor hallucis, flexor digitorum brevis, flexor hallucis brevis & the first lumbrical.
- **Cutaneous branches** include the plantar cutaneous nerve to the medial two thirds of the sole and the plantar digital nerves to the medial three & a half toes.
- **Articular branches** to small joints of the foot.

Clinical correlation: *Medial plantar nerve entrapment (Jogger's foot): The medial plantar nerve may be compressed either deep to flexor retinaculum or deep to abductor hallucis due to the repetitive eversion of the foot (e.g., during gymnastics and running). Clinically, it presents as burning, numbness, and tingling (paresthesia) on the medial side of the sole and in the region of navicular tuberosity.*

Lateral planter nerve

It is the smaller terminal branch if the tibial nerve & begins deep to the flexor retinaculum, appears in the sole deep to the abductor hallucis. It runs forward and laterally to the base of the fifth metatarsal accompanying to the lateral planter artery. On reaching between flexor digitorum brevis & abductor digiti minimi it divides into 2 branches; superficial & deep.

Branches:

- **Cutaneous branches**: supply the lateral one third of the sole & planter digital branches suppling the lateral one and a half toes.
- **Muscular branches**: to abductor digiti minimi, quadratus plantae, flexor digiti minimi brevis, adductor hallucis, the lateral 3 lumbricals and all the interosseous muscles.
- **Articular branches** to the small joints of the foot.