

# Anatomy of the lower limb

## Arches & sole of the foot

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## 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
<b>Medial longitudinal arch</b>	Calcaneus, talus, navicular, 3 cuneiforms & the medial 3 metatarsals	<ul style="list-style-type: none"> <li>- <u>The posterior pillar</u> is the medial calcaneal tubercle</li> <li>- <u>The anterior pillar</u> is the heads of the medial 3 metatarsals (especially the 1<sup>st</sup>)</li> <li>- <u>The keystone</u>: the head of talus is fitted between the sustentaculum tali &amp; the navicular</li> </ul>	Plantar ligaments especially the spring ligament (plantar 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
<b>Lateral longitudinal arch</b>	Calcaneus, Cuboid & the lateral 2 metatarsals	<ul style="list-style-type: none"> <li>- <u>The posterior pillar</u> is the calcaneus</li> <li>- <u>The anterior pillar</u> is the heads of metatarsals</li> <li>- <u>The keystone</u>: the cuboid</li> </ul>	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
<b>Transverse arch</b>	Cuboid, 3 cuneiforms & the bases of all metatarsals	<ul style="list-style-type: none"> <li>- <u>The lateral pillar</u> is the tuberosity of the 5th metatarsal</li> <li>- <u>The keystone</u>: the middle cuneiform closely wedged with the 2nd metatarsal base between the medial &amp; lateral cuneiforms</li> </ul>	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 **planta 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.

The 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 if the foot by acting as tie beam.

### **Clinical correlation**

**Plantar 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 leads to ossification in the posterior attachment of the plantar aponeurosis forming a calcaneal spur.

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**

<b>MUSCLE LAYERS OF THE SOLE OF THE FOOT</b>		
<b>Layer</b>	<b>Muscles</b>	<b>Features</b>
<b>First layer</b>	<ul style="list-style-type: none"><li>- Flexor digitorum brevis</li><li>- Abductor hallucis</li><li>- Abductor digiti minimi</li></ul>	They cover whole of the sole
<b>Second layer</b>	<ul style="list-style-type: none"><li>- Flexor digitorum accessories (AKA; quadratus plantae)</li><li>- Tendons of flexor digitorum longus</li><li>- Tendon of flexor hallucis longus</li><li>- 4 lumbricals</li></ul>	Flexor digitorum accessorius and lumbricals are attached to the tendon of flexor digitorum longus
<b>Third layer</b>	<ul style="list-style-type: none"><li>- Flexor hallucis brevis</li><li>- Flexor digiti minimi</li><li>- Adductor hallucis</li></ul>	They are confined to the metatarsal region of the sole
<b>Fourth layer</b>	<ul style="list-style-type: none"><li>- Interossei (3 plantar &amp; 4 dorsal)</li><li>- Tendon of tibialis posterior</li><li>- Tendon of peroneus longus</li></ul>	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
<b>Abductor hallucis</b>	Abducts & flexes the metatarsophalangeal joint of the big toe
<b>Flexor digitorum brevis</b>	Flexes lateral 4 toes at the proximal interphalangeal joints
<b>Flexor digitorum accessorius (quadratus plantae)</b>	Assists flexor digitorum longus tendon in flexing the lateral 4 toes
<b>Lumbricals (4 muscles)</b>	Flexion of metatarsophalangeal joint and extension of interphalangeal joints
<b>Flexor hallucis longus</b>	Flexes the big toe at metatarsophalangeal joint
<b>Adductor hallucis</b>	Adducts great toe at metatarsophalangeal joint
<b>Flexor digiti minimi brevis</b>	Flexes little toe at metatarsophalangeal joint
<b>Dorsal interossei</b>	Abduction of lateral 4 toes
<b>Plantar interossei</b>	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:

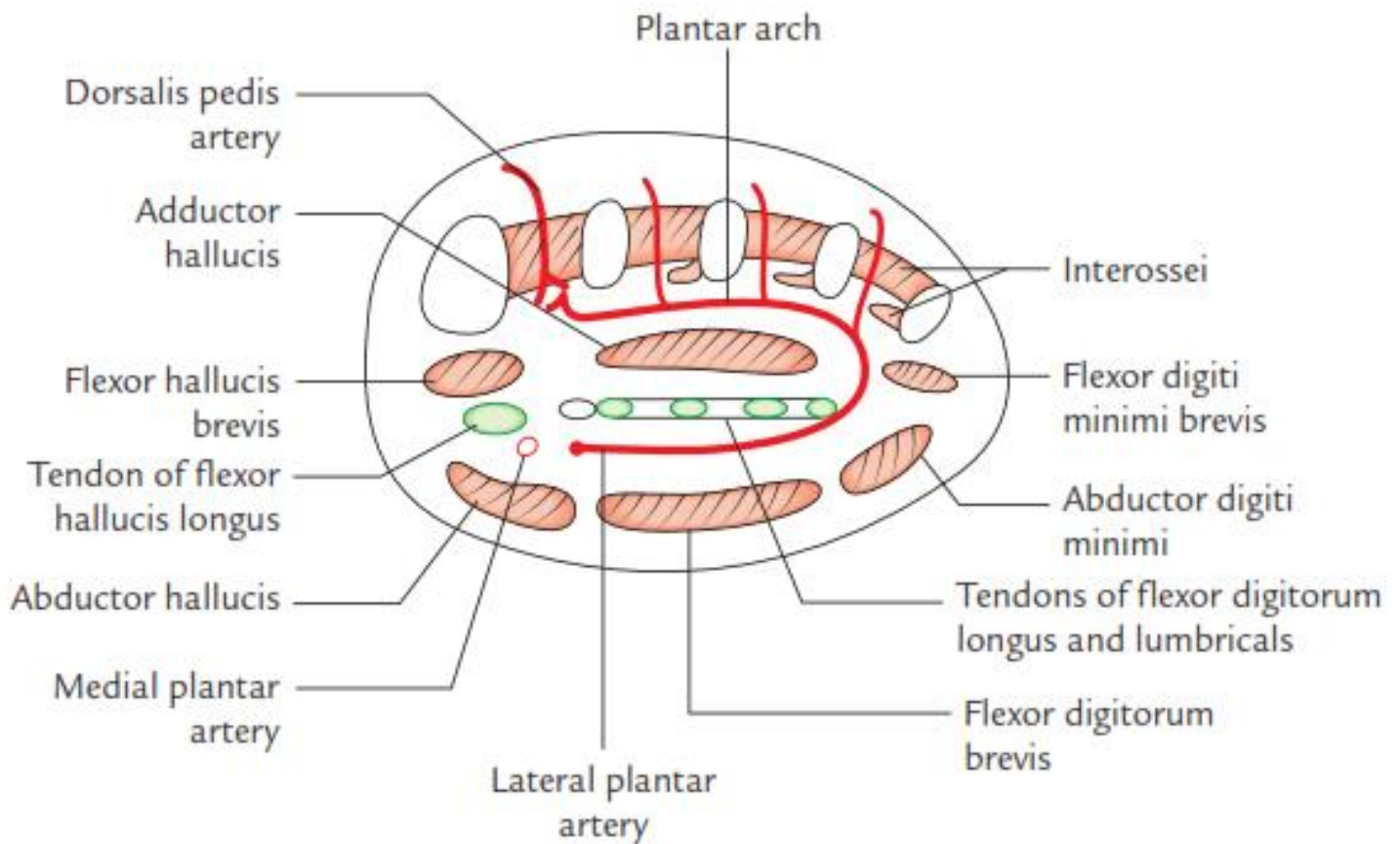
- Medial planter digital artery for the medial side of the big toe.
- Large branch that splits into 3 branches that anastomose with the first 3 metatarsal arteries.

### 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 5<sup>th</sup> metatarsal accompanying the lateral planter nerve. At the base of the 5<sup>th</sup> 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 2<sup>nd</sup>, 3<sup>rd</sup> & 4<sup>th</sup> 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 ligament

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 3 & 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 (paraesthesia) on the medial side of the sole and in the region of navicular tuberosity.

### Lateral planter nerve

It is the smaller terminal branch of 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 & plantar digital branches supplying 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.