The Foot as a Functional Unit

The Foot as a Weight Bearer and a Lever

The foot has two important functions: to support the body weight and to serve as a lever to propel the body forward in walking and running. If the foot possessed a single strong bone instead of a series of small bones, it could sustain the body weight and serve well as a rigid lever for forward propulsion (Fig. 10.66). However, with such an arrangement, the foot could not adapt itself to uneven surfaces, and the forward propulsive action would depend entirely on the activities of the gastrocnemius and soleus muscles. Because the lever is segmented with multiple joints, the foot is pliable and can adapt itself to uneven surfaces. Moreover, the long flexor muscles and the small muscles of the foot can exert their action on the bones of the forepart of the foot and toes (i.e., the takeoff point of the foot) and greatly assist the forward propulsive action of the gastrocnemius and soleus muscles (Fig. 10.66).

The Arches of the Foot

A segmented structure can hold up weight only if it is built in the form of an arch. The foot has three such arches, which are present at birth: the **medial longitudinal, lateral longitudinal,** and **transverse arches** (Fig. 10.67). In the young child, the foot appears to be flat because of the presence of a large amount of subcutaneous fat on the sole of the foot.

On examination of the imprint of a wet foot on the floor made with the person in the standing position, one can see that the heel, the lateral margin of the foot, the pad under the metatarsal heads, and the pads of the distal phalanges are in contact with the ground (Fig. 10.67). The medial margin of the foot, from the heel to the 1st metatarsal head, is arched above the ground because of the important medial longitudinal arch. The pressure exerted on the ground by the lateral margin of the foot is greatest at the heel and the 5th metatarsal head and least between these areas because of the presence of the low-lying lateral longitudinal arch. The transverse arch involves the bases of the five metatarsals and the cuboid and cuneiform bones. This is, in fact, only half an arch, with its base on the lateral border of the foot and its summit on the foot's medial border. The foot has been likened to a half-dome, so that when the medial borders of the two feet are placed together, a complete dome is formed.

From this description, it can be understood that the body weight on standing is distributed through a foot via the heel behind and six points of contact with the ground in front, namely, the two sesamoid bones under the head of the first metatarsal and the heads of the remaining four metatarsals.

The Bones of the Arches

An examination of an articulated foot or a lateral radiograph of the foot shows the bones that form the arches.

- **Medial longitudinal arch:** This consists of the calcaneum, the talus, the navicular bone, the three cuneiform bones, and the first three metatarsal bones (Fig. 10.63).
- **Lateral longitudinal arch:** This consists of the calcaneum, the cuboid, and the 4th and 5th metatarsal bones (Fig. 10.67).
- **Transverse arch:** This consists of the bases of the metatarsal bones and the cuboid and the three cuneiform bones (Fig. 10.67).

Mechanisms of Arch Support

Examination of the design of any stone bridge reveals the following engineering methods used for its support (Fig. 10.68):

- **The shape of the stones:** The most effective way of supporting the arch is to make the stones wedge shaped, with the thin edge of the wedge lying inferiorly. This

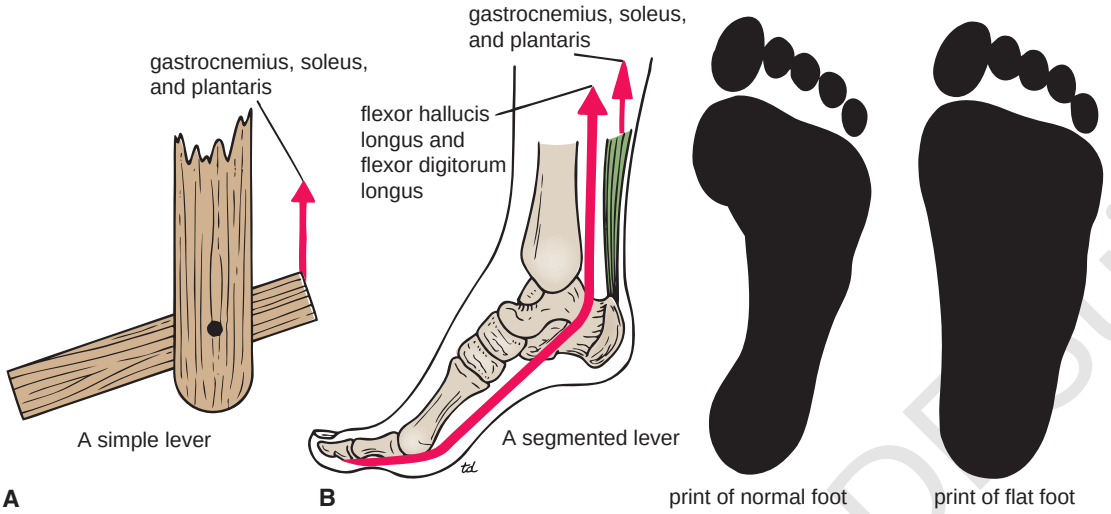

FIGURE 10.66 The foot as a simple lever **(A)** and as a segmented lever **(B)**. Floor prints of a normal foot and a flat foot are also shown.

applies particularly to the important stone that occupies the center of the arch and is referred to as the "keystone."

- **The inferior edges of the stones are tied together:** This is accomplished by interlocking the stones or binding their lower edges together with metal staples. This method effectively counteracts the tendency of the lower edges of the stones to separate when the arch is weight bearing.
- **The use of the tie beams:** When the span of the bridge is large and the foundations at either end are insecure, a tie beam connecting the ends effectively prevents separation of the pillars and consequent sagging of the arch.
- **A suspension bridge:** Here, the maintenance of the arch depends on multiple supports suspending the arch from a cable above the level of the bridge.

Using the bridge analogy, one can now examine the methods used to support the arches of the feet (Fig. 10.68).

Maintenance of the Medial Longitudinal Arch

- **Shape of the bones:** The sustentaculum tali holds up the talus; the concave proximal surface of the navicular bone receives the rounded head of the talus; the slight concavity of the proximal surface of the medial cuneiform bone receives the navicular. The rounded head of the talus is the keystone in the center of the arch (Fig. 10.68).
- **The inferior edges of the bones are tied together** by the plantar ligaments, which are larger and stronger than the dorsal ligaments. The most important ligament is the plantar calcaneonavicular ligament (Fig. 10.68). The tendinous extensions of the insertion of the tibialis posterior muscle play an important role in this respect.
- **Tying the ends of the arch together** are the plantar aponeurosis, the medial part of the flexor digitorum brevis, the abductor hallucis, the flexor hallucis longus, the medial part of the flexor digitorum longus, and the flexor hallucis brevis (Fig. 10.68).
- **Suspending the arch from above** are the tibialis anterior and posterior and the medial ligament of the ankle joint.

Maintenance of the Lateral Longitudinal Arch

- **Shape of the bones:** Minimal shaping of the distal end of the calcaneum and the proximal end of the cuboid. The cuboid is the keystone.

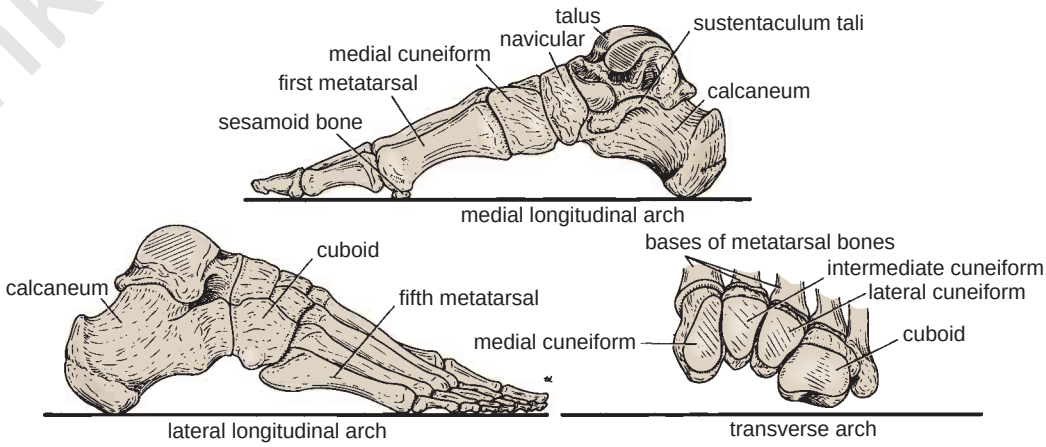

FIGURE 10.67 Bones forming the medial longitudinal, lateral longitudinal, and transverse arches of the right foot.

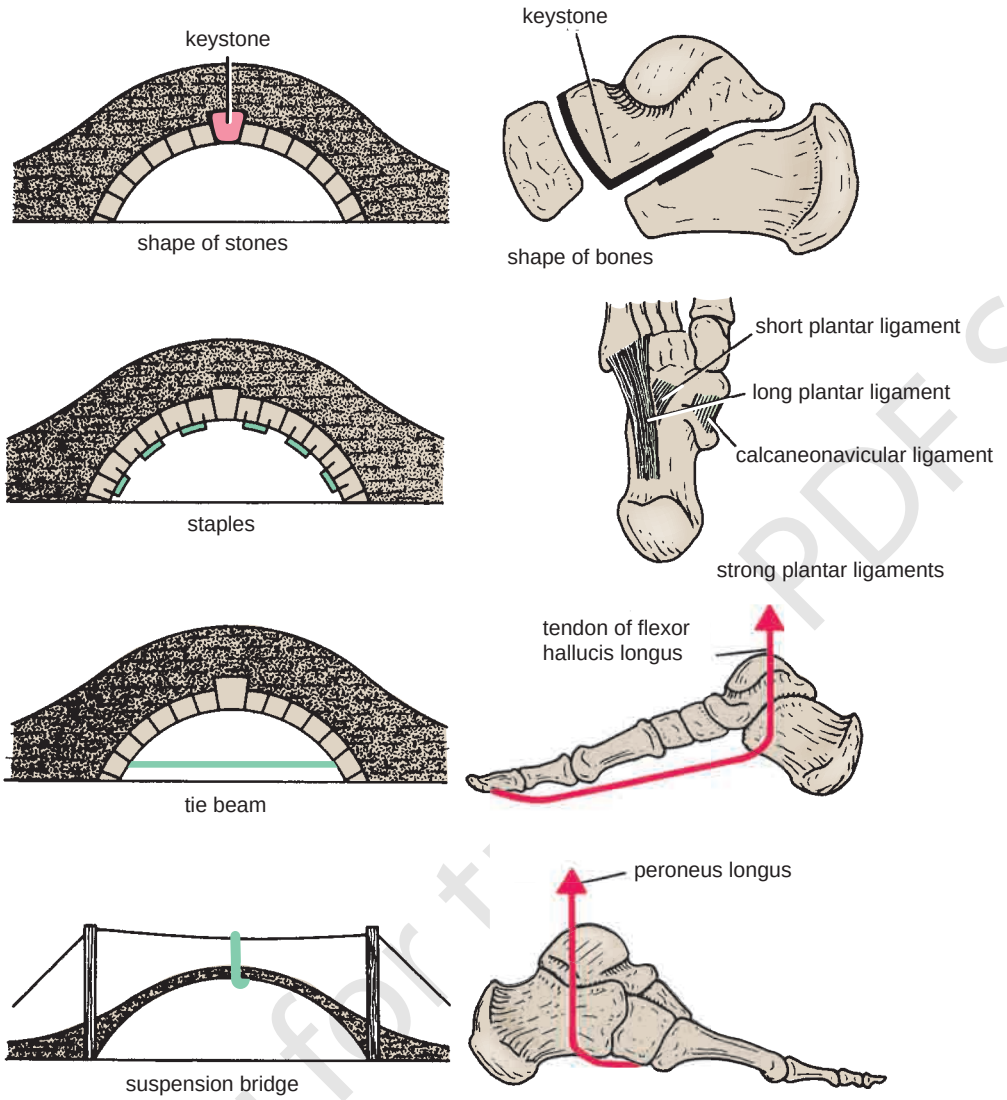

FIGURE 10.68 Different methods by which the arches of the foot may be supported.

- **The inferior edges of the bones are tied together** by the long and short plantar ligaments and the origins of the short muscles from the forepart of the foot (Fig. 10.68).
- **Tying the ends of the arch together** are the plantar aponeurosis, the abductor digiti minimi, and the lateral part of the flexor digitorum longus and brevis.
- **Suspending the arch from above** are the peroneus longus and the brevis (Fig. 10.68).

Maintenance of the Transverse Arch

- **Shape of the bones:** The marked wedge shaping of the cuneiform bones and the bases of the metatarsal bones (Fig. 10.67).
- **The inferior edges of the bones are tied together** by the deep transverse ligaments, the strong plantar ligaments, and the origins of the plantar muscles from the forepart of the foot; the dorsal interossei and the transverse head of the adductor hallucis are particularly important in this respect.
- **Tying the ends of the arch together** is the peroneus longus tendon.
- **Suspending the arch from above** are the peroneus longus tendon and the peroneus brevis.

The arches of the feet are maintained by the shape of the bones, strong ligaments, and muscle tone. Which of these factors is the most important? Basmajian and Stecko demonstrated electromyographically that the tibialis anterior, the peroneus longus, and the small muscles of the foot play no important role in the normal static support of the arches. They are commonly totally inactive. However, during walking and running, all these muscles become active. Standing immobile for long periods, especially if the person is overweight, places excessive strain on the bones and ligaments of the feet and results in fallen arches or flat feet. Athletes, route-marching soldiers, and nurses are able to sustain their arches provided that they receive adequate training to develop their muscle tone.

CLINICAL NOTES

Clinical Problems Associated with the Arches of the Foot

Of the three arches, the medial longitudinal is the largest and clinically the most important. The shape of the bones, the strong ligaments, especially those on the plantar surface of the foot, and the tone of muscles all play an important role in supporting the arches. It has been shown that in the active foot the tone of muscles is an important factor in arch support. When the muscles are fatigued by excessive exercise (a long-route march by an army recruit), by standing for long periods (waitress or nurse), by overweight, or by illness, the muscular support gives way, the ligaments are stretched, and pain is produced.

Pes planus (flat foot) is a condition in which the medial longitudinal arch is depressed or collapsed. As a result, the forefoot is displaced laterally and everted. The head of the talus is no longer supported, and the body weight forces it downward and medially between the calcaneum and the navicular bone. When the deformity has existed for some time, the plantar, calcaneonavicular, and medial ligaments of the ankle joint become permanently stretched, and the bones change shape. The muscles and tendons are also permanently stretched. The causes of flat foot are both congenital and acquired.

Pes cavus (clawfoot) is a condition in which the medial longitudinal arch is unduly high. Most cases are caused by muscle imbalance, in many instances resulting from poliomyelitis.

The Propulsive Action of the Foot

Standing Immobile The body weight is distributed via the heel behind and the heads of the metatarsal bones in front (including the two sesamoid bones under the head of the first metatarsal).

Walking As the body weight is thrown forward, the weight is borne successively on the lateral margin of the foot and the heads of the metatarsal bones. As the heel rises, the toes are extended at the metatarsophalangeal joints, and the plantar aponeurosis is pulled on, thus shortening the tie beams and heightening the longitudinal arches. The "slack" in the long flexor tendons is taken up, thereby increasing their efficiency. The body is then thrown forward by the actions of the gastrocnemius and soleus (and plantaris) on the ankle joint, using the foot as a lever, and by the toes being strongly flexed by the long and short flexors of the foot, providing the final thrust forward. The lumbricals and interossei contract and keep the toes extended so that they do not fold under because of the strong action of the flexor digitorum longus. In this action, the long flexor tendons also assist in plantar flexing the ankle joint.

Running When a person runs, the weight is borne on the forepart of the foot, and the heel does not touch the ground. The forward thrust to the body is provided by the mechanisms described for walking (above).

CLINICAL NOTES

Bursae and Bursitis in the Lower Limb

A variety of bursae are found in the lower limb where skin, tendons, ligaments, or muscles repeatedly rub against bony points or ridges.

Bursitis, or inflammation of a bursa, can be caused by acute or chronic trauma, crystal disease, infection, or disease of a neighboring joint that communicates with the bursa. An inflamed bursa becomes distended with excessive amounts of fluid. The following bursae are prone to inflammation: the bursa over the ischial tuberosity; the greater trochanter bursa; the prepatellar and superficial infrapatellar bursae; the bursa between the tendons of insertion of the sartorius, gracilis, and semitendinosus muscles on the medial proximal aspect of the tibia; and the bursa between the tendo calcaneus and the upper part of the calcaneum (long-distance runner's ankle).

Two important bursae communicate with the knee joint, and they can become distended if excessive amounts of synovial fluid accumulate within the joint. The suprapatellar bursa extends proximally about three fingerbreadths above the patella beneath the quadriceps femoris muscle. The bursa, which is associated with the insertion of the semimembranosus muscle, may enlarge in patients with osteoarthritis of the knee joint.

The anatomic bursae described should not be confused with **adventitious bursae,** which develop in response to abnormal and excessive friction. For example, a subcutaneous bursa sometimes develops over the tendo calcaneus in response to badly fitting shoes. A **bunion** is an adventitial bursa located over the medial side of the head of the 1st metatarsal bone.