**FOOT AND ANKLE ANATOMY**

The ankle-foot complex (AFC) is made up of numerous joints including the inferior tibiofibular, talocrural, subtalar, transverse tarsal, tarsometatarsal, metatarsal-phalangeal and interphalangeal joints (1). All of these joints will directly affect the ankle complex by transmitting forces up the kinematic chain.

**Osseous Structures**

There are 26 bones in each foot. It is best to describe the osseous structures based on location for understanding of the contribution to structural function. Classically, the foot is divided into the forefoot, midfoot, and hindfoot (1) (Table 14.1).

*Table 14.1: Bones and Joints of the Lower Leg and Ankle-Foot Complex.*

<table>
<thead>
<tr>
<th>Region</th>
<th>Bones</th>
<th>Joints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower leg</td>
<td>Tibia and fibula</td>
<td>• Distal tibiofibular joint</td>
</tr>
<tr>
<td>Hindfoot</td>
<td>Calcaneus and Talus</td>
<td>• Talocrural</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Subtalar joint</td>
</tr>
<tr>
<td>Mid-foot</td>
<td>Navicular, cuboid, and cuneiform</td>
<td>• Transverse tarsal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>o Talonavicular</td>
</tr>
<tr>
<td></td>
<td></td>
<td>o Calcaneocuboid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Distal Intertarsal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>o Cuneonavicular</td>
</tr>
<tr>
<td></td>
<td></td>
<td>o Cuboideonavicular</td>
</tr>
<tr>
<td></td>
<td></td>
<td>o Intercuneiform and Cuneocuboid complex</td>
</tr>
<tr>
<td>Forefoot</td>
<td>Metatarsals and phalanges</td>
<td>• Tarsometatarsal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Intermetatarsal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Metatarsophalangeal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Interphalangeal</td>
</tr>
</tbody>
</table>
Hindfoot Bones

There are two bones of the hindfoot, the calcaneus and talus. The calcaneus is the largest tarsal bone, forms the heel of the foot, and provides significant structural integrity to the ankle-foot complex.
The talus is the second largest tarsal bone and forms the articulation between the lower leg and the foot. The articulation site of the talus is complex and consists of a number of facets with both convex and concave features.

**Figure 14.3**: Medial View of the Whole Foot

**Mid-foot Bones**

The five mid-foot bones are bordered by the Lisfranc joint distally and the transverse tarsal joint (Chopart's joint) proximally. The bones of the mid-foot include the three cuneiforms, the cuboid, and the navicular. The navicular is responsible for transmitting forces from the hindfoot to the forefoot and demonstrates numerous articular facets. Otherwise, the majority of the mid-foot bones articulate and function as a complex system that provides stability, transmits mobility, and adapts appropriately to ground surface changes (2).

**Forefoot Bones**

The forefoot boundaries include the distal-most phalanges and the tarsometatarsal joint (Lisfranc joint). The forefoot contains 5 metatarsals and 14 phalanges. The metatarsals are described by the medial to lateral position, therefore, the medial-most metatarsal is designated as digit 1, digit 2, digit 3, and so on. The articulation points of each metatarsal include medial and lateral articulations with other metatarsals and proximal articulations with the cuboid (4 and 5), and...
Cuneiforms (3). The metatarsals are unique as they are the only bones in the body that are weight bearing at a perpendicular axis.

Like the hand, there are two phalanges at digit 1 and three for digits 2 through 5. The digits serve as connection points for a number of muscles and are used primarily during propulsion. Occasionally, phalanges will be accompanied by sesamoid bones, which aid in providing an improved mechanical lever (2).

### Summary
- There are 26 or more bones in the AFC.
- The osseous structures are generally divided into three primary groups, the hindfoot, mid-foot, and forefoot.
- The calcaneus is the largest bone in the foot, followed by the talus.

### Hindfoot Joints of Stabilizing Structures of the Ankle-Foot Complex

There are two primary joints of the hindfoot, the talocrural joint, which consists of the articulations of the tibiotalar, tibiofibular, and fibulotalar structures and the subtalar joint which consists of the articulations of the talus superiorly and calcaneus inferiorly.

#### Talocrural Joint

The distal tibiofibular joint is a syndesmotic joint connected by fibrous bands of tissue. The slightly concave tibial surface articulates with the plane (3) to the convex (3,4), triangular-shaped distal end of the fibula. The structure of the mortise is represented by the tibia superiorly, the medial malleolus medially, and the lateral malleolus of the fibula laterally. The distal tibiofibular joint is stabilized by several ligaments including the anterior and posterior tibiofibular ligaments, interosseus ligament, and superior extensor retinaculum. The architecture of the tibia and fibular creates the mortise of the talocrural joint.
The mortise functions as a concave surface to accept the convex surface of the talus. The trochlea of the talus is up to 6 millimeters (mm) wider anteriorly than posteriorly, causing the talus to act as a wedge within the ankle mortise as the ankle dorsiflexes. The tibiotalar joint, fibulotalar joint, and the distal portion of the tibiofibular joint reside in the same joint capsule and make up the synovial hinge joint known as the talocrural (4).

**Figure 14.4: The Talocrural Articulation**

Displacement (distraction) of the joint can allow excess talar rotation within the talocrural joint. This excess rotation can cause the triplanar movement to occur out of the normal triplanar pattern, disrupting force translation in closed chain.

Ligaments supporting the talocrural joint include the anterior and posterior talofibular ligaments (ATFL and PTFL, respectively), the calcaneofibular ligament laterally, and the deltoid ligament medially. The ATFL is frequently sprained during an uncontrolled inversion moment, typically from a plantarflexed position (5). When compared to other ligaments, ATFL sprains occur relatively easily secondary to low load to failure and high strain to failure (6).
Subtalar Joint

The subtalar joint is irregularly shaped and can be classified as a synovial bicondylar joint (3). There are two articulating surfaces between the talus and the calcaneus. The anterior articulation is comprised of the anterior and middle facets, which are convex on the talus and concave on the calcaneus, while the posterior articulation is concave on the talus and convex on the calcaneus. Between these two articulations is the interosseous membrane, also referred to as the axial ligament, which assists in stabilization of an eversion movement (7). With the anterior articulation lying medial to the posterior articulation and with the irregular joint surfaces, the subtalar joint will move in opposite directions during functional weight bearing (3).

Figure 14.5: The Articular Processes that form the Subtalar Joint

Ligaments are present to assist in maintaining the integrity of the subtalar joint. They include the medial and lateral interosseous, the calcaneofibular (CFL), the deltoid (DL), and the lateral talocalcaneal ligaments (LTCL). The medial talocalcaneal interosseous ligament projects from the medial tubercle of the talus posteriorly to just behind the sustentaculum tali of the calcaneous and serves to prevent the talus from anterior translation on the calcaneous. The lateral talocalcaneal interosseous ligament (cervical ligament) projects from the sinus tarsi posteriorly to the calcaneous and serves to prevent the excess separation of the talus from the calcaneous during inversion moments. This ligament is typically injured when an excessive moment is applied
in inversion coupled with dorsiflexion (3). The cervical ligament is further fortified in preventing subtalar inversion by the deep fibers of the extensor retinaculum. Medially, the deltoid and calcaneonavicular ligaments prevent excessive eversion. Laxity of the ligaments in the lateral compartment is implicated frequently in lateral instability due to an excess of active and passive range of motion. Laxity in the medial compartment is less prevalent but may be functionally more problematic because this type of sprain is associated with a higher incidence of cartilage damage and concomitant lateral ligamentous damage (8).

**Midfoot Joints of Stabilizing Structures of the Ankle-Foot Complex**

Multiple joints make up the mid-foot region. The proximal and distal boundaries include the proximal transverse tarsal joint and the distal Lisfranc joint. Between these boundaries exist the talonavicular joint, calcaneocuboid joint, cuneonavicular joint, and intermetatarsal joints (2).

**Transverse Tarsal Joint (Chopart’s Joint)**

The transverse tarsal joint, or “Chopart's joint,” includes the articulations of the talus and navicular (Talonavicular joint) and the calcaneus and the cuboid (calcaneocuboid joint). The talonavicular joint is a ball-and-socket joint that allows triplanar movement. The anterior aspect of the talus is convex and articulates with the posterior concave aspect of the navicular. It is stabilized by the joint capsule, the dorsal talonavicular, and the medial portion of the bifurcate and the plantar calcaneonavicular (spring) ligaments.

The calcaneocuboid complex allows movement in both transverse and longitudinal planes. The anterior aspect of the calcaneus is convex in the horizontal plane and concave in the vertical plane articulating with the cuboid, which is concave in the horizontal plane and convex in the vertical plane (9), making the joint a synovial–modified sellar joint (3). This joint is stabilized by the joint capsule, the spring ligament, the long plantar ligament, and dorsally by the bifurcate ligament.
Cuneonavicular Joint

The convex surface of the navicular articulates with the combined concave surfaces of the three cuneiforms (medial, intermediate, and lateral) to form a compound synovial–modified sellar joint (3). The three cuneiforms form the transverse arch. This arch is important for allowing room for neurovascular and musculotendinous structures to pass through the plantar aspect of the foot (3). The joint is stabilized by the joint capsule, and the dorsal and plantar cuneonavicular ligaments. The transverse arch is stabilized and maintained by the peroneus longus muscle.

Cubonavicular Joint

The cubonavicular joint is a plane joint, and when synovial, is continuous with the cuneonavicular joint (3). The cubonavicular joint is sometimes referred to as the cuboid-third cuneiform-navicular joint (10). The joint is stabilized by the plantar cubonavicular ligament. The cuboid and the navicular bones tend to move together rather than on each other, allowing the forefoot to move as a unit on the hindfoot through the midtarsal joint.

Tarsometatarsal Joints (Lisfranc Joint)

The convex distal cuneiforms and cuboid bones articulate with the concave bases of the metatarsals to form plane synovial joints within three separate joint cavities (4). The first joint cavity or medial tarsometatarsal joint consists of the medial cuneiform and the first metatarsal and is the most mobile. The intermediate tarsometatarsal joint consists of all three cuneiforms articulating with the second and third metatarsals and is the least mobile of the joint cavities. It is also important to note that the second metatarsal articulates with the intermediate cuneiform between the distal aspects of the larger medial and lateral cuneiforms. This articulation creates a bony invagination to further stabilize this joint cavity, immobilizing the structure. This fact may become clinically important in the second ray’s ability to absorb stress because this region is frequently the site of stress fractures. The ligament of Lisfranc crosses from the medial cuneiform to the second metatarsal base to provide a strong stabilizing mechanism that is important in
keeping the first ray from separating from the second ray. If this ligament is torn, the medial forefoot becomes very mobile, acting independently of the rest of the forefoot. The final joint cavity consists of the articulations between the lateral cuneiform and the third metatarsal and the cuboid with the fourth and fifth metatarsals (4).

**Forefoot Joints of Stabilizing Structures of the Ankle-Foot Complex**

**Metatarsal Phalangeal Joints (MTP)**

Each of the metatarsals articulates with the proximal phalanx. The metatarsal is biconvex and the base of the phalanx is biconcave, making the metatarsalphalangeal joints both condyloid and synovial (4). These joints are stabilized in part by the deep transverse metatarsal ligaments, and the medial and lateral collateral ligaments, in addition to the plantar metatarsophalangeal ligaments and the dorsal extensor hood expansion (11). The first MTP also receives stabilization from the expansion of the extensor hallucis tendon and ventrally from the plantar accessory ligament. Within the plantar accessory ligament lie the flexor hallucis tendon and the medial and lateral sesamoid bones (3).

**Intermetatarsal Joints**

The intermetatarsal joints are plane-type synovial joints that are considered extensions of the tarsometatarsal joints. The deep transverse metatarsal ligament and the interosseous ligaments, which assist in maintaining the transverse arch of the foot, stabilize them. The bases of the metatarsals glide both dorsally and plantarly and do not demonstrate much individual movement (4).

**Interphalangeal Joints**

Each of the phalanges has a base and a head described from proximal to distal (4). The interphalangeal joints are synovial–modified sellar joints that primarily move in flexion and extension. The convex phalangeal heads articulate with the concave bases of the phalanx just
distal to it. It must be noted that a certain degree of freedom is also apparent in abduction, adduction, and rotation both medially and laterally. The joints are stabilized by the joint capsule and collateral ligaments. There are two interphalangeal joints in the first ray and three interphalangeal joints in rays 2–5. A summary of the joints of the AFC is provided by Table 14.2.

**Table 14.2: Selected Joint Planes and Arthrokinematics of the Ankle-Foot Complex**

<table>
<thead>
<tr>
<th>Joint</th>
<th>Type</th>
<th>Specifics</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talocrural joint</td>
<td>Is a synovial, uniaxial, modified hinge joint</td>
<td>Convex talus, and concave distal tibia and fibula follow the concave/convex rules</td>
<td>Because the lateral malleolus is longer (more distal) than the medial malleolus, the axis is slightly oblique</td>
</tr>
<tr>
<td>Subtalar joint</td>
<td>The joint has three parts and is a synovial uniaxial (oblique) joint and a pivot joint</td>
<td>Concave anterior and medial facets Convex posterior facet</td>
<td>The joint between the talus and the calcaneus. There are 3 facets between the 2 bones (posterior, middle, and anterior facets), with the posterior facet being by far the largest.</td>
</tr>
<tr>
<td>Talonavicular joint</td>
<td>Ball-and-socket joint</td>
<td>Concave on convex. Proximal component is a convex talar head and the distal component is concave navicular bone</td>
<td>Allows for movements in all ranges</td>
</tr>
<tr>
<td>Calcaneocubiod joint</td>
<td>Saddle joint</td>
<td>Proximal component = calcaneus Convex in the dorsoplantar direction Concave in the mediolateral direction Distal component = concave navicular end Concave in the dorsoplantar direction Convex in the mediolateral direction</td>
<td>Allows for triplanar movements</td>
</tr>
</tbody>
</table>
Summary

- The joints of the foot are further divided into the hindfoot joints, midfoot joints, and forefoot joints.
- Each joint system consists of numerous smaller joints.
- The majority of the stabilization associated with the joints in the AFC is primarily ligamentous supported.

Pseudojoints (Longitudinal and Transverse Arches)

There are two major arches present in the mechanically normal foot, the transverse arch and the longitudinal arch. The longitudinal arch has two components, the medial and lateral arches. The medial arch, described from posterior to anterior, consists of the calcaneous, talus, navicular, three cuneiforms, and the first three metatarsals, with the head of the talus acting as the keystone because it bears the direct pressure of the body’s weight in a closed kinematic chain (4).

The lateral arch consists of the calcaneous, cuboid, and lateral two metatarsals and lies on the ground during weight bearing. The difference in height between the medial and lateral longitudinal arches assists in the formation of the transverse arch, demonstrating the integration between the arches in the dispersion of forces during weight bearing. The medial longitudinal arch tends to be more important in function because it contributes to the positional mechanics of the mid- and forefoot and helps determine the force transferral between the parts of the foot.

Numerous structures are required to maintain the arches of the foot including the plantar fascia (primarily), the central aponeurosis, the plantar ligaments and capsules, the congruency of bony anatomy, and tension within the tendons from their muscular action. Muscle action contributes the least since electromyographic analysis of the muscles of the foot has determined that very little muscle activity occurs until locomotion begins (2). The plantar calcaneonavicular ligament (spring ligament) is the main structure responsible for maintaining the medial longitudinal arch. The long plantar ligament extends the length of the lateral longitudinal arch and is its main structure of support for the lateral arch.
The plantar aponeurosis supports the entire longitudinal arch with a fibrous band connecting the calcaneous to the tuberosity of the fifth metatarsal and the medial band attaching to the sesamoids under the first metatarsal. The plantar aponeurosis stabilizes the medial arch in toe standing. Finally, the plantar calcaneocuboid ligament, also known as the short plantar ligament, assists the spring and long plantar ligaments in supporting the longitudinal arches (4). The plantar aponeurosis and plantar fascia in general frequently becomes the source of mechanical and chemical pain in dysfunction through apparent injuries involving repeated microtrauma.

**Summary**

- Several pseudojoints make up the AFC that provide the foot with an arch shape.
- The longitudinal arch has two components—a medial and lateral arch.
- The stabilization of the arches is from the combined efforts of passive and active stabilizers.

**Muscle of the Ankle-Foot Complex**

Like the joints of the AFC, the muscles are best divided into groups based on the compartments of the leg. However, division of compartments is generally described as lateral, medial, anterior, and posterior.

**Anterior Compartment**

The tibialis anterior originates on the anterior proximal tibia and fibula and inserts on the first metatarsal and medial aspect of the medial cuneiform. Combined with the extensor digitorum longus, the tibialis anterior promotes dorsiflexion of the ankle. The extensor digitorum longus originates from the upper two-thirds of the anterior border of the fibula, the lateral condyle of the tibia and the interosseous membrane and inserts on the lateral four digits through the expansion hoods into the bases of the middle and distal phalanges effecting dorsiflexion and digit extension.
Less prominent muscles may assist in dorsiflexion. The peroneus tertius originates on the distal third of the anterior fibula, and the interosseous membrane inserts on the dorsum of the fifth metatarsal and lateral aspect of the cuboid, which serves to dorsiflex and evert the foot. The extensor hallucis longus originates on the anterior fibula, inserts on the distal phalange of the first digit, and primarily extends the great toe and secondarily dorsiflexes the foot.

**Lateral Compartment**

Muscles of the lateral compartment are primarily responsible for eversion. The peroneus longus originates off the proximal half of the fibula on the lateral side, inserts on the plantar aspect of the first metatarsal and medial cuneiform, and is a strong evertor of the foot and a weak plantarflexor. The peroneus brevis originates on the distal lateral half of the fibula, inserts on the lateral base of the fifth metatarsal and cuboid and functions to evert the foot, and is a weak plantarflexor.

**Posterior Compartment**

The posterior compartment is subdivided into the superficial and the deep posterior compartments. Within the superficial posterior compartment lie the triceps surae, which include the medial and lateral heads of the gastrocnemius and the soleus muscles. The gastrocnemius medial and lateral heads originate on the posterior femoral condyles and insert in the common calcaneal tendon in the posterior aspect of the calcaneus. This muscle is a strong plantarflexor and is used extensively for powerful movements. The soleus originates on the proximal third of the tibia and fibula and inserts on the common calcaneal tendon. The soleus plays a significant role in postural control. Lastly, the plantaris, which originates on the supracondylar ridge of the femur and inserts into the posterior calcaneus through the calcaneal tendon, is also a weak plantarflexor of the foot and a knee flexor.

The deep posterior compartment includes the popliteus, the tibialis posterior, the flexor digitorum longus, and the flexor hallucis longus. The popliteus originates on the lateral epicondyle
of the femur and inserts on the posterior proximal tibia above the origin of the soleus (2). While the popliteus does not directly affect the foot and ankle, it is within the deep posterior compartment and can functionally influence the ankle by unlocking extension of the knee and allowing dorsiflexion of the ankle in closed chain activity.

The tibialis posterior lies deep within the posterior compartment, originates on the posterior aspect of the tibia and fibula, and inserts on the navicular tubercle, the medial cuneiform, and the plantar aspect of the base of the lateral four metatarsals through fibrous attachments. It is important in maintaining the medial longitudinal arch of the foot as well as being a weak plantarflexor and invertor.

The flexor digitorum longus originates on the middle third of the posterior tibia just distal to the soleal line, inserts on the planar aspect of the bases of metatarsals 2–5, serves to flex the toes, invert the foot, and assists in maintaining the medial longitudinal arch of the foot. The flexor hallucis longus originates on the distal two-thirds of the posterior fibula and inserts on the base of the distal phalanx of the first digit and acts as a flexor of the great toe and a plantarflexor of the foot.

**Dorsal Compartment of the Foot**

The extensor digitorum brevis originates on the dorsal surface of the calcaneus and inserts onto the base of the proximal phalanx of digit one and into the tendons of extensor digitorum longus for digits 2–4 to extend the first four toes.

**Plantar Compartment of the Foot**

There are four layers of muscle on the plantar aspect of the foot. Within the first layer lie the abductor hallucis, flexor digitorum, and the abductor digiti minimi. The abductor hallucis originates on the medial tuberosity of the calcaneus and from the flexor retinaculum and inserts on the medial aspect of the base of the proximal great toe, abducts, flexes the great toe in non–weight bearing, and braces the medial longitudinal arch in weight bearing. The flexor digitorum
brevis originates on the medial tuberosity of the calcaneus and the plantar aponeurosis and inserts on the medial and lateral aspects (tendon bifurcates at insertion) of the middle phalanges of the lateral four digits and serves to flex the metatarsal-phalangeal (MTP) and interphalangeal (PIP) joints. The abductor digiti minimi originates from the medial and lateral calcaneal tuberosities, inserts on the lateral base of the proximal fifth phalanx, abducts, flexes the fifth digit in non–weight bearing, and braces the lateral longitudinal arch in weight bearing.

The second layer consists of the lumbricals and the quadratus plantae. The lumbricals originate from the tendons of FDL, insert on the extensor expansion, base of proximal phalanges of digits 2–5 and the tendons of EDL, and serve to flex the MTP and extend the PIP joints. The quadratus plantae originates from the medial and lateral plantar surfaces of the calcaneus, inserts on the posterior aspect of the FDL tendon, and assists in the flexion of the lateral four DIP joints.

Within the third layer lie the muscles of the flexor hallucis brevis, the abductor hallucis, and the flexor digiti minimi. The flexor hallucis brevis originates from the cuboid and lateral cuneiform, inserts on the medial and lateral sides of the proximal great toe, and flexes the MTP of the first digit. The abductor hallucis has two heads: 1) the oblique, which originates from metatarsals 2–4, and 2) the transverse, which originates from the plantar ligaments of the lateral four MTPs and inserts on the lateral side of the base of the proximal phalanx of the first digit. The oblique head adducts and flexes the MTP of the great toe and the transverse head pulls all the metatarsals together, supports the transverse arch of the foot, and adducts the first digit. The flexor digiti minimi brevis originates off the base of the fifth metatarsal, inserts on the base of the proximal phalanx of digit 5, and serves to flex the fifth MTP joint.

Within the fourth layer lie the plantar interossei and the dorsal interossei. The plantar interossei originate on the plantar aspect of metatarsals 3–5 and insert on the medial planar surface of the base of the proximal phalanx of digits 3–5. The dorsal interossei originate on the medial aspect of one metatarsal and the lateral aspect of the adjacent metatarsal in all four intermetatarsal spaces. The lateral three dorsal interossei insert on the lateral plantar surface of
the base of proximal phalanx on digits 2–4 and on the medial aspect of the base of the proximal phalanx of digit 2 (remember no plantar interosseus inserts here) (12).

**Summary**

- The muscles are best divided into lateral, medial, anterior, and posterior compartments.
- There are four layers of muscle on the plantar aspect of the foot.

**FOOT AND ANKLE BIOMECHANICS**

As in all joints, the ankle complex has two types of possible motion, translatory movement, also known as arthrokinematic motion and rotational movement (also known as osteokinematic motion). Osteokinematic movement incorporates translatory motion in order to stabilize the instantaneous axis of rotation. This is important to translate forces over a larger surface area within the joint as well as to prevent unnatural forces during end ranges, which may damage the passive structures of the joint.

The collective movement patterns and passive and active control of foot motion allows for transferral of force throughout the foot for confirmation to surfaces and propulsion during gait. This process involves the individual range of motions (ROM) provided at each articulation.

**Range of Motion**

The talocrural joint demonstrates approximately 50° of plantarflexion and 20° of dorsiflexion. The subtalar joint is reported to have 40° of inversion and 20° of eversion. The tarsal joints are reported to have 10° of pronation and 20° of supination (18). Extension of the digits 2 through 5 includes 40° of extension in the MTPs, 0° of PIP extension, and 30° of DIP extension. The first MTP has 70° of extension and 0° of IP extension. For flexion, the MTPs have 40°, PIPs have 35°, and the DIPs have 60°. The great toe exhibits 45° of flexion at the MTP and 90° at the IP.
Open and Close-Packed Positions

The terms open and close packed positions of the ankle are in reference to the theoretical supposition that selected movements will increase the compression (close packed) or distraction (open packed) position between the joints of the ankle. The articular reference of close-packed position refers to a specific joint preposition when the articular surfaces are at the maximum point of congruency while open packed is the opposite of this joint position. Unfortunately, no studies exist that support this assumption, thus the validity behind open and close packed is essentially unknown.

Neumann suggests an alternative to the Cyriax-based definition of open and closed packed positions (13). He reports that supination of the subtalar joint, the combined movement of inversion and adduction, increases the rigidity of the foot and should be considered the closed pack position of the foot. Conversely, pronation of the subtalar joint (combined movement of abduction and eversion) is the loose packed position of the foot and creates the most flexible environment for the mid- and forefoot (Table 14.3).

Table 14.3: Joint Patterns of the Ankle-Foot Complex.

<table>
<thead>
<tr>
<th>Region</th>
<th>Joint</th>
<th>Pattern Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hindfoot</td>
<td>Distal tibiofibular</td>
<td>Resting position = plantarflexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Close pack position = maximum Dorsiflexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capsular pattern = pain on stress</td>
</tr>
<tr>
<td>Talocrural</td>
<td>Resting position = 10° PF midway between inversion and eversion</td>
<td>Close pack position = maximum Dorsiflexion</td>
</tr>
<tr>
<td></td>
<td>Capsular pattern = PF, DF</td>
<td></td>
</tr>
<tr>
<td>Subtalar joint</td>
<td>Resting position = midway</td>
<td>Close pack position = supination Dorsiflexion</td>
</tr>
<tr>
<td></td>
<td>Capsular pattern = varus and valgus</td>
<td></td>
</tr>
<tr>
<td>Mid-foot</td>
<td>Midtarsal joint</td>
<td>Resting position = midway between the extremes of motion</td>
</tr>
<tr>
<td></td>
<td>Close pack position = supination</td>
<td>Capsular pattern = DF, PF, adduction, and medial rotation</td>
</tr>
<tr>
<td>Forefoot</td>
<td>Tarsometatarsal joints</td>
<td>Resting position = midway between extremes of motion</td>
</tr>
<tr>
<td></td>
<td>Close-pack position = supination</td>
<td></td>
</tr>
</tbody>
</table>
Axis of Rotation/Movement

Axis of rotation refers to an imaginary line around which an object rotates. Rarely does the axis of rotation fall in a single plane. At the ankle, most motions are coupled, thus leading to complex multiplanar axes of rotations (1). For example, pronation is a coupled movement pattern of dorsiflexion, abduction, and eversion. Supination is a coupled pattern of plantarflexion, adduction, and inversion (13). The coupled movement allows greater confirmation between the ground reaction forces and the limb and allows alterations in the axis of rotation toward a more functional pattern.

The close and open packed positions at the hindfoot work in concert with the axis of motion to create movement patterns in the lower extremity (13). Subtalar supination assists in locking the midtarsal joints so the foot is rigid during push-off. Pronation at the subtalar joint unlocks the midtarsal joints, prompting a flexible foot when ambulating on unlevel surfaces. The axes of rotation allow the foot to further confirm and/or stabilize depending on the demands required. Table 14.4 outlines the axis of rotation for each of the movements available at the ankle-foot complex.

Table 14.4: Axes of Rotation for the Ankle-Foot Complex.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Primary Joint</th>
<th>Axis of Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pronation</td>
<td>Subtalar joint and transverse tarsal,</td>
<td>Combined axis of valgus, medial to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lateral, and vertical</td>
</tr>
<tr>
<td>Supination</td>
<td>Subtalar joint and transverse tarsal,</td>
<td>Combined axis of varus, medial to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lateral, and vertical</td>
</tr>
<tr>
<td>Abduction</td>
<td>Transverse tarsal and metatarsophalangeal</td>
<td>Vertical</td>
</tr>
<tr>
<td>Adduction</td>
<td>Transverse tarsal and</td>
<td>Vertical</td>
</tr>
<tr>
<td>Movement</td>
<td>Joint Components</td>
<td>Direction</td>
</tr>
<tr>
<td>------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Inversion</td>
<td>Subtalar, talocrural and transverse tarsal, metatarsophalangeal</td>
<td>Varus Flare</td>
</tr>
<tr>
<td>Eversion</td>
<td>Subtalar, talocrural, and transverse tarsal</td>
<td>Valgus flare</td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td>Talocrural joint, first tarsometatarsal joint, metatarsophalangeal, and interphalangeal joint</td>
<td>Medial to lateral</td>
</tr>
<tr>
<td>Plantarflexion</td>
<td>Talocrural joint, first tarsometatarsal joint, metatarsophalangeal, interphalangeal joint</td>
<td>Medial to lateral</td>
</tr>
</tbody>
</table>

**Articular Movements**

The axis of rotation of the talocrural joint is primarily in the sagittal plane around a frontal axis but is 23° lateral in the transverse plane secondary to external tibial torsion. The talocrural joint is also angled medially in the frontal plane around the sagittal axis, as the lateral malleolus is distal to the medial malleolus. The fact that the talocrural joint has components in all three planes makes dorsiflexion and plantarflexion triplanar movements. The talocrural joint can be considered to have 20° of offset to the sagittal plane, causing motion in inversion or eversion, and adduction or abduction, accordingly (14-16).

During dorsiflexion, the superior surface of the talus slides posteriorly simultaneously with anterior rotation (rolling). During plantarflexion, the talus slides anteriorly but also rotates posteriorly (13). The motion, however, is not purely planar and may consist of movements of eversion and inversion.

The complex articulation of the subtalar joint is less easily described. Mantar describes the axis of rotation as 42° from the horizontal plane and 16° from the sagittal plane, running in an anterior, medial, and superior direction (17). During subtalar pronation, the calcaneus moves in a curvilinear pattern around the axis of rotation. Thus, in pronation, the calcaneus moves into eversion and abduction, and during supination, the calcaneus moves into inversion and adduction. During gait, when the calcaneus is fixed, the talus primarily moves on the calcaneus. This movement incorporates more adduction and abduction of the talus controlled in part by rotation of...
the lower extremity. Talar adduction and abduction are enhanced by the conflicting
arthrokinematic movements of the anterior and posterior subtalar articulations. As the foot
pronates, the concave anterior calcaneal facet moves laterally and the convex posterior talar facet
moves medially, increasing forefoot abduction.

Movements of the midtarsal joints occurs around two separate, independent axes (16). The longitudinal axis occurs through the length of the foot in a cephalomedial direction and an oblique axis that occurs closer to the horizontal but is also cephalomedial (16,17). When the subtalar joint is pronated, the two axes become parallel to one another and maximum amount of motion is possible between the forefoot and hindfoot; but when the subtalar joint is supinated, the axes approach right angles to one another, providing little movement. This biomechanical variation allows the foot to adapt to uneven surfaces during the early stance phase of gait but then allows rigidity for an effective push-off during the terminal stance phase of gait (15).

The Lisfranc joint primarily allows dorsiflexion and plantarflexion, mostly at the first tarsometatarsal joint (13). Dorsiflexion of the first ray results in a superior migration of the metatarsal on the first cuneiform. Conversely, plantarflexion requires an inferior migration of the metatarsal on the first cuneiform. The movement patterns of the metatarsal phalangeal and interphalangeal joints are similar to those of the first metatarsal on the first cuneiform.

Summary
- There is little evidence to support the theory of open and close packed positions proposed by Cyriax.
- The axes of motion throughout the foot are reflective of the multiplanar movements of each joint.
- The articular movements of the joint involve complex movements reflective of convex on concave and variable axes of rotations during movements.

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