FOOT AND ANKLE BIOMECHANICS

ABSTRACT: Foot and ankle injuries are common in sportsmen and the general population. The impact that the functional anatomy and biomechanics of the foot and ankle complex has on normal gait is reviewed. The abnormal biomechanics associated with overpronation and oversupination are discussed, as are their consequences. The management principles of foot and ankle injuries are briefly described.

HUNTER L J, BSc PHYSIOTHERAPY[1]
FORTUNE J, BSc PHYSIOTHERAPY[2]

[1]Physiotherapy Department, University of the Witwatersrand
[2]Physiotherapy Department, University of the Witwatersrand

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INTRODUCTION

Foot and ankle injuries are extremely common, both in sportsmen and in the general population (Rundle, 1995). Fifty-three percent of all basketball injuries, and 31% of soccer injuries involve the foot and ankle (Garrick, 1977). Ankle sprains account for the most time lost by athletes due to injury (Reid, 1992). The estimated incidence of ankle sprains is 1:10 000 people per day in the United States (McCulloch, et al, 1985).

The predisposition to injury of the foot and ankle complex can only be understood by studying the anatomy and biomechanics of this region.

THE ANATOMY (See Figure 1.)

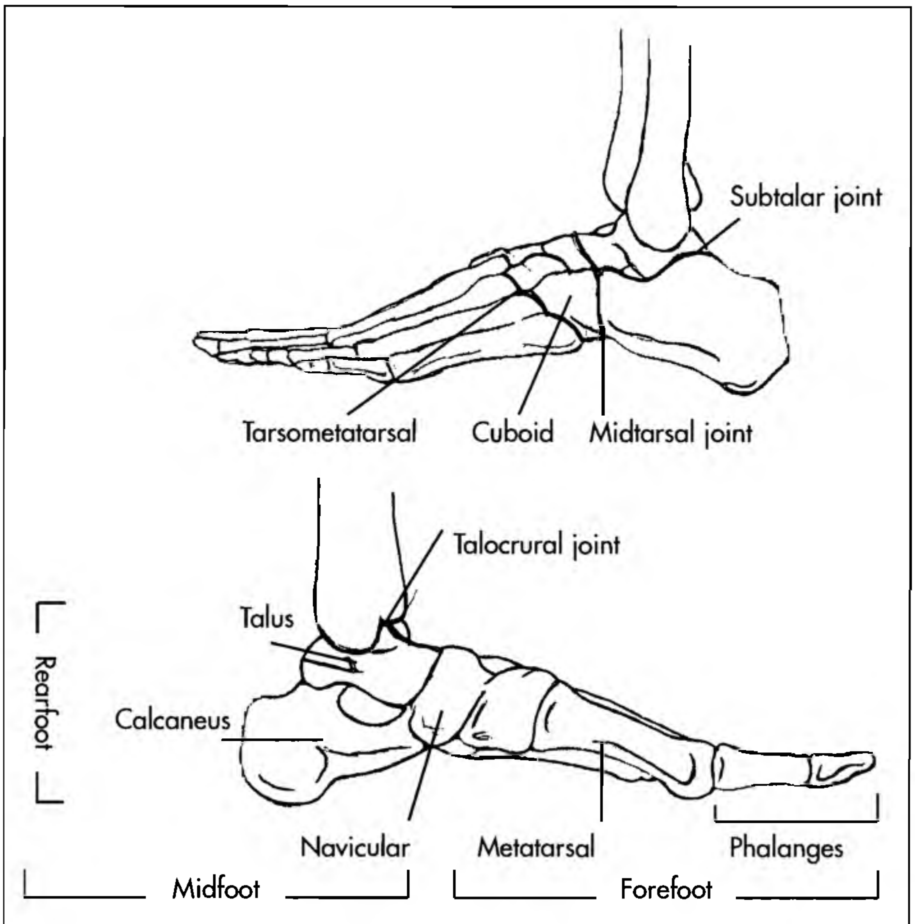
1. Talocrural Joint

The ankle is a uniaxial hinge joint. The medial and lateral malleoli (mortice) and the talus, also known as the talocrural joint, have an inherent bony stability. The position and orientation of the ligaments (predominantly the lateral ligament complex, the deltoid or medial ligament and ligaments of the syndesmosis) further enhance this passive stability. The muscles crossing the ankle (flexor hallucis brevis; flexor digitorum; gastrocnemius; soleus; peroneus longus; brevis and tertius; extensor digitorum longus and extensor digitorum brevis) provide active stability.

Figure 2.1 show the lateral ligament complex consisting of the anterior talofibular ligament (ATL), the calcaneofibular ligament (CFL) and the posterior talofibular ligament (PTL). Renström and Konradsen (1997) include the subtalar ligaments in the lateral ligament complex, and Boruta et al (1990), include the lateral talocalcaneal ligament as a fourth component of the complex, but most authors are in agreement about the ligaments named above.

The ATL is long and thin and may be considered a thickening of the anterior joint capsule. Because of its orientation, its main function is to limit inversion while the foot is plantar flexed (Rasmussen, 1985). The ATL is relaxed

FIGURE 1. The joints of the ankle and foot contribute to the combination of movements that occur during gait. (Adapted from "Reid D 1992 Sports injury assessment and rehabilitation. New York: Churchill Livingstone.)



CORRESPONDENCE:
L J Hunter
Physiotherapy Department
University of the Witwatersrand
7 York Road
Parktown
2193
Tel: (011) 488-3450/2 (w)
(011) 465-4615 (h)
Fax: (011) 488-3210

FIGURE 2.1. The lateral ligament complex consisting of the anterior talofibular ligament, the calcaneofibular ligament and the posterior talofibular ligament. (Adapted from "Reid D 1992 Sports injury assessment and rehabilitation. New York: Churchill Livingstone.)

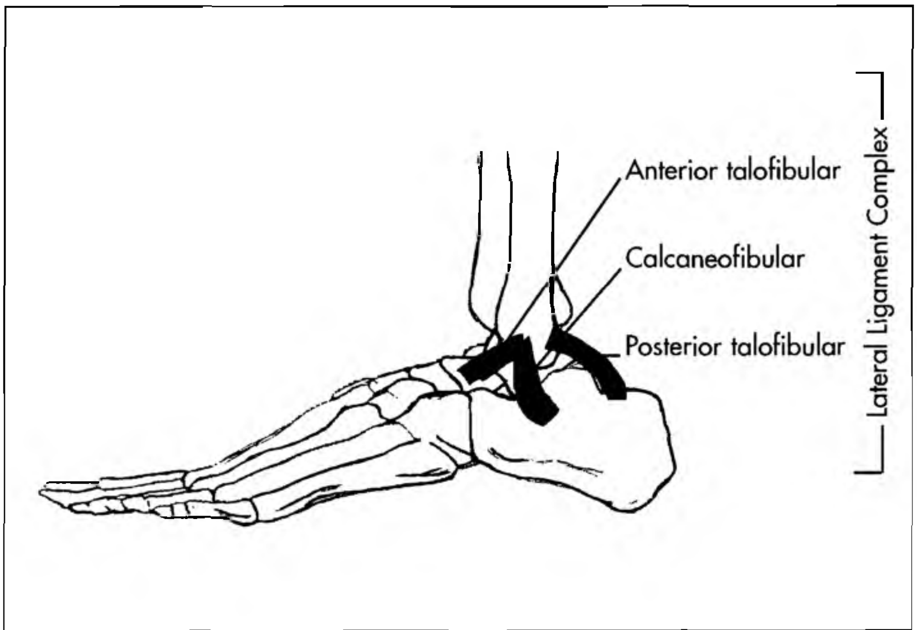
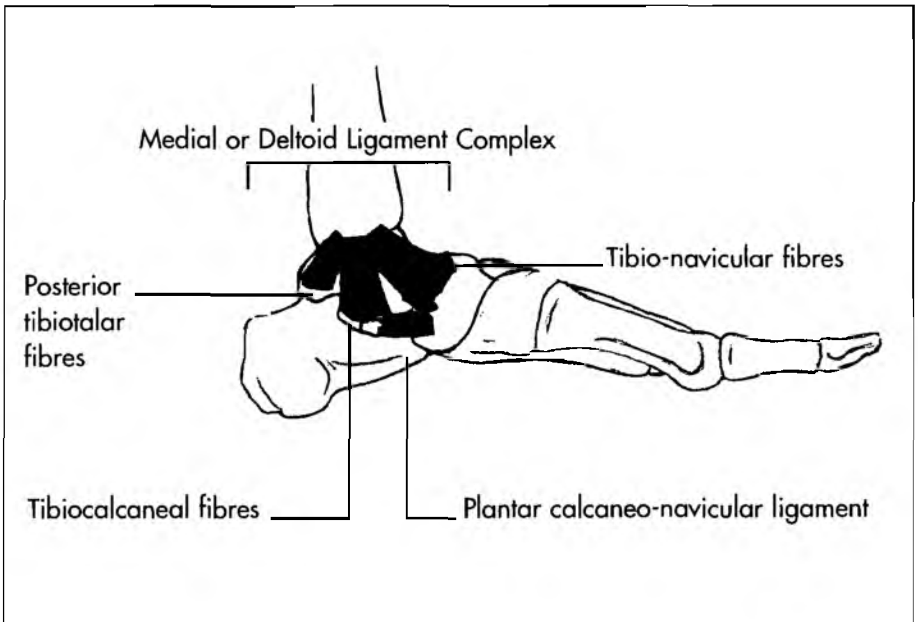


FIGURE 2.2. The medial or deltoid ligament complex consisting of the posterior tibiotalar fibres, tibiocalcaneal fibres, and tibio-navicular fibres. The plantar calcaneo-navicular ligament is depicted. (Adapted from "Reid D 1992 Sports injury assessment and rehabilitation. New York: Churchill Livingstone.)



in the neutral position of the foot. The CFL is relaxed in normal standing and does not have a major role in talotibial joint stability. It appears to limit excessive dorsiflexion and acts as a guide for the axis of subtalar joint motion (Renstrom et al, 1988). The role of the PTL is unclear and controversial (Rundle 1995, Renstrom and Konradsen, 1997), but it may be taut in dorsiflexion (Renstrom and Konradsen, 1997) or in eversion and plantar flexion (Rundle, 1995). Donatelli (1996) claims the PTL is the prime stabiliser during plantar flexion. The lateral ligament complex is therefore vulnerable to injury during dorsiflexion, plantar flexion and inversion.

Figure 2.2 shows the medial or deltoid ligament. The deltoid ligament is strong and therefore much less likely to be injured. It limits eversion of the ankle. If the deltoid ligament is damaged, an associated fracture of the lateral malleolus or a tearing of the tibiofibular syndesmosis must be excluded.

The hinge joint allows dorsi and plantar flexion with some accessory gliding. Dorsi and plantar flexion movement does not occur in one plane, but three (the triplanar movement of the ankle). This is due to the asymmetrical shape of the body of the talus, and the obliquity of the ankle joint axis (approximately 40° anterior of the frontal plane on the medial side of the ankle) (Norkin and Levangie, 1992).

The 'components' of dorsi and plantar flexion will vary, depending on whether the movement is performed in an open chain or a closed chain. In an open chain movement, i.e. the foot is free and non-weight bearing, dorsi-flexion involves abduction and eversion, and plantar flexion includes adduction and inversion. However, during a closed chain movement, i.e. weight bearing position, dorsiflexion includes adduction and inversion, and plantar flexion involves abduction and eversion. Patients with foot and ankle problems must therefore be assessed in weight-bearing and non-weight bearing positions e.g. lying and standing (Donatelli, 1996).

The most stable position of the ankle is in dorsiflexion as the talus 'locks' into the ankle mortice (the close-pack position). Conversely plantar flexion is the most unstable position.

2. Subtalar Joint

This is the articulation between the calcaneus and the talus, i.e. the rearfoot. Supination and pronation occur at the subtalar joint, in combination with accessory movements. Abduction and dorsiflexion occur with pronation, and adduction and plantar flexion with supination. This movement of the subtalar joint alters the rearfoot and forefoot angles (Heil, 1992), and allows the foot to adapt to changes in terrain. When the subtalar joint is in a neutral position, the joints of the foot, ligaments and tendons of the foot are least stressed.

This is the position in which the foot best supports the body's weight (Heil, 1992).

3. Midtarsal Joint

This joint complex consists of the calcaneocuboid and talonavicular joints, which link the subtalar joint with the forefoot. Due to the shape of the articular surfaces, the movements in the midtarsal joint occur in combination, i.e. plantar flexion and adduction occur with supination, and dorsiflexion and abduction occur with pronation (Donatelli, 1996).

NORMAL BIOMECHANICS

The normal biomechanics of the foot and ankle depend on static and dynamic components. The bones, articular surface congruity, ligaments and fascia constitute the static component. The dynamic component depends on muscle work and movement of the tarsal bones. The functions of the foot and ankle are to provide:

i. a flexible base to adapt to uneven surfaces.
ii. support for the body's weight in both static (standing) and dynamic (walking) positions.

The talocrural, subtalar and midtarsal joints work together.

During walking, the gait cycle is divided into the stance (weight bearing) and swing phases. Traditionally, the stance phase is further divided into heel strike, foot flat, midstance, heel off and toe off (Norkin and Levangie, 1992). The gait laboratory at Rancho Los Amigos Medical Center describes the subunits of gait by another set of terms. The stance phase is divided into initial contact, loading response, midstance, terminal swing and pre-swing. The swing phase is divided into initial swing, mid swing and terminal swing (Norkin and Levangie, 1992; Donatelli, 1996).

At initial contact, (See Table 1) the heel strikes the ground on its lateral aspect. The body's weight is transmitted down through the tibia and talus, which is medial to the ground reaction force. This results in adduction of the talus, which initiates and produces pronation of the foot. The pronation 'unlocks' the midtarsal joint, allowing the foot to absorb shock and adjust to the terrain.

Supination occurs during early midstance, bringing the foot to a neutral position at midstance. Supination continues during the midstance and toe-off (pre-swing) stages. This is essential as supination 'locks' the midtarsal joint making the foot into the rigid lever necessary for effective push-off.

During the swing-through phase the foot moves from plantar flexion to dorsiflexion and is relaxed.

Just before initial contact (heel strike), tibialis anterior contracts to produce dorsiflexion and this results in slight supination of the foot. At initial contact (heel strike), therefore, the foot is supinated and rigid. As the lateral aspect of the heel connects with the ground, the talus adducts, initiating pronation once more.

During gait, the muscles initiate movement, stabilize the bones and decelerate movement. This unloads the ligaments and joints (Donatelli, 1996) e.g. tibialis anterior contracts maximally immediately after heel strike to decelerate the tibia and prevent a posterior shearing force at the talocrural joint, and to control pronation of the foot.

Incorrect biomechanics will not only affect the ankle and subtalar joints, but may well result in dysfunction of, and pain in, the other joints of the lower limb and spine, especially the knee, midtarsal and forefoot joints.

ABNORMAL BIOMECHANICS

Abnormal pronation and supination result in hypermobility and hypomobility of the foot respectively (Donatelli, 1996).

The **overpronated** foot can be recognised by an everted calcaneus, medial bulging of the navicular tubercle, abduction of the forefoot relative to the rearfoot and a reduced height of the medial longitudinal arch (Donatelli, 1996). This should be assessed in standing.

Abnormal pronation results in a reduced time for resupination of the foot to occur (Paulsen, 1991). The forefoot remains unlocked and hypermobile, which reduces its ability to bear weight, and substantially reduces its effectiveness as a rigid lever for push-off. If this is the case, soft tissues break down, muscle functions change and bony remodeling may occur. These changes may produce a secondary rigid deformity, which mimics the oversupinated foot in its inability to absorb shock and adapt to changes in terrain (Donatelli, 1996). The **overpronated** foot is associated with overuse injuries. James et al (1978) established that 58% of patients with overuse injuries overpronated their feet. Chronic inflammation, as found in overuse injuries, results in large numbers of fibroblasts in the area causing increased collagen production. This increased collagen reduces joint mobility and soft tissue extensibility.

During midstance the foot is pronated and not neutral. This creates a torque in the leg, as the foot is internally rotating as the hip is pushed into external

TABLE 1. The phases of gait, comparing the Traditional and Rancho Los Amigos nomenclatures. (Adapted from "Donatelli R 1996 The biomechanics of the foot and ankle. Second Edition. Philadelphia: F A Davis Company"

	Stance Phase					Swing Phase		
Traditional	Heel strike	Foot flat	Midstance	Heel off	Toe off	Acceleration	Midswing	Deceleration
Rancho Los Amigos	Initial contact	Loading response	Midstance	Terminal swing	Pre-swing	Initial swing	Midswing	Terminal swing

rotation by the swing-through action of the opposite leg (Heil, 1992). The overpronated foot may produce knee symptoms, especially medially. The normal cephalad and external rotation movements of the fibula during weight bearing are also reduced, resulting in dysfunction of the superior tibio-fibular joint and pain (Donatelli, 1996).

The **oversupinated** foot lacks pronation, making the foot rigid. This can increase ankle lateral ligament stability problems and pain due to reduced shock absorption e.g. lateral knee pain and stress fractures.

The oversupinated foot has an inverted calcaneus, a high medial arch and forefoot plantar flexion – again, this needs to be assessed in a weight-bearing position (Donatelli, 1996).

MANAGEMENT PRINCIPLES

The general principles of managing patients with foot and ankle injuries are to:

i) identify and treat the precipitating factors (biomechanics)
ii) estimate the stage of healing of the injury
iii) determine the focus of the initial treatment
iv) control the pain and inflammation
v) initiate an appropriate tensile loading programme (Chazan, 1998)

It is essential to identify the source and contributing factors of painful inflammation of the ankle and foot to ensure proper diagnosis and treatment (Mooney and Maffey-ward, 1995).

In the acute inflammatory stage, the principles of PRICE (protection, rest, ice, compression and elevation) are used to minimise the inflammatory response and decrease the pain, enhancing the conditions for healing (Donatelli, 1996).

The contributing biomechanical factors should be addressed through the wearing of corrective footwear or foot orthoses, as well as appropriate mobilisation and strengthening (Heil, 1992). External cushioning, cupping or taping of the heel can improve shock absorbency and allow early weight bearing (Schrier, 1995). Increased strength and flexibility of the posterior calf muscles may decrease weight-bearing forces, preventing excessive pronation at the subtalar joint. The intrinsic foot muscles should also be strengthened. If there are any signs of neural tissue involvement, techniques should be used to increase neural mobility as described by Butler (1991).

Patient education and proprioception exercises should be included through all stages of healing.

The incidence of re-injury is decreased with the restoration of normal biomechanics of the foot and ankle. Restoration of function includes sequential loading of the tendons and ligaments; returning the normal range of motion; flexibility and muscle strengthening; proprioceptive retraining; endurance training and cardiovascular fitness.

The healing process can take months. To achieve successful rehabilitation, the patient has to become involved and responsible. This can only be achieved by education and motivation of the patient.

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