Biomechanics of the ankle

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Abstract

This paper provides an introduction to the biomechanics of the ankle, introducing the bony anatomy involved in motion of the foot and ankle. The complexity of the ankle anatomy has a significant influence on the biomechanical performance of the joint, and this paper discusses the motions of the ankle joint complex, and the joint at which it is proposed they occur. It provides insight into the ligaments that are critical to the stability and function of the ankle joint. It describes the movements involved in a normal gait cycle, and also highlights how these may change as a result of surgical intervention such as total joint replacement or fusion.

Keywords ankle biomechanics; subtalar joint; talocrural joint; tibiotalar joint

Introduction

The ankle joint complex is comprised of the lower leg and the foot and forms the kinetic linkage allowing the lower limb to interact with the ground, a key requirement for gait and other activities of daily living. Despite bearing high compressive and shear forces during gait, the ankle's bony and ligamentous structure enables it to function with a high degree of stability, and compared with other joints such as the hip or knee, it appears far less susceptible to degenerative processes such as osteoarthritis, unless associated with prior trauma. This paper will highlight key anatomical bony structures and soft tissues that form the ankle joint complex and will further highlight how the ankle joint complex functions during walking and how pathology changes these movements.

Anatomy of the ankle

The foot and ankle is made up of the twenty-six individual bones of the foot, together with the long-bones of the lower limb to form a total of thirty-three joints.[1] Although frequently referred to as the 'ankle joint', there are a number of articulations which facilitate motion of the foot. The ankle joint complex is made up of the talocalcaneal (subtalar), tibiotalar (talocrural) and transverse-tarsal (talocalcaneonavicular) joint.

The subtalar joint

The calcaneus is the largest, strongest and most posterior bone of the foot, providing attachment for the Achilles tendon. It is located inferiorly to the talus, and forms a triplanar, uniaxial joint with the talus.[2] The talus rests on the anterior portion of the calcaneus. The two similarly articulated facets of the anterior talocalcaneal joint on the inferior aspect of the talus are convex, and on the superior aspect of the calcaneus are concave, while the facets for articulation of the posterior talocalcaneal joint on the inferior aspect of the talus are concave, and on the superior aspect of the calcaneus are convex. This geometry allows inversion and eversion of the ankle, and whilst other motion is permitted at this joint, most of eversion and inversion of the foot is provided here.[3] A number of ligaments form attachments between the two bony surfaces. The key linkage between the two is the interosseous talocalcaneal ligament, a strong, thick ligament that extends from the articular facets of the inferior talus to the superior surface of the calcaneus. Two further ligaments, the lateral talocalcaneal ligament and the anterior talocalcaneal ligament also contribute to the connection of this joint,[1] however these are relatively weak. The talocalcaneal joint is also supported by the calcaneofibular part of the lateral collateral ligament and the tibiocalcaneal ligament of the deltoid. Furthermore, the long tendons of peroneus longus, peroneus brevis, flexor hallucis longus, tibialis posterior, and flexor digitorum longus provide additional support.[4]

The tibiotalar joint (Talocrural joint)

The tibiotalar joint forms the junction between the distal tibia and fibula of the lower leg and the talus. The load-bearing aspect of this joint is the tibial-talar interface. The talus bone includes the head, neck and body, and has no direct muscle connection. The trochlea of the talus fits into the mortise formed from the distal ends of the long bones of the shin. The malleoli of the tibia and fibula act to constrain the talus, such that the joint functions as a hinge joint, and primarily contributes to the plantar- and dorsiflexion motion of the foot. However, the geometry of the joint, such as the cone-shaped trochlea surface and the oblique rotation axis do indicate it may not function simply as a hinge.[1,4] The talus is at its widest anteriorly, meaning the joint is more stable in dorsiflexion.[5] The conforming geometry of the tibiotalar joint is considered to contribute to the stability of the joint. In stance phase, the geometry of the joint alone is sufficient to provide resistance to eversion; otherwise stability is derived from the soft tissue structures.

The tibiotalar joint is a diarthrosis and is covered by a thin capsule attaching superiorly to the tibia, and the malleoli, and inferiorly to the talus. Stability is given to the joint through three groups of ligaments. The tibiofibular syndesmosis limits motion between the tibia and fibula during activities of daily living, maintaining stability between the bone ends. The syndesmosis consists of three parts – the anterior tibiofibular ligament, the posterior tibiofibular ligament and the interosseous tibiofibular joint.[1,5] The medial aspect of this ankle joint is supported by the medial collateral ligaments (or deltoid ligaments) and these are

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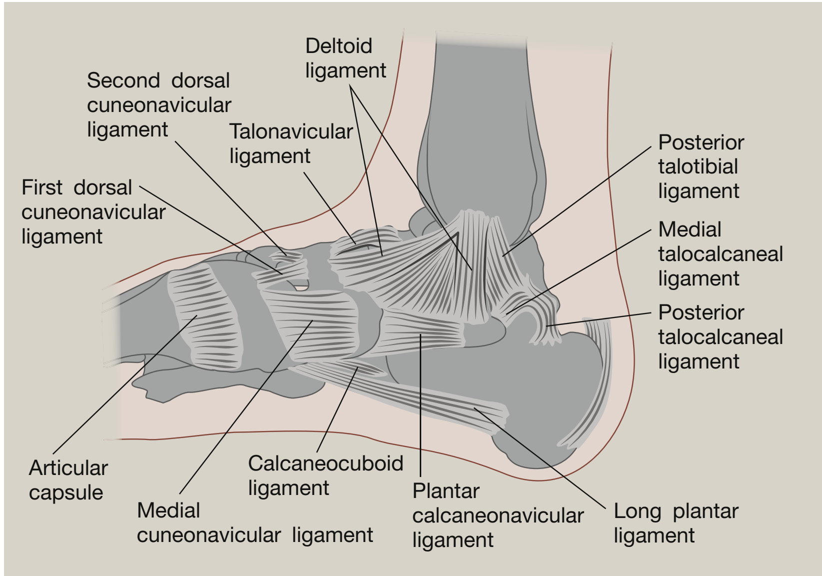

Figure 1 Medial ligaments of the tibiotalar joint. By Henry Vandyke Carter – Henry Gray (1918) Anatomy of the Human Body (See "Book" section below) Bartleby.com: Gray's Anatomy, Plate 354, Public Domain, https://commons.wikimedia.org/w/index.php?curid=537826).

key to resisting eversion motion and valgus stresses within the joint[1] (Figure 1). The deltoid ligament is fan shaped and comprises the anterior and posterior tibiotalar ligaments, the tibionavicular ligament and the tibiocalcaneal ligament. The lateral collateral ligaments reduce inversion of the joint, limiting varus stresses and reduce rotation. They consist of the anterior and posterior talofibular ligaments and the calcaneofibular ligament (Figure 2). The anterior and posterior ligaments withstand high tensile forces under plantar and dorsiflexion respectively. These ligaments provide stability to the lateral tibiotalar joint,[4–6] and are frequently damaged during inversion injuries such as ankle sprain. The calcaneofibular ligament is the only direct connective tissue between the tibiotalar and subtalar joints.

Inferior tibiofibular joint

This joint has already been referred to in the explanation of the tibiotalar joint. In some literature it is considered as a core aspect of the tibiotalar joint, but may also be considered as a distinct joint.[7] This is not a synovial articulating joint, the interosseous membrane, a fibrous tissue, connects the two distal portions of the fibula and tibia.[6] The primary function of this joint is a stabilizing role, adding stability, rather than additional motion to the foot and ankle. As previously detailed, the anterior and posterior tibiofibular ligaments and interosseous ligament maintain the joint between the tibia and fibula. The ligamentous constraint of the joint makes it highly susceptible to injury, and is often involved in ankle fracture and eversion injuries.

Transverse tarsal joint

The transverse tarsal joint (Chopart's joint) combines the junction between the talus and navicular, where anteriorly, the talar head articulates with the posterior aspect of the navicular, and the calcaneocuboid joint, the joint between the calcaneus and the cuboid. The transverse tarsal joint is considered as part of the same functional unit as the subtalar joint as they share a common axis of motion,[3,4] also contributing to eversion-inversion motion of the foot.

Muscles of the ankle

The majority of motion within the foot and ankle is produced by the twelve extrinsic muscles, which originate within the leg and insert within the foot. These muscles are contained within four compartments. The anterior compartment consists of four muscles: the tibialis anterior, the extensor digitorum longus, the extensor hallucis longus, and the peroneus tertius. The tibialis anterior and the extensor hallucis longus produce dorsiflexion and inversion of the foot. The peroneus tertius produces dorsiflexion and eversion of the foot. The extensor digitorum longus only produces dorsiflexion of the foot. The lateral compartment is composed of two muscles: the peroneus longus and the peroneus brevis, which produce plantarflexion and eversion of the foot. The posterior compartment consists of three muscles: the gastrocnemius, the soleus, and the plantaris, which contribute to plantarflexion of the foot. The deep posterior compartment is composed of three muscles: the tibialis posterior, the flexor digitorum longus, and the flexor hallucis longus, which produce plantarflexion and inversion of the foot.[1,6]

Biomechanics of the ankle

Motion of the foot and ankle

The key movement of the ankle joint complex are plantar- and dorsiflexion, occurring in the sagittal plane; ab-/adduction occurring in the transverse plane and inversion-eversion, occurring in the frontal plane[8] (Figure 3). Combinations of these motions across both the subtalar and tibiotalar joints create three-dimensional motions called supination and pronation.[5] Both terms define the position of the plantar surface of the foot