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Subtalar joint kinematics and arthroscopy: insight in the subtalar joint range of motion and aspects of subtalar joint arthroscopy

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CHAPTER 1

General introduction

Anatomic description of the subtalar joint

The foot and ankle joints work in an intricate way in the complex action of propulsion of the human body. The talocalcaneal joint, or subtalar joint, plays a significant role in the transmission of loads between the leg and the foot and the adaptation of the foot to the slope of the ground. The subtalar joint consists of multiple articulations between the talus, the calcaneus and the navicular bone. [Fig. 1] There are two independent synovial subtalar joint cavities, the anterior and posterior chambers, separated by the tarsal canal. The anterior talocalcaneal chamber is also part of the talocalcaneonavicular joint. The calcaneonavicular ligament, also known as the spring ligament, supports the floor of the anterior chamber. The dorsal surface of the spring ligament presents a fibrocartilaginous facet, on which the head of the talus partially rests. The posterior calcaneal facet is convex and the corresponding talar facet is concave. The reverse is true for the articular surfaces of the anterior chamber where the navicular and calcaneal facets are concave and provide a socket into which the convex facets of the talar neck and head fit. Anatomical variations of the number, the shape and orientation of the articular facets of the subtalar joint have been documented for both the talus and the calcaneus.¹⁻⁸ The talus is interposed between the mortise of the ankle and the underlying tarsal bones. No muscle tendons originate from or insert to the talus. The calf muscles insert through the Achilles tendon on the dorsal aspect of the calcaneal bone. On the medial side of the calcaneal tuberosity the plantaris tendon inserts. The muscles that originate from the calcaneus are the extensor and flexor digitorum brevis, the abductor hallucis and the abductor digiti minimi muscles. The complex geometry of the subtalar joint articulations provides substantial intrinsic stability for the joint. Extrinsic stability results from the joint capsule and the numerous ligaments that surround the subtalar joint. The lateral ligamentous support of the subtalar joint consists of a superficial, intermediate and deep layer.⁹⁻¹¹ The superficial layer comprises the lateral talocalcaneal ligament, the lateral root of the inferior extensor retinaculum and the calcaneofibular ligament. The intermediate layer is formed by the intermediate root of the inferior extensor retinaculum and the cervical ligament. Finally, the deep layer consists of the medial root of the inferior extensor retinaculum and the interosseous ligament in the tarsal canal. [Fig. 2] On the medial side of the subtalar joint, the deep and superficial layer of the medial collateral ligament (including the medial talocalcaneal ligament) provide secondary stability to the subtalar joint. [Fig. 3] In addition, stability of the subtalar joint is provided by forces from the muscles that span the subtalar joint.

Subtalar joint motion

The main function of the subtalar joint is to adapt the foot to the slope of the ground and to facilitate internal and external rotation of the lower leg during the stance phase of gait.¹²⁻¹⁴ To achieve this, the subtalar joint allows for supination and pronation of the foot to occur. Subtalar joint supination is defined as the combined triplanar motion of hindfoot inversion, adduction of the foot and ankle joint plantarflexion. The combined triplanar motion of subtalar joint pronation includes hindfoot eversion, foot abduction and ankle joint dorsiflexion. [Fig. 4] Many attempts have been made to determine the position and orientation of the subtalar joint axis for motions between the talus and calcaneus. Early in-vitro studies used cadaveric ankle and foot specimens for assessment of the anatomical location and angulation of the subtalar joint axis relative to the anatomic planes.^{13,15-18} Pins were introduced in the bones and the relative motion occurring between the bones was analysed by holding one bone stationary and observing the path travelled by the other bone. Other studies used the tactile, visual, or goniometric assessment of the subtalar joint axis.¹⁹⁻²² Authors agreed on the average resultant subtalar joint axis to run in an oblique infero-postero-lateral to supero-antero-medial direction.^{15,16,18,23-25} This resultant subtalar joint axis deviated from the sagittal plane by a mean of 23 degrees (medial angulation) and from the transverse plane by a mean inclination of 42 degrees (upward tilt).^{15,16,24,25} However, considerable variation was found for the position and direction of the subtalar joint axis between the subjects in these studies. Detailed analysis of the movements of the talus and calcaneus during weight-bearing supination and pronation of the foot using roentgen stereophotogrammetric analysis (RSA) in cadaveric specimens and healthy volunteers confirmed that subtalar motion takes place around an axis of which the position and orientation change during joint motion.^{14,22,26} Van Langelaan studied 10 cadaveric specimens using RSA and his results appear to suggest a medially and superiorly directed change in axis position as the subtalar joint supinates from a pronated position.²⁶ The main explanation for the variable subtalar joint axis position and orientation is that changes in the curvature of an articular surface produce a variety of centres of rotation during joint motion.²⁵ Joint motion involving rotation combined with translation occurs around a so-called helical or screw axis. Manter was one of the first authors to recognize that the subtalar joint had a helical axis and calculated that for 10 degrees of rotation around the axis, the talus translated 1.5 mm along the subtalar joint axis.¹⁵ Other authors found no evidence of translation along the rotation axis of the subtalar joint.^{16,21,27}

The assessment of the amount of motion of the foot and ankle joints during walking or standing or with the ankle and foot unconstrained has challenged numerous investigators.²⁸⁻⁴⁰ In clinical practice, the range of subtalar joint motion is usually assessed by measuring the range of supination and pronation separately. The subtalar neutral position is used as a reference position from which the ranges in the two motion directions can be measured. However, there is little consensus on the subtalar joint neutral position. In addition, as the position of the talus cannot be exactly determined visually or by palpation, the accuracy of these measurements is also questionable. Studies on calcaneal inversion and eversion measurements showed low to moderate interrater reliability.⁴¹⁻⁴³ The subtalar joint range of motion should be calculated as the total amount of rotation around the subtalar joint axis. As the subtalar joint axis is not parallel to any of the anatomical planes, measuring heel inversion and eversion relative to the lower leg in the frontal plane is only indicative of the range of subtalar joint motion.⁴³⁻⁴⁵ With the introduction of computed tomography (CT) and magnetic resonance imaging (MRI) new imaging tools have become available to study ankle and hindfoot joint motion in-vivo in a less invasive fashion.⁴⁶⁻⁴⁹ In general, these studies were able to confirm the results of the early cadaveric studies on ankle and subtalar joint motion and also confirmed the concept of the moving subtalar joint axis. However, the outcomes of most reports are difficult to compare as the type of motion that was studied varied and different coordinate systems were used. More specific, most reports investigated stepwise input motion of the subtalar joint and the total range of subtalar joint motion was not assessed. Insight in subtalar joint motion is relevant for the understanding, the diagnosis and the classification of subtalar joint pathology and surgical procedures. Secondly, it is important for the development of biomechanical models of the ankle and foot, the design of subtalar joint implants and the design of footwear and orthotic devices. Therefore, the total range of subtalar joint motion needs further investigation.

Subtalar joint injuries

Subtalar joint injuries can lead to a stiff and painful joint resulting in limited mobility. However, the true incidence of subtalar joint injuries seen in the emergency department is not known. Physical examination of the subtalar joint in the acute phase of injury is generally painful and difficult. Furthermore, no specific diagnostic tests exist for acute subtalar joint injury. Subtalar joint injuries range from mild sprains of the lateral ligaments to intra-articular subtalar fracture dislocations with comminution. The mechanism of injury in subtalar sprains is described as an inversion force applied to the foot while the ankle is in dorsiflexion. In this

position, the lateral ligaments that mainly stabilize the subtalar joint (i.e. the talocalcaneal interosseous ligament, lateral talocalcaneal ligament, calcaneofibular ligament, cervical ligament) are stressed causing disruption and subsequent subtalar joint instability.⁵⁰⁻⁵⁴ In the acute phase of a lateral ankle or subtalar joint sprain, there is seldom an indication for surgical intervention.⁵⁵⁻⁵⁷ The conservative treatment of these injuries generally includes rest, ice, compression and elevation (RICE) in combination with physical therapy for strengthening of the peroneal muscles and improving proprioception of the ankle and hindfoot. Subtalar joint injuries have been associated with other injuries of the lower extremity. The subtalar joint instability is thought to occur in 10 – 25% of the patients suffering from lateral ankle instability.⁵⁸⁻⁶⁴ Subtalar joint instability has received increasing attention in the literature as a cause for chronic functional ankle and hindfoot instability.^{63,65-67} Symptomatic chronic subtalar joint instability can be treated either with a tendon transfer or tenodesis procedure, or with an anatomic ligament reconstruction depending on the extent of damage to the ligaments.^{55,56,60} Because subtalar ligamentous injury is often associated with ankle ligamentous injury, most of the surgical procedures for subtalar instability are aimed at resolving both. Several diagnostic techniques have been proposed in the assessment of chronic subtalar joint instability including arthrography, stress radiography and computed tomography.⁶⁸⁻⁷⁶ However, most techniques are cumbersome to use and the lack of standardized values make the results difficult to interpret. Therefore, the range of subtalar joint motion has to be quantified to create a database of standardized values for assessment of subtalar joint motion in healthy and symptomatic individuals.

Adult acquired flatfoot deformity is a problem frequently seen in adults and may lead to a painful foot. The normal vault structure of the foot is considered to be built up essentially by two longitudinal arch systems; a short and lower lateral arch and a long and higher medial arch.⁷⁷ A variety of foot problems can lead to adult acquired flatfoot deformity, a condition that results in a fallen medial arch with the foot pointed outward. The most common cause for the adult acquired flatfoot is incompetence of the posterior tibial tendon (PTT) and the supporting medial ligaments.⁷⁸ The treatment of the adult acquired flatfoot depends on the symptoms and the stage of the flatfoot deformity. Surgical treatment for painful flexible adult acquired flatfoot deformity resulting from PTT insufficiency usually includes a flexor digitorum longus (FDL) tendon transfer in combination with a bony procedure. The rationale for the lateral column lengthening procedure is to restore the medial longitudinal arch by realigning the foot around the talus, thereby correcting the hindfoot valgus and neutralizing

the forefoot abduction.^{78,79} Evans described an anterolateral open wedge calcaneal distraction osteotomy (ACDO) just proximal to the calcaneocuboid joint for lateral column lengthening.⁸⁰ Another surgical option for lateral column lengthening is a calcaneocuboid joint distraction arthrodesis (CCDA). Both techniques showed significant improvement in terms of the postoperative radiographic parameters of the foot and the American Orthopaedic Foot and Ankle Society (AOFAS) clinical scores.⁸¹⁻⁸⁹ Following CCDA for flexible flatfoot deformity, one might expect a decreased tarsal and thus a decreased subtalar joint range of motion. This results from an essential structural and functional feature of the tarsal joints, the interdependence of tarsal joint motion which means that the immobilization of one joint in the hindfoot limits the mobility of other joints.⁷⁷ This loss of subtalar joint motion could possibly lead to a symptomatic hindfoot. On the other hand, there also might be an effect on the subtalar joint range of motion with the ACDO procedure if the anteroposterior length of the calcaneus is increased. To our knowledge, the effect of the two different LCL procedures on the talocrural and subtalar joint ranges of motion in-vivo was not previously described. This matter should be analysed further in detail to gain insight in the surgical treatment of adult acquired flatfoot deformity.

Degeneration, inflammation, fractures and subtalar joint dislocations can eventually lead to osteoarthritic changes of the articular surfaces. Patients with degenerative, inflammatory and post-traumatic osteoarthritis of the subtalar joint have a stiff and painful joint and report difficulties with walking on uneven terrain. The diagnosis of subtalar joint osteoarthritis is usually based on the history, physical examination and plain radiographic images of the hindfoot. A chronic symptomatic osteoarthritic subtalar joint, which is unresponsive to conservative treatment may be treated with a subtalar arthrodesis in which the bones of the subtalar joint are surgically fused. The subtalar arthrodesis is commonly carried out through an open procedure. Although open subtalar joint arthrodesis is considered a routine surgical procedure in orthopaedic practice, authors have described several issues such as wound healing problems and non-union of the subtalar arthrodesis.⁹⁰⁻⁹² A detailed analysis of the open subtalar arthrodesis procedure may help to clarify these issues.

In recent years, arthroscopy for the treatment of hindfoot pathology has received increasing attention in the literature. The advantages of minimally invasive hindfoot surgery include a decrease in tissue trauma during surgery, yielding less postoperative pain, fewer wound problems such as infection or skin break down and a quicker recovery for the patient.

However, the complex anatomy of the subtalar joint makes the arthroscopic evaluation challenging. The development of small diameter arthroscopes along with precise surgical techniques has allowed arthroscopy of the subtalar joint to expand. In 1986, Parisien was the first to report preliminary clinical results of diagnostic and therapeutic arthroscopy of the posterior subtalar joint for adhesiolysis, manipulation of the subtalar joint or removal of loose chondral bodies in three cases with good results.⁹³ From then on an increasing number of reports were published on subtalar joint arthroscopy yielding good results.⁹⁴⁻⁹⁶ In 1998, Jerosch reported excellent results in 3 patients with osteoarthritis of the subtalar joint treated with an arthroscopic subtalar arthrodesis using lateral portals with the patient in the supine position.⁹⁷ In 2000, a 2-portal posterior portal approach for hindfoot arthroscopy with the patient in the prone position was introduced.⁹⁸ The posterior approach using separate posterolateral and posteromedial portals has clear advantages. It gives very good access to the posterior ankle compartment, the subtalar joint, and the extra-articular structures such as the os trigonum.⁹⁸ Furthermore, it seems more accurate to assess hindfoot alignment with the patient in the prone position in case of an arthroscopic subtalar arthrodesis. The introduction of talocalcaneal lag screws is also convenient with the patient in the prone position. The posterior approach was successfully used for arthroscopic subtalar arthrodesis in a series of patients with post-traumatic osteoarthritis.⁹⁹ A painful talocalcaneal coalition is another recognized indication for talocalcaneal arthrodesis in skeletally mature patients.^{100,101} The presence of a talocalcaneal coalition presents a technical challenge since the talocalcaneal bar only allows limited opening up of the subtalar joint during surgery. As standard arthroscopic techniques for subtalar arthrodesis do not provide means of opening up the joint, they are difficult to use in patients with limited subtalar joint space. The development of an arthroscopic technique for subtalar joint arthrodesis could therefore be beneficial for patients with a talocalcaneal coalition.

Aim of thesis

The aim of this thesis is firstly to obtain insight in the normal subtalar joint range of motion. Secondly, to provide knowledge of the subtalar joint range of motion following two different surgical procedures for flexible adult acquired flatfoot deformity. And finally, to enhance endoscopic treatment options for subtalar joint pathology. More specific, the purpose of this thesis is: (1) to investigate the accuracy of a computed tomography based bone contour segmentation and registration method (CT-BCM) to measure bone to bone motion in the hindfoot and compare CT-BCM to the current gold standard roentgen stereophotogrammetric

analysis (RSA), (2) to analyse the normal ranges of motion of the subtalar joint in healthy individuals using the CT-BCM technique, (3) to describe the difference between two surgical techniques for lateral column lengthening in patients with adult flatfoot deformity with regard to postoperative ankle and subtalar joint ranges of motion, (4) to investigate the problems with the surgical techniques of subtalar joint arthrodesis by reviewing the literature that is available and provide possible solutions, (5) to provide an overview of the aspects of the surgical technique for subtalar joint arthroscopy, and (6) to report on the technique and results of the arthroscopic subtalar arthrodesis technique in patients with a symptomatic talocalcaneal coalition using the 2-portal posterior approach with an accessory sinus tarsi portal.

Outline of the chapters

As stated earlier, there is no accurate technique for in-vivo assessment of the normal subtalar joint range of motion. Our group has developed a bone contour segmentation and registration technique using CT images (CT-BCM), to measure relative bone to bone motion in-vivo under non-weightbearing circumstances. The purpose of this CT-based technique is to acquire data of the position and the orientation of the ankle and hindfoot bones in the CT images in an accurate and time efficient way. Therefore, the CT-BCM technique has to be compared to the current gold standard technique, the roentgen stereophotogrammetric analysis (RSA). Validation of the CT-BCM technique by assessment of its accuracy is reported in **Chapter 2**. The hypothesis was that CT-BCM was at least as accurate as the RSA method. There are no studies available that have measured the range of motion of the subtalar joint with an accurate technique in-vivo. In **Chapter 3**, the normal ranges of motion of the subtalar joint are studied in 20 healthy individuals using the CT-BCM technique.

Two frequently used surgical techniques for stage two adult acquired flatfoot deformity not responding to conservative treatment combine the augmentation of the posterior tibial tendon with a realignment osteotomy. The aim of these procedures is to help restore the normal architecture of the foot. Both the calcaneocuboid distraction arthrodesis (CCDA) and the anterior calcaneal open wedge osteotomy (ACDO) procedure result in lengthening of the lateral bony column of the foot. The ACDO procedure was compared to the CCDA for lateral column lengthening in patients with adult acquired flatfoot deformity in terms of postoperative ranges of motion of the ankle and subtalar joint in **Chapter 4**. Our hypothesis was that the ACDO is the preferred procedure in these patients as the CCDA has the possible disadvantage of restricting hindfoot motion as the calcaneocuboid joint is fused. The CT-BCM method that was validated in Chapter 2 was used.

The subtalar joint arthrodesis is the treatment of choice for severe symptomatic osteoarthritis of the subtalar joint unresponsive to conservative treatment. Although subtalar joint arthrodesis is considered a routine orthopaedic surgical procedure, a number of authors have described serious peri-operative problems with this procedure. In **Chapter 5** the aspects of the different subtalar arthrodesis procedures are reviewed based on a literature study. The goal of this chapter was to present surgical pitfalls and possible solutions for problems with the subtalar arthrodesis techniques.

In recent years, there has been an increasing interest in arthroscopically assisted surgery of the subtalar joint. An overview of the indications, contraindications and different approaches for subtalar joint arthroscopy is provided in **Chapter 6**. Furthermore, the literature on arthroscopic treatment and results of sinus tarsi syndrome, os trigonum syndrome and subtalar arthrodesis is presented.

A painful talocalcaneal coalition is a recognized indication for a subtalar arthrodesis procedure in skeletally mature patients. However, because of the talocalcaneal coalition the workspace in the hindfoot is reduced. The hypothesis of **Chapter 7** is that the posterior 2-portal approach to the subtalar joint could be used for arthroscopic subtalar arthrodesis in the patients with a symptomatic talocalcaneal coalition. An accessory portal at the level of the sinus tarsi is created to introduce a blunt trocar for opening up of the joint and providing more workspace for an arthroscopic subtalar arthrodesis. The results of this 3-portal technique used in three patients are also presented in Chapter 7.

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FIGURES

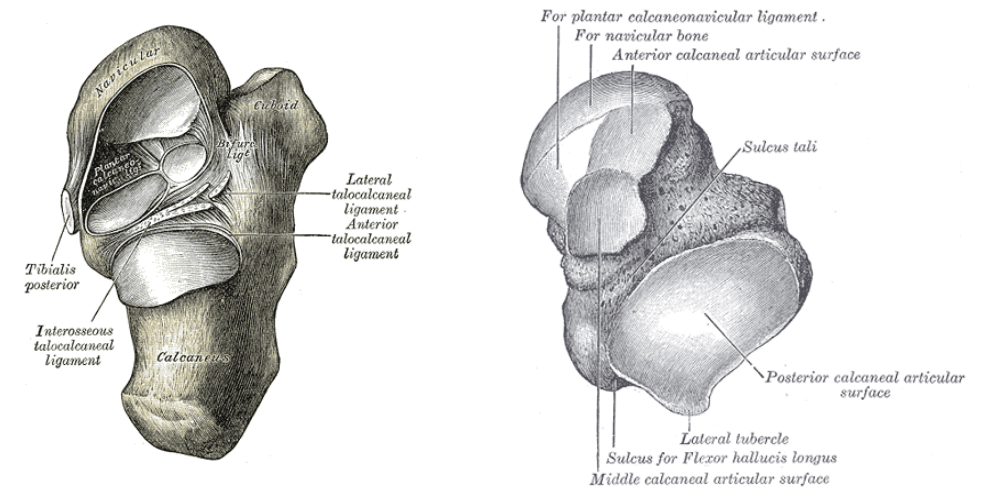


Figure 1 The talocalcaneonavicular, or subtalar joint, consists of the multiple articular surfaces between the talus, the calcaneus and the navicular bone. In this figure on the left side the upper surface of a right calcaneus is shown and the dorsal aspect of the navicular bone. On the right side a drawing of the under surface of a left talus is shown with its three corresponding calcaneal articulating surfaces of the subtalar joint.

From Gray's Anatomy of the Human Body, 1918.

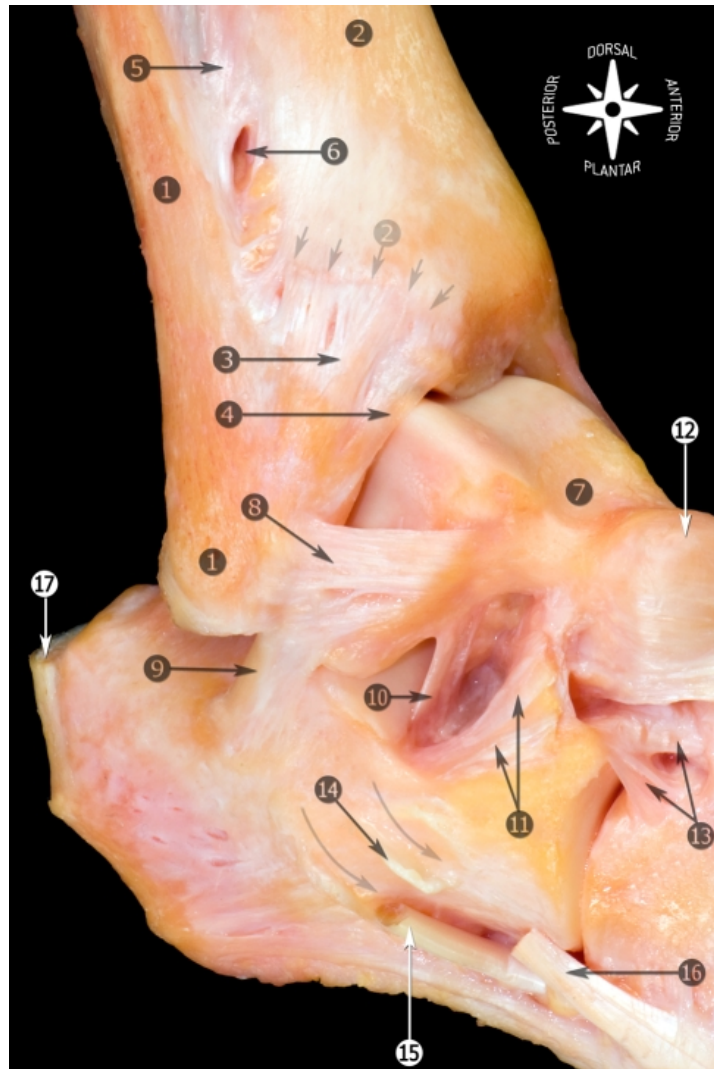


Figure 2 Anatomic dissection of the lateral region of the foot and ankle. 1 Fibula and tip of the fibula; 2 tibia (anterior tubercle with arrows); 3 anterior tibiofibular ligament; 4 distal fascicle of the tibiofibular ligament; 5 interosseous membrane; 6 foramen for the perforating branch of the peroneal artery; 7 talus; 8 anterior talofibular ligament; 9 calcaneofibular ligament; 10 talocalcaneal interosseous ligament; 11 inferior extensor retinaculum (cut); 12 talonavicular ligament; 13 bifurcate ligament; 14 peroneal tubercle (arrows showing the peroneal tendons sulcus); 15 peroneus longus tendon; 16 peroneus brevis tendon; 17 calcaneal tendon.

From Golano P, Vega J, de Leeuw PAJ, et al. *Anatomy of the ankle ligaments: a pictorial essay. Knee Surg Sports Traumatol Arthrosc* (2010) 18:557-569 (With permission)

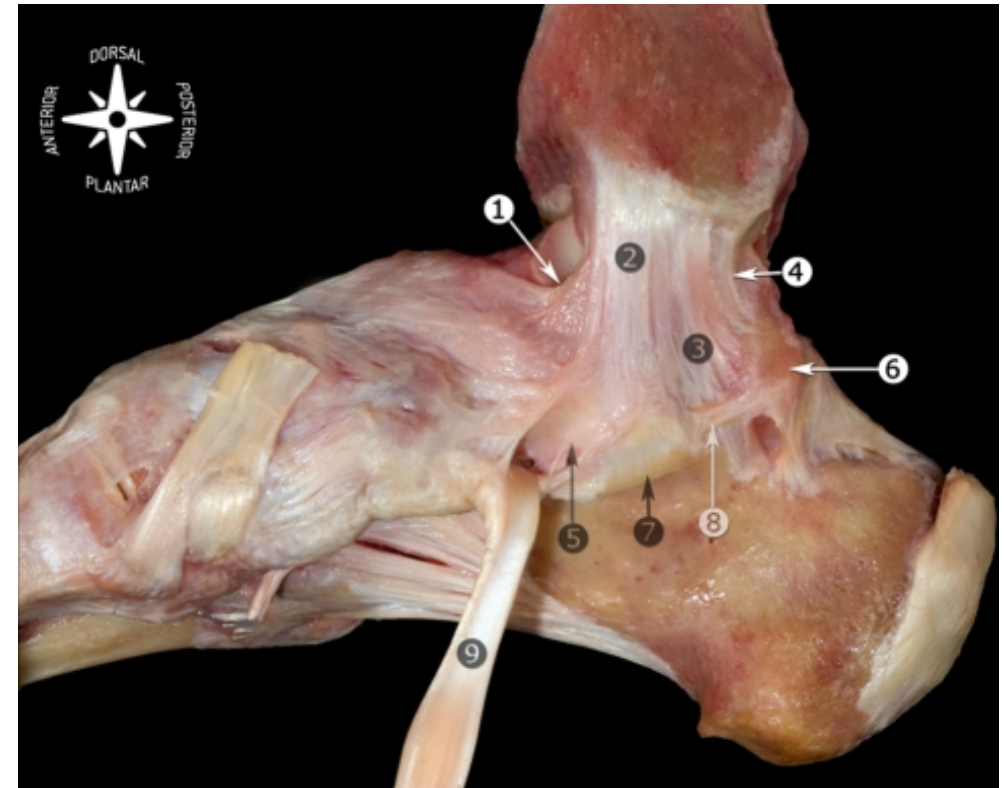


Figure 3 Medial view of the foot and ankle following anatomic dissection. 1 Tibionavicular ligament; 2 tibiospring ligament; 3 tibiocalcaneal ligament; 4 deep posterior tibiotalar ligament; 5 spring ligament complex (superomedial calcaneonavicular ligament); 6 medial talar process; 7 sustentaculum tali; 8 medial talocalcaneal ligament; 9 tibialis posterior tendon.

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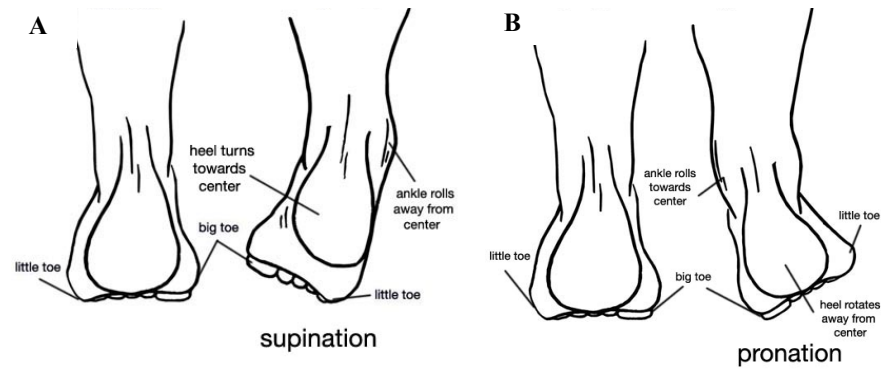


Figure 4 A) Right foot supination as seen from a posterior view. Supination is the combined triplanar motion of hindfoot inversion, adduction of the foot and ankle joint plantarflexion. **B)** The right foot is in pronation; the combined triplanar motion of hindfoot eversion, foot abduction and ankle joint dorsiflexion.

CHAPTER 2

Accuracy of a CT-based bone contour registration method to measure relative bone motions in the hindfoot

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