



The subtalar joint: a complex mechanism

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- Subtalar joint anatomy is complex and can vary significantly between individuals.
- Movement is affected by several adjacent joints, ligaments and periarticular tendons.
- The subtalar joint has gained interest from foot and ankle surgeons in recent years, but its importance in hindfoot disorders is still under debate.
- The purpose of this article is to give a general overview of the anatomy, biomechanics and radiographic assessment of the subtalar joint.
- The influence of the subtalar joint on the evolution of ankle joint osteoarthritis is additionally discussed.

Keywords: subtalar joint; hindfoot; malalignment; osteoarthritis

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Introduction

Anatomy of the subtalar joint

In a simplified way, one can divide the subtalar joint into two parts, an anterior and a posterior part. Anteriorly, the talar head is located on the anterior and middle facets of the calcaneus, forming the acetabulum pedis with the posterior surface of the navicular bone.¹ However, it is important to mention that the talar head is not only supported by the articulating surfaces of the calcaneus and the navicular bone, but also by the ‘spring’ ligament. This ligament complex plays a key role in stabilising the talar head. Insufficiency of this structure can lead to acquired flat foot deformity. Posteriorly, the concave facet of the talus lies on the convex posterior facet of the calcaneus.^{1,2} The size and shape of the three calcaneal facets vary between individuals. Both the anterior and middle facets are concave, while the posterior facet is convex.^{1,3} The posterior facet is larger compared with the middle and the

anterior facets and is separated from the other two facets by the interosseous calcaneal ligament.³⁻⁵ For the anterior and middle calcaneal facets, different anatomical variations have been described in the literature. Studies found that 42% have a combined anterior and middle facet in an ovoid form, 22% a ‘bean’ form and 36% have a complete separation.⁶ The sustentaculum tali is formed by the middle calcaneal facet (dorsal surface) and provides a sliding surface for three tendons (plantar surface): the tibialis posterior, flexor hallucis longus and flexor digitorum longus tendons.³ Subtalar joint anatomy is shown in Figure 1.

The ligaments around the subtalar joint can be distinguished as intrinsic (cervical ligament, interosseous talocalcaneal ligament) and extrinsic ligaments (calcaneo-fibular ligament, tibio-calcaneal part of the deltoid ligament).¹ Malfunction of the interosseous talocalcaneal ligament, especially in combination with failure of the anterior talofibular ligament, leads to an unphysiological anterolateral rotation of the talus during gait.⁷ As a result, subtalar joint and secondary ankle joint instability may occur.⁷ The importance of the calcaneo-fibular ligament for subtalar stabilisation is still being debated. In both cadaveric and clinical studies, where the calcaneo-fibular ligament had failed, an increase of subtalar movement and instability was observed.⁸⁻¹² In contrast, Michelson et al¹³ could not find any changes in subtalar joint stability during the stance phase, after transection of all lateral ligaments, including the calcaneo-fibular ligament. A further structure which affects the subtalar joint in terms of stability and movement is the inferior extensor retinaculum. Acting like a pulley, movement of the extensor tendons influences the subtalar stability and movement.^{3,14}

Biomechanics of the subtalar joint

Subtalar joint movement and axis of rotation are difficult to understand. Due to the convex posterior facet of the calcaneus and corresponding concave facet of the talus, subtalar joint movement can be described as rotation, translation or a combination of both.¹ Manter¹⁵ described a helical subtalar joint movement based on the helicoid

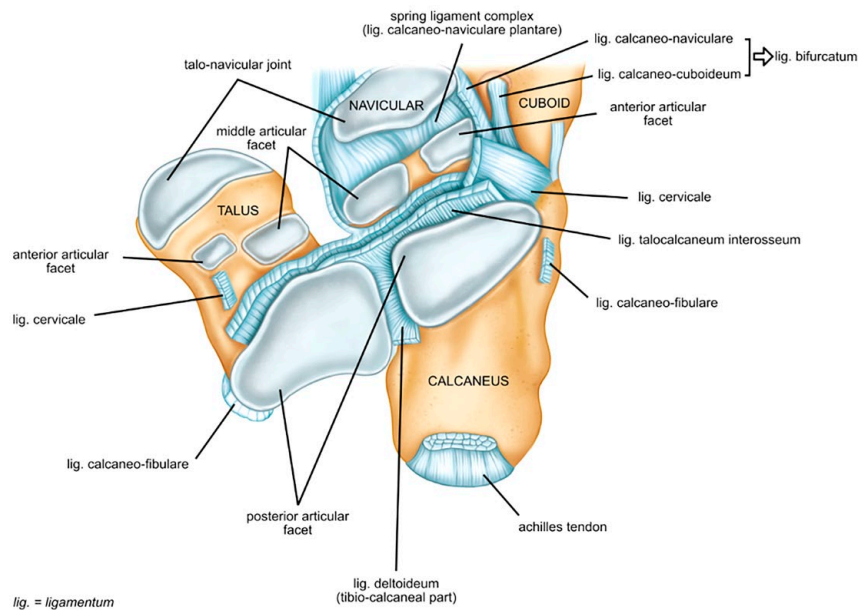


Fig. 1 Subtalar joint anatomy.

contour of the posterior calcaneal facet. According to these findings, for every 10° of rotation around the subtalar axis, the talus advances 1.5 mm. However, Inman² questioned this finding. In his cadaver study, half of the specimens showed a screw-like movement, while the other half showed translation in different directions or only in rotation. Regarding the subtalar joint axis, Inman² described an average inclination of 42° in the sagittal plane and 23° medial deviation in the axial plane when relating to the long axis of the foot.² However, the axis of the subtalar joint movement is reported to have a high variability in the literature.^{2,15-21} This may be due to several factors, one of which is the method used for its determination. While the axis was primarily determined using static radiographic images, *in vivo* studies were performed later on, followed by the use of magnetic resonance tomographic images in recent years.²¹

Clinically, subtalar joint movement is classified as inversion-eversion. The other components, e.g. anteroposterior (AP) and mediolateral translation are not assessable on clinical examination. Range of movement is in the range of 25° to 30° in inversion and 5° to 10° in eversion, respectively.^{1,2,8,16,22-27} The high variability of the range of movement found in the literature can be explained when considering the different techniques used for its determination.²⁶ Furthermore, the position of the ankle joint also affects subtalar movement, for example, dorsal extension of the ankle joint decreases subtalar movement.²⁵

Several tendons cross the subtalar joint to balance the ankle in the stance phase and during gait.³ Their function is dependent on the relation of the tendons to the subtalar

joint axis. The extensor hallucis longus, extensor digitorum longus and peroneus longus/brevis belong to the evertors. The tibialis posterior, flexor digitorum longus, flexor hallucis longus and tibialis anterior are considered to be invertors. The moment arm of the tendons and thus the amount of force translated by the tendons is dependent on the subtalar joint position. The tibialis posterior and the peroneus longus are the strongest invertor and evertors, respectively. Interestingly, the triceps surae has a slight inversion function while the ankle joint is in flexion/inversion and may change to an evertor when the subtalar joint is in eversion.³

Radiographic evaluation of the hindfoot

Radiographically, the subtalar joint is difficult to assess. In general, a weight-bearing AP or mortise view combined with a lateral view is sufficient to assess the foot and ankle (Fig. 2). If necessary, a dorso-plantar view should be added. This allows assessment of talo-calcaneal angle, which is enlarged in flat feet and diminished in cavus feet. In patients with chronic ankle instability, a hindfoot view (e.g. hindfoot alignment view, long axial view) should additionally be done to assess the hindfoot axis.²⁸ In contrast, stress radiographs of the ankle joint are not routinely recommended as they may cause further damage. However, intra-operative stress views of the ankle and subtalar joint may help to distinguish ankle from subtalar joint instability. For proper assessment of the subtalar joint, a Harries-Beth view, Broden view or lateral oblique axial projection can be added.²⁹



Fig. 2 Plain weight-bearing radiographs of a healthy foot and ankle: a) anteroposterior view; b) hindfoot alignment view; c) dorso-plantar view; d) lateral view.

Hindfoot alignment assessment using plain radiographic images

Cobey³⁰ introduced the hindfoot alignment view, which was modified by Saltzman and el-Khoury³¹ in 1995 (Fig. 3). For these radiographs, the patient is asked to stand on a platform, while the x-ray beam is tilted 20° downwards. The radiographic film is placed parallel to the medial border of the feet while the knees are in extension.³¹ Hindfoot alignment is assessed using the moment arm of the calcaneus. This is determined by measuring the perpendicular distance between the longitudinal mid-axis of the tibia to the lowest point of the calcaneus. Johnson et al³² modified the hindfoot alignment view in order to prevent the natural standing position of the patient. Using this technique, better interpretation of the relationship between the tibia and the calcaneus and thus the hindfoot alignment is possible. For assessment of the hindfoot, the angle between the calcaneal axis and the tibial axis was measured. Ikoma et al³³ used a modified hindfoot alignment view to assess the angle between the longitudinal axis of the tibia and the line between sustentaculum tali to the lateral-inferior end of the posterior articular surface of the calcaneus.

Another radiographic technique used for hindfoot assessment is the long axial view, where the inclination of the radiographic beam is 45° to the floor.³⁴⁻³⁶ Several

authors compared the long axial view with the hindfoot alignment view when assessing the hindfoot. Reilingh et al³⁷ assessed the reliability of both the hindfoot alignment view and the long axial view. The results of this study suggest that the long axial view is more reliable. Buck et al³⁸ investigated the influence of foot rotation on hindfoot alignment measurements using the hindfoot alignment view and the long axial view. They concluded that for hindfoot alignment measurements, the medial or lateral calcaneal contour should be preferred rather than the calcaneal axis. The long axial view was less affected by foot rotation than the hindfoot alignment view.

Tanaka et al³⁹ introduced the subtalar view in 1999. For this view, the x-ray beam is directed with a 30° downwards tilt. The position of the foot is standardised with the help of an imaginary line connecting the heel with the second metatarsal. Tanaka et al³⁹ used three inframalleolar angles for hindfoot measurements: (1) the angle between the tibial axis and a line on the surface of the posterior subtalar joint of the calcaneus; (2) the angle between the tibial axis and a line on the surface of the medial subtalar joint on the calcaneus; and (3) the angle between the tibial axis and the surface of the talus (TTS). In 2008, Hayashi et al⁴⁰ used the same radiographic technique to assess ankles suffering from primary varus osteoarthritis and added the angle between the talar dome and the posterior joint facet of the calcaneus (subtalar inclination angle). However, in this study, the TTS was measured using weight-bearing AP views. In 2012, Nosewicz et al⁴¹ determined the TTS using the mortise view. Min and Sanders⁴² assessed hindfoot alignment by determining the position of the medial process of the calcaneal tuberosity relative to the anatomical axis of the tibia using the mortise view. Hindfoot alignment measurements are summarised in Table 1.

Hindfoot alignment assessment using CT scans

CT scans can also be used to determine hindfoot alignment. Seltzer et al⁴³ first introduced the heel valgus angle in 1984 using simulated-weight-bearing CT scans. Van Berkeyk et al⁴⁴ investigated several different methods to assess the orientation of the hindfoot in patients suffering from chronic ankle instability (simulated-weight-bearing CT scans). Apostle et al⁴⁵ assessed the posterior facet of the calcaneus using three different coronal planes: the first cut went through the middle of the posterior facet; the second through the anterior; and the third through the posterior limit of the posterior facet (simulated weight-bearing CT scans).

In recent years, weight-bearing CT scans were introduced for the assessment of foot and ankle disorders. Compared with non-weight-bearing or simulated-weight-bearing CT scans, the hindfoot alignment can be determined under physiological load. Thus, the relationship between the distal tibia, talus and calcaneus can be

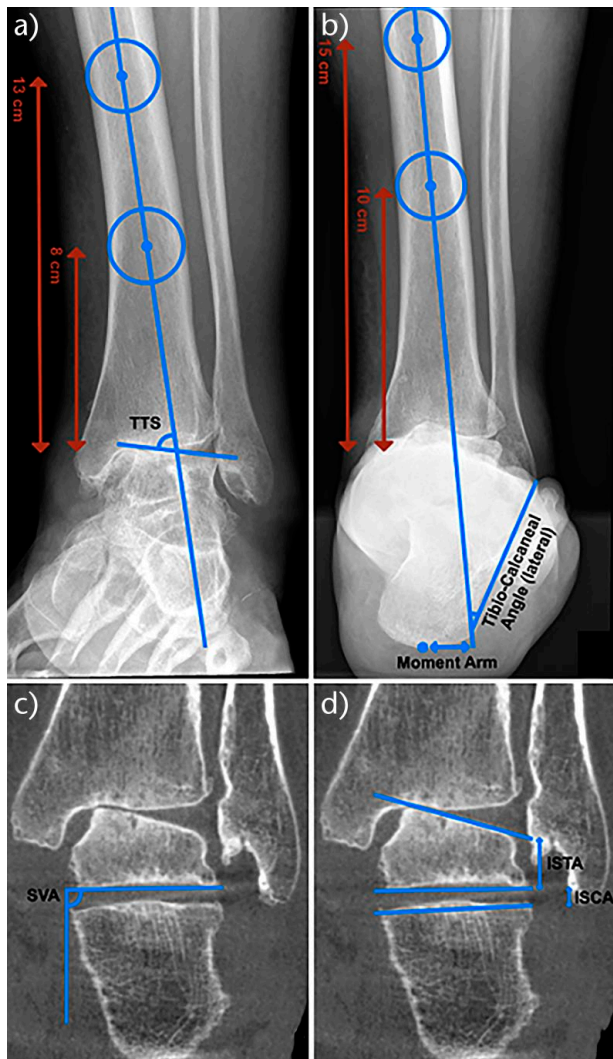


Fig. 3 Hindfoot alignment measurements using plain weight-bearing radiographs and weight-bearing CT scans: a) anteroposterior view, tibiotalar surface angle (TTS) is used to measure inclination of the talus in relation to the tibial axis; b) hindfoot alignment view, the moment arm of the calcaneus and lateral tibio-calcaneal angle are used to assess the hindfoot alignment; c) weight-bearing CT scan, subtalar vertical angle (SVA) is used to measure the subtalar joint axis relative to the ground; d) weight-bearing CT scan, infratalar-subtalar angle (ISTA) is used to assess the talar morphology and infratalar-supratalar angle (ISCA) to determine the inclination of the calcaneus in relation to the talus.

assessed in a more physiological and thus more accurate manner.^{46,47} The following studies used weight-bearing CT scans to assess hindfoot alignment in the coronal plane: Hirschmann et al⁴⁷ found significant changes in weight-bearing or non-weight-bearing CT scans regarding the hindfoot alignment. Bursens et al⁴⁸ introduced a novel hindfoot angle in varus and valgus malaligned feet. However, no control group was assessed in this study.

Richter et al⁴⁹ found more accurate angle measurement using weight-bearing CT scans compared with non-weight-bearing CT scans and plain radiographs. Probasco et al⁵⁰ assessed the posterior facet of the calcaneus using three different coronal planes: the first cut went through the middle of the posterior facet (50%), the second 25% anterior to and the third 25% posterior to the middle of the posterior facet. Colin et al⁵¹ assessed the configuration of the posterior facet of the subtalar joint in a healthy cohort and found a flat configuration in 12%. Similar to previous studies, three different coronal planes were used to determine the configuration of the posterior facet of the subtalar joint. Compared with Probasco et al,⁵⁰ the planes were chosen 5 mm anterior and 5 mm posterior to the middle plane. Krahenbuhl et al⁵² assessed the subtalar joint configuration in patients suffering from asymmetric ankle joint osteoarthritis and found a valgus configuration in patients suffering from valgus osteoarthritis and a more neutral configuration in varus ankles. Hindfoot alignment measurements using simulated and true weight-bearing CT scans are summarised in Table 2.

Impact of the subtalar joint on ankle joint osteoarthritis

In the development of ankle joint osteoarthritis, instability and alignment of the hindfoot play a key role.^{53,54} Both factors can derive from intra-articular pathologies (e.g. post-traumatic malalignment of the tibial plafond) or pathologies of adjacent structures (e.g. tendon insufficiency). The latter can be located proximal or distal to the ankle joint. Ankle sprains, being the main cause of ankle instability, affect about 1/10000 inhabitants per day.⁵⁵ Out of them, 20% develop chronic problems in the hindfoot.⁵⁶ In 25% of all cases, post-traumatic subtalar joint instability is the reason for the chronic problems. These facts underline the importance of the subtalar joint in the evolution of ankle joint osteoarthritis.

Ankle joint osteoarthritis: what impact does the subtalar joint have?

Up to 60% of patients suffering from ankle joint osteoarthritis develop a tilt of the talus in the ankle mortise over time.^{54,57} The impact of the subtalar joint on this process is still not thoroughly clear and understood. Hintermann et al^{58,59} introduced the concept of peri-talar instability, e.g. combined instability of the ankle, the subtalar and the talonavicular joint. Subtalar subluxation was interpreted because of the insufficiency of the peri-articular tendons and ligaments. However, newer studies using weight-bearing CT scans underlined the importance of the subtalar joint morphology as a factor that impacts the progression of ankle joint osteoarthritis.^{45,50,52,60,61} Recent studies suggest that in patients with a supramalleolar

Table 1. Assessment of the hindfoot alignment using plane radiographs (studies including a control group)

Study	Ankles (healthy)	Radiography technique	Hindfoot measurement	Normal value
Saltzman and el-Khoury (1995) ³¹	57	HAV	Moment arm	Straight: -3.2 mm Natural: -1.6 mm
Johnson et al 1999 ³²	10	HAV (modified Cobey view)	Tibio-calcaneal angle (middle)	5.5°
Tanaka et al (1999) ³⁹	67	HAV (modified) Subtalar view	TTS TMC TPC	6.0° 91.5° 98.8° 88.3°
Hayashi et al (2008) ⁴⁰	62	AP view Subtalar view	TTS TPC SIA	87.2° 88.3° 1.5°
Arangio et al (2009) ⁶⁵	30	HAV	Tibio-calcaneal angle (lateral)	63°
Nosewicz et al (2012) ⁴¹	30	Mortise view	TTS	89.0°
Ikoma et al (2013) ³³	46	HAV (modified)	Varus-valgus angle Tibia-hindfoot angle	76.4° 1.5°
Wang et al (2015) ⁶³	60	HAV	TTS Moment arm Tibio-calcaneal angle (lateral)	89.1° -1.2 mm -2.7°

HAV, hindfoot alignment view; AP, anteroposterior; TTS, tibio-talar surface angle; TMC, tibio-medial calcaneal surface angle; SIA, subtalar inclination angle

Table 2. Hindfoot alignment measurements using computed tomography (CT) scans (coronal plane)

Study	Ankles (healthy)	Radiography technique	Hindfoot measurement	Normal value
Seltzer et al (1984) ⁴³	10	Sim-WB CT scan	Heel valgus angle Angle of elevation of the sustentaculum tali	5.2° 18.3°
Van Bergeyk et al (2002) ⁴⁴	12	Sim-WB CT scan	Medial offset of talar head Medial calcaneal varus angle Central calcaneal varus angle Subtalar vertical angle Ankle vertical angle Talar slope	5.2° 99.3° 92.7° 85.4° 94.3° 8.9°
Apostle et al (2014) ⁴⁵	18	Sim-WB CT scan	Subtalar joint axis	-5.0°
Hirschmann et al (2013) ⁴⁷	0	WB-CT scan	Hindfoot alignment angle	n.a.
Richter et al (2014) ⁴⁹	0	WB-CT scan	Hindfoot angle	n.a.
Probasco et al (2014) ⁵⁰	18	WB-CT scan	Infтал-suptal angle (50% plane) Infтал-hor angle (50% plane) Infтал-supcal angle (50% plane)	8.6° 4.3° -1.6°
Colin et al (2014) ⁵¹	59	WB-CT scan	Subtalar vertical angle (middle plane)	100.6°
Burssens et al (2015) ⁴⁸	0	WB-CT scan	Hindfoot angle Novel hindfoot angle Talar shift Tibial inclination angle Talar tilt	n.a. n.a. n.a. n.a. n.a.
Krahenbuhl et al (2016) ⁵²	20	WB-CT scan	Subtalar vertical angle	n.a.
Cody et al (2016) ⁶⁰	17	WB-CT scan	Subtalar vertical angle Infтал-subtal angle (50% plane) Infтал-hor angle (50% plane)	98.0° 10.7° 5.7°

Sim, simulated; WB, weight-bearing

deformity, the subtalar joint may prevent a tilt of the talus and thus inhibit early deterioration of the periarticular tendons and ligaments.^{40,62-64} As a result, patients who are able to compensate supramalleolar deformities through their subtalar joint show a slower progression of ankle joint osteoarthritis. Limitations of subtalar compensation may be due to the orientation of the joint and a limited range of movement (arthritic joint, tarsal coalitions, previous fusion). If a critical amount of supramalleolar deformity is reached, inframalleolar compensation is no longer possible and the osteoarthritic process proceeds. However,

in the literature, there is only little evidence supporting this assumption and more biomechanical and clinical studies are needed to further investigate this hypothesis.

Compensatory mechanism: what does this mean?

The ability of the subtalar joint to compensate for supramalleolar deformities can be explained when considering the orientation and the geometry of the posterior facet of the calcaneus. Manter¹⁵ compared the posterior facet of a right calcaneus with a right-handed screw. If supramalleolar deformities occur, a healthy subtalar joint theoretically

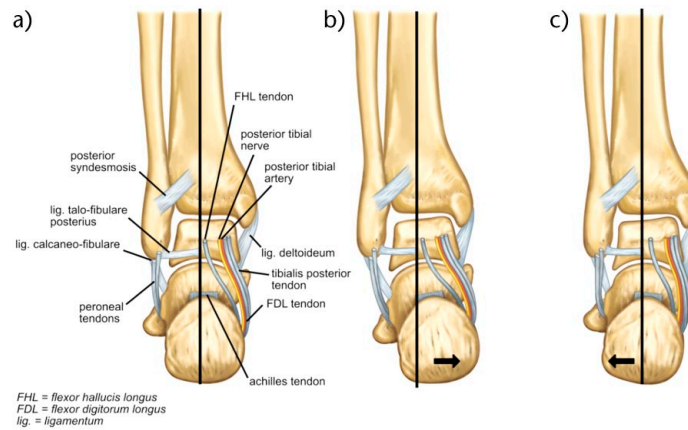


Fig. 4 Schematic illustration of subtalar compensation: a) healthy ankle; b) varus tilt of the talus without subtalar compensation; c) varus tilt of the talus with subtalar compensation.

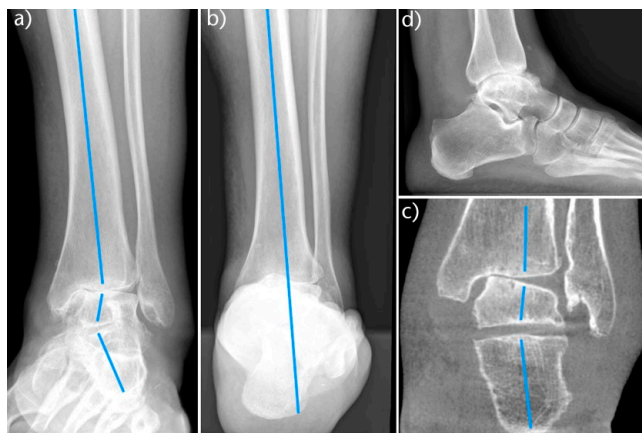


Fig 5 Example of subtalar compensation in varus ankle osteoarthritis: a) anteroposterior view; b) hindfoot alignment view, the calcaneal tuberosity is almost in the line of the tibial axis; c) weight-bearing CT scan; d) lateral view.

has the possibility to tilt in the opposite direction, compensating for the deformity (Fig. 4). Thus, the hindfoot is well balanced. This mechanism may be a reason for the long process, in terms of time, involved in the development of post-traumatic ankle joint osteoarthritis.⁵⁷ Surprisingly, Wang et al⁶³ reported higher compensation potential in patients suffering from varus ankle osteoarthritis. Range of movement in inversion is higher compared with eversion and consequently subtalar compensation should be more pronounced in the valgus ankle.²⁵ Colin et al⁵¹ showed in a healthy cohort that the subtalar joint is mostly found in a valgus position in weight-bearing conditions. This might be the explanation for better compensation in varus deformity of the ankle joint (Fig. 5).

Hayashi et al⁴⁰ first proposed a possible compensatory mechanism of the subtalar joint for supramalleolar

deformities in 2008. Using the subtalar radiograph view, they investigated the subtalar joint and its relation to the tibial axis in different stages of varus ankle osteoarthritis. They found a compensatory mechanism for patients suffering from early- to mid-stage (Takakura stage \leq 3a) of varus ankle joint osteoarthritis. This would correspond to a valgus position of the subtalar joint. Whether the ankle osteoarthritis increased to a higher stage, compensation in the subtalar joint was not possible anymore. Recently, Wang et al⁶³ published the results of the hindfoot alignment, measured using the weight-bearing hindfoot view, of 226 patients suffering from end-stage ankle joint osteoarthritis. These results support the compensatory mechanism in the subtalar joint in hindfoot malalignment.

Using weight-bearing CT scans Krahenbuhl et al⁵² found a more pronounced valgus orientation of the subtalar joint in case of valgus ankle osteoarthritis. A more neutral orientation was found for varus ankle osteoarthritis. No subdivision into different stages of ankle joint osteoarthritis was done in this study. Several studies are available investigating the hindfoot alignment in adult flatfoot deformities with subluxation of the talus using weight-bearing CT scans.^{45,50,60,61,65} Zhang et al⁶¹ investigated the configuration in a ‘virtually’ weight-bearing condition in patients suffering from stage II tibialis posterior tendon insufficiency. Cody et al⁶⁰ recently published the hindfoot alignment in a cohort of 45 patients suffering from flatfoot deformity. Apostle et al⁴⁵ and Probasco et al⁵⁰ investigated the hindfoot alignment in patients suffering from subluxation of the subtalar joint and both found a more pronounced hindfoot valgus in these patients compared with a healthy control group. Several authors also investigated the hindfoot alignment in patients with knee osteoarthritis.⁶⁶⁻⁶⁹ Interestingly, patients with valgus knee osteoarthritis tend to a varus hindfoot alignment and *vice versa*.⁶⁸

Conclusions

Subtalar joint anatomy is complex and shows a high variability between individuals. Instability and variations of the subtalar joint morphology contribute to failures in the treatment of ankle joint instability and favour the development of ankle joint osteoarthritis. Coronal plain deformities of the lower leg can, to a certain extent, be compensated by inversion and eversion of the subtalar joint. Subtalar joint compensation of ankle joint deformities may play a key role in the evolution of ankle joint osteoarthritis as 60% of the patients present with an underlying varus or valgus deformity of their hindfoot. Progression of ankle joint osteoarthritis might be decelerated if the subtalar joint configuration allows for compensation. Consequently, the assessment of the subtalar joint should be included in all patients with chronic ankle problems (e.g. instability, ankle joint osteoarthritis). However, the understanding of subtalar joint biomechanics is still limited and further biomechanical and clinical studies are necessary to gain a clearer understanding of the relationships between supramalleolar deformities and inframalleolar compensation mechanisms.

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