



Subtalar joint alignment in ankle osteoarthritis



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ABSTRACT

Background: Although it has been proposed that in mid-stage ankle osteoarthritis, the subtalar joint can compensate for deformities above the ankle joint, the evidence is weak. We thus investigated subtalar joint alignment in different stages of ankle osteoarthritis using weightbearing computed tomography (CT) scans.

Methods: The subtalar joint of 88 patients with osteoarthritis of the ankle joint and a control group of 27 healthy volunteers were assessed. Subgroups were performed according to the ankle deformity (varus and valgus) and stage of ankle joint osteoarthritis. Subtalar joint alignment was assessed on weightbearing CT scans.

Results: A more valgus subtalar joint alignment was found in patients with varus ankle osteoarthritis. No significant difference of the subtalar joint alignment was evident when comparing different stages of ankle osteoarthritis.

Conclusions: Varus ankles compensate in the subtalar joint for deformities above the ankle joint. Compensation does not correlate with the stage of ankle osteoarthritis.

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1. Introduction

The influence of supramalleolar deformities and ankle joint instability on the development of ankle joint osteoarthritis has extensively been investigated [1–5]. However, only little information is available regarding inframalleolar risk factors [1,6–9]. Hayashi et al. first introduced the concept of subtalar joint compensation for deformities above the ankle joint in patients suffering from primary varus ankle osteoarthritis [8]. They assessed the subtalar joint alignment on plain weightbearing radiographs. A compensatory mechanism, i.e. a more valgus inclination of the subtalar joint in primary varus osteoarthritis was found in mid-stage ankle osteoarthritis. They concluded that the subtalar joint has a protective function on the progression of the varus type ankle osteoarthritis. Recently, this concept was supported by the assessment of the hindfoot alignment in a cohort of 233 ankles suffering from end-stage ankle osteoarthritis. Compensation of the subtalar joint was identified in 39% of valgus and 53% of varus ankles [9].

Weightbearing computed tomography (CT) scans have increased the possibilities in the assessment of hindfoot alignment

[6,10–14]. Earlier studies using this novel technique found differences of the subtalar joint orientation in the varus and valgus type ankle osteoarthritis [6]. However, there is a lack of evidence in the literature regarding alterations and adaptations of the subtalar joint in different stages of ankle osteoarthritis. Furthermore, it remains unclear if the subtalar joint is able to protect an osteoarthritic ankle joint from further degeneration.

In this study, we investigated the subtalar joint alignment in different stages of ankle joint osteoarthritis using weightbearing CT scans. We sought to reproduce the results of Hayashi et al. i.e. a compensatory subtalar deviation in case of a varus ankle deformity [8]. We further hypothesized that subtalar joint compensation rises with an increasing deformity above or in the ankle joint (tilt of the talus in the ankle joint mortise) and decreases with presence of subtalar joint osteoarthritis.

2. Material and methods

2.1. Data source and study population

The local Ethics Committee approved the protocol prior to inclusion of subjects. Eighty-eight (88) patients suffering from ankle joint osteoarthritis with a complete radiographic evaluation (anterior to posterior weightbearing radiograph, lateral weightbearing radiograph and weightbearing CT scan) treated in our

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Table 1
Summarized demographic data.

Parameter	Controls	Varus	Valgus
Number of ankles (no)	27	58	30
Male (no; %):female (no; %)	15 (55.6):12 (44.4)	44 (75.9):14 (24.1)	17 (56.7):13 (43.3)
Side (left, no; %:right, no; %)	13 (48.1):14 (51.9)	19 (32.8):39 (67.2)	15 (50.0):15 (50.0)
Age (SD)	49.8 (13.5)	61.0 (11.6)	54.6 (17.6)
Takakura stage of ankle OA (no; %)			
Stage 1–2	–	11 (19.0)	7 (23.3)
Stage 3a	–	18 (31.0)	8 (26.7)
Stage 3b	–	10 (17.2)	7 (23.3)
Stage 4	–	19 (32.8)	8 (26.7)
Tilt of the talus in the ankle joint mortise (no; %)			
0–<4°	27 (100)	20 (34.5)	14 (46.7)
4–10°	–	21 (36.2)	9 (30.0)
>10°	–	17 (29.3)	7 (23.3)
Kellgren–Lawrence stage of ST joint OA (no; %)			
Absence of OA (stage 0)	27 (100)	24 (41.4)	13 (43.3)
Minor OA (stage 1–2)	–	27 (46.6)	12 (40.0)
Major OA (stage 3–4)	–	7 (12.0)	5 (16.7)

OA, osteoarthritis; ST, subtalar; values are presented as the mean and standard deviation.

institution between January 2013 and April 2016, were included. Exclusion criteria were presence of tarsal coalition, preexisting arthrodesis of the hind- and/or midfoot and history of any osteotomy of the hind- and/or midfoot. Varus and valgus ankles were subdivided according to the modified Takakura classification (Takakura stage 1–4), the tilt of the talus in the ankle joint mortise (0–<4°, 4–10°, >10°) and stage of subtalar joint osteoarthritis (Kellgren–Lawrence stage 0–4) [15–19]. A control group of 27 ankles was additionally assessed. Patients included as controls were selected from the foot and ankle outpatient clinic. Only patients with a forefoot disorder and neutral hindfoot alignment without history of any hindfoot disorders or surgery were included as controls. Demographic data are summarized in Table 1. The etiology of ankle joint osteoarthritis is shown in Table 2.

2.2. Imaging and measurement methods

The type of ankle joint osteoarthritis was diagnosed using plain weightbearing anterior to posterior (AP) and lateral radiographs of the ankle. The angle between the tibial shaft and the talar dome (TTS, normal values $89.0 \pm 2.6^\circ$) was measured on the medial side of AP radiographs (Fig. 1) [20]. A valgus deformity was defined as being a TTS of more than 94.2° and a varus deformity as being a TTS of less than 83.8° [21]. Additionally, the tibial articular surface angle (TAS, normal values $89.0 \pm 2.3^\circ$) was measured on the medial side of AP radiographs [22]. By calculating the difference between the TAS and the TTS, the congruency of the tibiotalar joint was determined [16]. A difference of less than 4° was defined as being a congruent joint and a difference of 4° or more as being an

incongruent joint [16]. Additionally, the modified Takakura stage of ankle joint osteoarthritis was determined on AP radiographs [17,18]. Ankles classified as Takakura stage 1 or 2 were combined in one group. On lateral radiographs of the foot, the tibial lateral surface angle (TLS, normal values $83.0 \pm 3.6^\circ$) was determined [23]. In addition, the stage of subtalar joint osteoarthritis was assessed on radiographs according to the Kellgren–Lawrence classification (stage 0 = no osteoarthritis, 1–2 = minor osteoarthritis, 3–4 = major osteoarthritis) [15,19]. The angles were measured digitally after importing the radiographs into an image processing software (Image ims Client, Version 12.23.019, Glattbrugg, Switzerland).

Weightbearing CT scans were reconstructed according to prior published protocols [6,14]. The CT scan was done using a standardized setting at our radiology department. Images were saved as Digital Imaging and Communications in Medicine (DICOM) files. A 3D Multi-Planar Reconstruction (3D-MPR) was performed using an image processing software (OsiriX MD[®], Pixmeo[®], Geneva, Switzerland). The weightbearing CT scan was started 10 cm proximal to the tibiotalar joint and terminated at the sole of the foot with the subjects standing upright and fully weightbearing on one foot (Planned Verity[®], Planned Oy[®], Helsinki, Finland; 0.2 mm slice thickness, 1 mm slice interval). A sagittal plane was set parallel to the projection of a line connecting the center of the heel and the base of the second metatarsal. Measurements were done on the coronal cut, which included the middle of the subtalar joint (middle plane). In consideration of the helical shape of the subtalar joint, additional measurements were done on a plane 5 mm anterior and posterior to the middle plane.

To investigate the subtalar joint alignment, three angles were assessed. The subtalar inclination angle (SIA) was measured to assess inframalleolar compensation for supramalleolar deformities [8]. The infital-subtal angle (ISA) was determined to assess the talar configuration [12,13,24]. The subtalar vertical angle (SVA) was assessed to investigate the orientation of the subtalar joint in relation to the ground [6,14,25]. The angles were measured digitally after importing the CT scan into an image processing software (Image ims Client, Version 12.23.019, Glattbrugg, Switzerland).

In order to assess the inter- and intra-observer reliability of our measurements, three independent investigators (one orthopaedic resident, N.K. and two scientific associates, M.D. and L.Z.) measured the TLS and SIA of 33 patients in a randomized order [26]. One

Table 2
Etiology of ankle osteoarthritis.

Etiology (no., %)	Varus ankles	Valgus ankles
Post-traumatic (fracture)	25 (43.1)	16 (53.3)
Post-traumatic (ligamentous)	24 (41.4)	9 (30.0)
Idiopathic (primary)	4 (6.9)	3 (10.0)
Septic	1 (1.7)	0 (0.0)
Hemochromatosis	2 (3.5)	1 (3.3)
Hemophilia	1 (1.7)	0 (0.0)
Rheumatoid	1 (1.7)	0 (0.0)
Others	0 (0.0)	1 (3.3)



Fig. 1. (A) Example of a healthy volunteer. The medial distal tibial angle (TAS) and tibiotalar angle (TTS) were measured on weightbearing anterior to posterior (AP) radiographs of the ankle. (B) Corresponding weightbearing computed tomography (CT) scan. The orientation of the subtalar joint to the ground was assessed using the subtalar vertical angle (SVA). (C) Plain weightbearing radiograph of a patient suffering from valgus ankle osteoarthritis. (D) Corresponding weightbearing CT scan. The subtalar inclination angle (SIA) was used to assess the inclination of the subtalar joint. (E) Plain weightbearing radiograph of a patient suffering from varus ankle osteoarthritis. (F) Corresponding weightbearing CT scan. The talar configuration was assessed using the infital-subtal angle (ISA).

investigator (N.K.) assessed the measurements three times with an interval of 2 weeks in order to determine the intra-observer reliability [26]. The assessment of the TTS, TAS, ISA and SVA was shown to be reliable in previous studies [6,13,20,22].

2.3. Statistical analysis

All measurements are expressed as mean \pm standard deviation (SD). A Kruskal–Wallis test followed by Dunn–Bonferroni's post-hoc comparison test was performed to test differences between the groups. The sample size chosen to determine the reliability of the TLS and SIA was based on studies by Walter et al. [26]. Minimum intra-class coefficient (ICC) was set at 0.8, and the desired ICC at 0.9. With three measurement replicates and a significance level of 0.05 with a power of 80%, a minimum of 33 samples were required. For the inter- and intra-observer reliability, the two-way random intraclass correlation coefficient (ICC 2,1) with single measurements and absolute agreement was calculated and presented with a 95% confidence interval (95% CI). Statistical significance was set as $P < 0.05$. IBM SPSS Statistics Version 22.0 (Armonk, NY, USA) was used for all statistical analyses.

3. Results

Osteoarthritic varus ankles showed significantly more valgus inclination of the subtalar joint compared to the controls (SIA middle plane, $P = 0.001$). Generally, the talar configuration was in significantly more in valgus in both, varus and valgus osteoarthritic feet when compared to the controls (ISA middle plane, $P = 0.001$ and 0.030 , respectively). The orientation of the subtalar joint compared to the ground was significantly more in valgus in the valgus osteoarthritic group and in a more neutral position in the varus osteoarthritic group (SVA middle plane, $P < 0.001$ and $= 0.008$, respectively) when compared to the controls. Results are summarized in Table 3.

From anterior to posterior, the subtalar joint inclination ($P < 0.001$), talar configuration ($P < 0.001$) and orientation of the subtalar joint to the ground ($P < 0.001$) increased significantly (Fig. 2). Thus, while the talar configuration is in a varus position on the anterior plane, it changes to a more valgus position on the middle and posterior plane. This finding was evident in the control group, varus and valgus group.

No significant difference in the subtalar joint inclination (SIA), talar configuration (ISA) or the orientation of the subtalar joint

Table 3
Comparison between varus ankles, valgus ankles and controls.

Parameter	Controls	Varus	Valgus	P-value
Plane radiographs				
Tibial articular surface angle (TAS, degrees)	88.9 (2.3)	84.4 (4.6)	94.2 (5.0)	<0.001
Tibiotalar angle (TTS, degrees)	88.9 (2.7)	76.7 (5.8)	99.7 (3.8)	<0.001
Tilt of the talus (degrees)	1.2 (0.9)	7.9 (7.1)	5.8 (5.2)	<0.001
Tibial articular surface angle (TLS, degrees)	82.4 (4.2)	81.7 (5.2)	81.5 (6.6)	0.484
Weightbearing CT scans (middle plain)				
Subtalar inclination angle (SIA, degrees)	2.2 (5.2)	8.2 (7.0)	4.4 (11.8)	0.001
Infntal-subtal angle (ISA, degrees)	2.6 (6.2)	9.2 (7.4)	8.2 (16.2)	0.002
Subtalar vertical angle (SVA, degrees)	94.6 (7.3)	88.3 (7.2)	109.2 (10.0)	<0.001

CT, computed tomography; values are presented as the mean and standard deviation; statistical significance was set as $P < 0.05$; italic values are statistical significant.

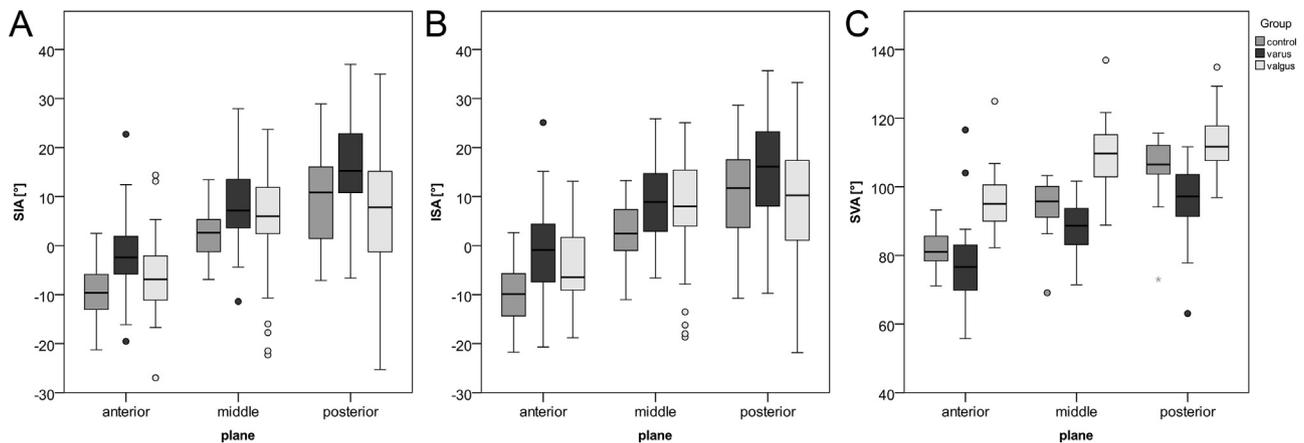


Fig. 2. Subtalar joint alignment from anterior to posterior. (A) Subtalar inclination angle (SIA). (B) Infntal-subtal angle (ISA). (C) Subtalar vertical angle (SVA).

compared to the ground (SVA) could be identified when comparing different stages of ankle joint osteoarthritis (Takakura stages) within each of the groups (varus or valgus). Furthermore, no significant difference in the subtalar joint inclination (SIA), talar configuration (ISA) or the orientation of the subtalar joint compared to the ground (SVA) could be identified when comparing the extent of the tibio-talar tilt or stage of subtalar joint

osteoarthritis (KLS) within each of the groups (varus or valgus). Results are summarized in Table 4 and Figs. 3–5.

The TLS and SIA were determined as being reliable measurements on weightbearing lateral views (plane radiographs) or coronal cuts (weightbearing CT scan) of the ankle joint. Inter-observer reliability was 0.749 (0.603–0.857) and intra-observer reliability 0.875 (0.792–0.931) for the TLS. Regarding the SIA, inter-

Table 4
Analysis of the subgroups in varus and valgus ankles (middle plain).

Subgroup	SIA		ISA		SVA	
	Varus	Valgus	Varus	Valgus	Varus	Valgus
Takakura stage of ankle OA						
Stage 1–2	6.0 (8.2)	3.3 (9.6)	7.2 (7.8)	3.3 (11.2)	87.9 (6.0)	104.4 (9.6)
Stage 3a	10.1 (6.9)	6.8 (9.6)	12.6 (6.9)	10.2 (7.1)	86.3 (6.0)	111.9 (4.5)
Stage 3b	8.5 (6.9)	−0.4 (16.5)	7.1 (7.0)	1.1 (15.3)	87.1 (12.0)	108.9 (8.9)
Stage 4	7.5 (6.4)	7.3 (11.6)	8.3 (7.3)	16.6 (23.8)	91.1 (4.8)	110.9 (14.7)
	<i>P</i> =0.586	<i>P</i> =0.797	<i>P</i> =0.150	<i>P</i> =0.328	<i>P</i> =0.169	<i>P</i> =0.360
Tilt of the talus in the ankle joint mortise						
0–<4°	6.1 (7.2)	5.8 (9.2)	6.8 (7.2)	10.8 (19.9)	89.3 (5.2)	108.6 (13.2)
4–>10°	9.3 (6.9)	5.5 (9.2)	10.0 (7.5)	7.5 (8.5)	90.2 (7.4)	108.3 (7.1)
>10°	9.3 (6.7)	0.4 (18.7)	11.1 (7.1)	3.8 (16.5)	84.7 (7.9)	111.5 (5.9)
	<i>P</i> =0.586	<i>P</i> =0.855	<i>P</i> =0.150	<i>P</i> =0.799	<i>P</i> =0.169	<i>P</i> =0.654
Kellgren–Lawrence stage of ST joint OA						
Absence of OA (stage 0)	7.4 (8.4)	6.5 (8.4)	8.1 (7.7)	6.8 (9.8)	88.4 (5.9)	108.5 (8.4)
Minor OA (stage 1–2)	8.7 (6.4)	4.4 (14.2)	10.0 (7.5)	7.3 (12.0)	88.7 (8.5)	107.9 (8.9)
Major OA (stage 3–4)	6.6 (2.8)	0.8 (13.9)	10.0 (6.2)	14.0 (34.2)	86.4 (5.8)	114.0 (16.3)
	<i>P</i> =0.597	<i>P</i> =0.553	<i>P</i> =0.579	<i>P</i> =0.921	<i>P</i> =0.637	<i>P</i> =0.785

OA, osteoarthritis; ST, subtalar; SIA, subtalar joint inclination angle; ISA, infntal-subtal angle; SVA, subtalar vertical angle; values are presented as the mean and standard deviation; statistical significance was set as $P < 0.05$.

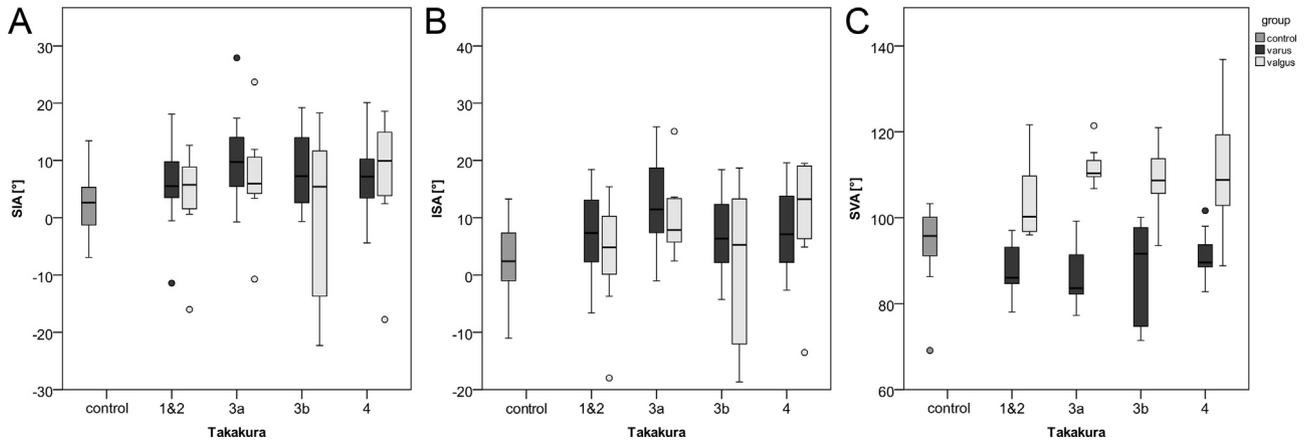


Fig. 3. Subtalar joint alignment in relation to the stage of ankle osteoarthritis. (A) Subtalar inclination angle (SIA). (B) Inftal-subtal angle (ISA). (C) Subtalar vertical angle (SVA).

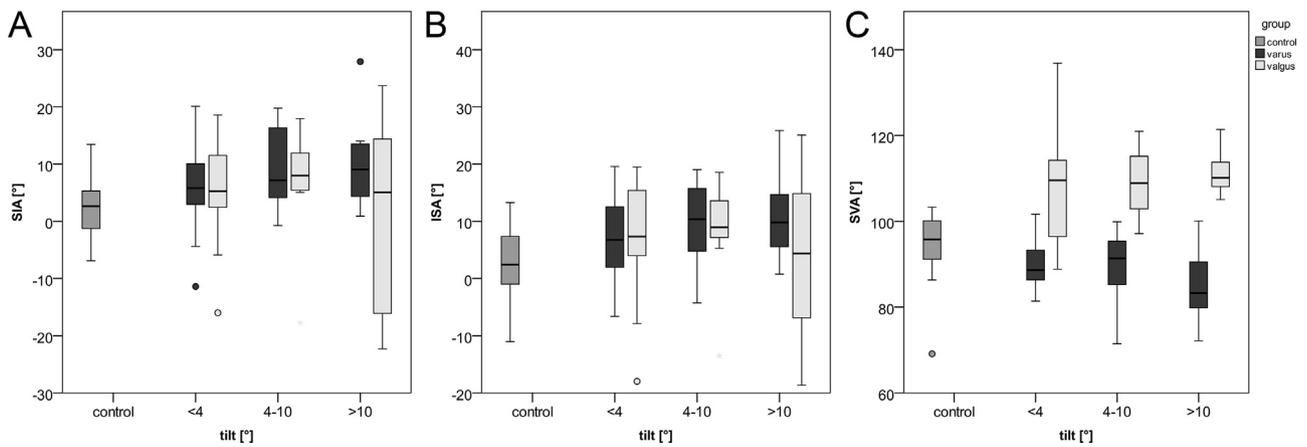


Fig. 4. Subtalar joint alignment in relation to the tilt of the talus in the ankle joint mortise. (A) Subtalar inclination angle (SIA). (B) Inftal-subtal angle (ISA). (C) Subtalar vertical angle (SVA).

observer reliability was 0.956 (0.924–0.977) and intra-observer reliability 0.944 (0.903–0.970).

4. Discussion

The complex biomechanics of the subtalar joint and its impact on degenerative changes of the ankle are poorly understood. A tilt of the talus in the ankle joint mortise can be found in up to 60% of

patients suffering from ankle joint osteoarthritis [1–3]. The subtalar joint may play a role in the progression of ankle joint osteoarthritis as it has the ability to compensate for the deformity of the ankle joint [7–9]. Hayashi et al. first introduced the idea of a compensatory mechanism of the subtalar joint in primary varus ankle osteoarthritis [8]. Recently, this concept was re-investigated in a cohort of 233 patients suffering from end-stage ankle osteoarthritis [9]. Using the hindfoot alignment view,

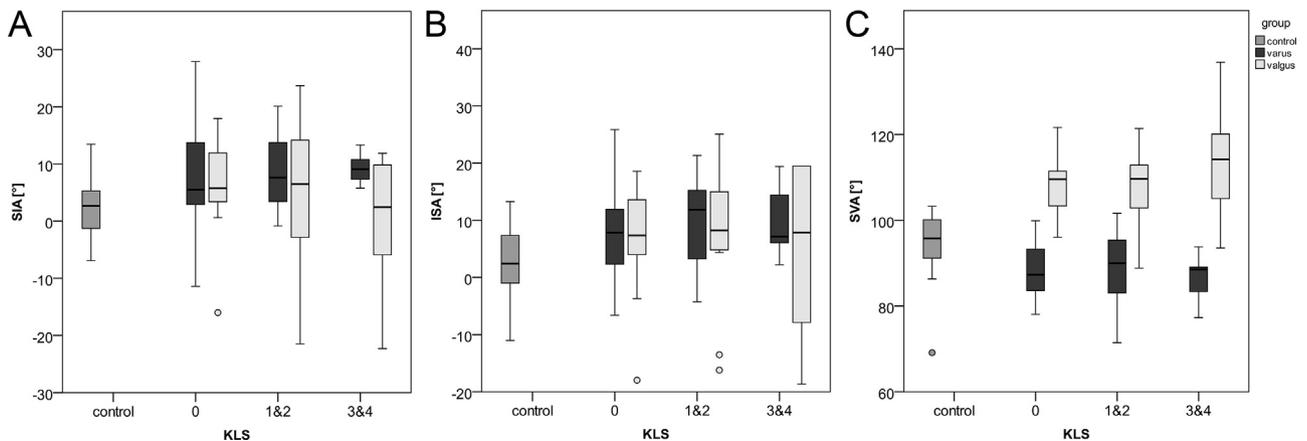


Fig. 5. Subtalar joint alignment in relation to the stage of subtalar joint osteoarthritis. Subtalar joint osteoarthritis was classified according to Kellgren–Lawrence (KLS). (A) Subtalar inclination angle (SIA). (B) Inftal-subtal angle (ISA). (C) Subtalar vertical angle (SVA).

compensation of the subtalar joint for deformities above the ankle joint, was found in 39% for valgus and 53% for varus ankles. The major limitation of both studies is that radiographic analysis was carried out on plain radiographs. This may be associated with a high risk of misinterpretation, as the subtalar joint is difficult to assess on plain radiographs.

With the introduction of weightbearing CT scans, determination of the subtalar joint alignment has become more reliable. Several studies investigated the alignment of the subtalar joint using this novel technique in adult acquired flatfoot deformities [12,13,27]. These studies showed that in the coronal plane, the subtalar joint in the adult acquired flatfoot has an increased valgus orientation compared to healthy controls [12,13]. The use of weightbearing CT scans is also advantageous for the assessment of the subtalar joint in patients suffering from ankle osteoarthritis [6,11]. A more valgus subtalar joint orientation has been found for valgus ankle osteoarthritis and a more neutral orientation for varus ankle osteoarthritis [6]. No data is available regarding the subtalar joint alignment in different stages of ankle joint osteoarthritis.

Using weightbearing CT scans, we investigated the subtalar joint inclination, the talar configuration and the orientation of the subtalar joint to the ground of patients suffering from ankle osteoarthritis when dividing them into a varus and valgus osteoarthritis group. We hypothesized that the results of earlier investigations done on plain radiographs can be confirmed [8,9]. Furthermore, we hypothesized that subtalar joint compensation rises with an increasing deformity (tilt of the talus in the ankle joint mortise) and decreases with the presence of subtalar joint osteoarthritis.

Varus ankles showed significant higher valgus inclination on the level of the subtalar joint when compared to controls. Consequently, the subtalar joint compensates for the deformity above the ankle joint. This observation was independent of the stage of ankle joint osteoarthritis, extent of the talar tilt in the ankle joint mortise and stage of subtalar joint osteoarthritis. This is in contrast to the findings of Hayashi et al., who found a higher inclination of the subtalar joint in mid-stage but not for end-stage ankle osteoarthritis [8]. We therefore question the idea that the subtalar joint compensates for an ankle deformity to a certain extent before ‘tipping’ over and accelerating the degenerative process [8,28].

Valgus ankles showed no significant difference of the subtalar joint inclination when compared to the controls. However, the talar configuration was significantly more in valgus. This observation is in accordance with earlier findings in adult acquired flatfoot deformity [12,13]. The results were independent of the stage of ankle joint osteoarthritis, extent of the talar tilt in the ankle joint mortise and stage of subtalar joint osteoarthritis. Subtalar joint compensation for an ankle deformity could not be verified.

There is a greater range of inversion than eversion at the subtalar joint [29]. Consequently, compensation of the subtalar joint for deformities above the ankle should be better in valgus ankles. However, in our study, subtalar compensation was only evident for varus ankles. An explanation for this finding might be the valgus configuration of the talus in both, varus and valgus ankles. While a valgus talar configuration compensates for an acquired varus deformity above the ankle, it worsens a valgus deformity. Despite the high range of motion for inversion, an acquired valgus deformity above the ankle combined with the given osseous valgus configuration of the talus cannot be fully compensated through subtalar motion. As a result, patients with valgus ankle osteoarthritis may become symptomatic earlier. This might explain the younger average age in the valgus osteoarthritis group in this study. The difference in age between patients suffering from varus or valgus ankle osteoarthritis has also been described in earlier studies investigating the potential of joint preserving surgery to address ankle osteoarthritis [30,31].

The talar configuration changes from anterior to posterior. While a varus configuration was evident in the most anterior part, it changes to a valgus configuration in the middle and posterior part of the subtalar joint. Because more than 50% of the subtalar joint is in a valgus position, the varus configuration in the anterior part may only have a minor influence on the compensatory mechanism in varus ankles. However, understanding the complex anatomy of the hindfoot is important when interpreting weight-bearing CT scans.

This study has several limitations. First, there is no evidence in the literature how to reconstruct weightbearing CT scans to gain reliable measurements of the hindfoot. Even though we used a general accepted protocol, severe varus or valgus malalignment may have potentially influenced our measurements. Secondly, analysis of a compensatory mechanisms measured in a static position may be limited. Thirdly, it is well known that the posterior facet of the subtalar joint has a helical shape [6,29]. In order to address the complex anatomy, measurements were done on three different coronal planes. Furthermore, one should also be aware that the subtalar joint consists of three different facets [29]. The influence of the anterior and middle facet on inversion and eversion movement of the foot is not fully understood. Finally, the influence of periarticular ligaments and tendons was not included in our model. To conclude, ankles with varus osteoarthritis compensate the supramalleolar deformity on the level of the subtalar joint, while compensation in osteoarthritic valgus ankles is limited. This finding is independent of the stage of ankle osteoarthritis, tilt of the talus in the ankle mortise or presence of subtalar joint osteoarthritis.

5. Conclusions

Compensation of the subtalar joint for an ankle deformity could only be verified for varus ankle osteoarthritis and not for valgus ankle osteoarthritis. In contrast to earlier reports which were based on plain radiographs, subtalar joint alignment had no influence on the stage of ankle osteoarthritis, extent of the tibiotalar tilt and stage of subtalar joint osteoarthritis in both, varus and valgus osteoarthritic ankles. The authors believe that the findings of this study proof that the subtalar joint may play a role in the evolution of ankle joint osteoarthritis, both as a protective compensator but also a trigger for progression. Furthermore, the findings may serve as an explanation on why some patients have failed surgery for ankle joint osteoarthritis (both, corrective osteotomies and ankle replacement).

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Conflict of interest

The authors declare no conflict of interest.

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