

Does the Subtalar Joint Compensate for Ankle Malalignment in End-stage Ankle Arthritis?

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Abstract

Background Patients with ankle arthritis often present with concomitant hindfoot deformity, which may involve the tibiotalar and subtalar joints. However, the possible compensatory mechanisms of these two mechanically linked joints are not well known.

Questions/purposes In this study we sought to (1) compare ankle and hindfoot alignment of our study cohort with end-stage ankle arthritis with that of a control group; (2) explore the frequency of compensated malalignment between the tibiotalar and subtalar joints in our study cohort; and (3) assess the intraobserver and interobserver

reliability of classification methods of hindfoot alignment used in this study.

Methods Between March 2006 and September 2013, we performed 419 ankle arthrodesis and ankle replacements (380 patients). In this study, we evaluated radiographs for 233 (56%) ankles (226 patients) which met the following inclusion criteria: (1) no prior subtalar arthrodesis; (2) no previously failed total ankle replacement or ankle arthrodesis; (3) with complete conventional radiographs (all three ankle views were required: mortise, lateral, and hindfoot alignment view). Ankle and hindfoot alignment was assessed by measurement of the medial distal tibial angle, tibial talar surface angle, talar tilting angle, tibiocalcaneal axis angle, and moment arm of calcaneus. The obtained values were compared with those observed in the control group of 60 ankles from 60 people. Only those without obvious degenerative changes of the tibiotalar and subtalar joints and without previous surgeries of the ankle or hindfoot were included in the control group. Demographic data for the patients with arthritis and the control group were comparable (sex, $p = 0.321$; age, $p = 0.087$). The frequency of compensated malalignment between the tibiotalar and subtalar joints, defined as tibiocalcaneal angle or moment arm of the calcaneus being greater or smaller than the same 95% CI statistical cutoffs from the control group, was tallied. All ankle radiographs were independently measured by two observers to determine the interobserver reliability. One of

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the observers evaluated all images twice to determine the intraobserver reliability.

Results There were differences in medial distal tibial surface angle ($86.6^\circ \pm 7.3^\circ$ [95% CI, 66.3° – 123.7°] versus $89.1^\circ \pm 2.9^\circ$ [95% CI, 83.0° – 96.3°], $p < 0.001$), tibiotalar surface angle ($84.9^\circ \pm 14.4^\circ$ [95% CI, 45.3° – 122.7°] versus $89.1^\circ \pm 2.9^\circ$ [95% CI, 83.0° – 96.3°], $p < 0.001$), talar tilting angle ($-1.7^\circ \pm 12.5^\circ$ [95% CI, -41.3° – 30.3°] versus $0.0^\circ \pm 0.0^\circ$ [95% CI, 0.0° – 0.0°], $p = 0.003$), and tibiocalcaneal axis angle ($-7.2^\circ \pm 13.1^\circ$ [95% CI, -57° – 33°] versus $-2.7^\circ \pm 5.2^\circ$ [95% CI, -13.3° – 9.0°], $p < 0.001$) between patients with ankle arthritis and the control group. Using the classification system based on the tibiocalcaneal angle, there were 62 (53%) and 22 (39%) compensated ankles in the varus and valgus groups, respectively. Using the classification system based on the moment arm of the calcaneus, there were 68 (58%) and 20 (35%) compensated ankles in the varus and valgus groups, respectively. For all conditions or methods of measurement, patients with no or mild degenerative change of the subtalar joint have a greater likelihood of compensating coronal plane deformity of the ankle with arthritis ($p < 0.001$ – $p = 0.032$). The interobserver and intraobserver reliability for all radiographic measurements was good to excellent (the correlation coefficients range from 0.820 to 0.943).

Conclusions Substantial ankle malalignment, mostly varus deformity, is common in ankles with end-stage osteoarthritis. The subtalar joint often compensates for the malaligned ankle in static weightbearing.

Level of Evidence Level III, diagnostic study.

Introduction

End-stage ankle arthritis is a debilitating condition that may lead to severe pain, functional disability, and limb deformity [3]. Glazebrook et al. [10] reported that the mental and physical disabilities caused by end-stage ankle arthritis were at least as severe as those observed in patients with end-stage hip arthritis. Patients with ankle arthritis often present with concomitant hindfoot deformity, which may involve the tibiotalar and subtalar joints [16]. The biomechanical relationship between the tibiotalar and subtalar joints is complex, as the subtalar joint may compensate the supramalleolar or intraarticular deformity of the tibiotalar joint [13–15].

To date, limited attention has been given to weight-bearing hindfoot alignment [1, 2, 4, 11, 18, 22, 24, 25, 28, 30, 31] or possible compensatory mechanisms of the

subtalar joint in patients with end-stage ankle arthritis [12, 14, 21, 23]. Similarly, classification methods of hindfoot alignment remain controversial and are based mainly on clinical visual judgment or on radiographic measurement (eg, quantification of the tibiocalcaneal axis or the hindfoot “apparent moment arm”) [8, 9, 21, 25]. Clinical visual judgment of the hindfoot alignment may be incorrect, for example, owing to compensatory mechanisms of the hindfoot mimicking normal hindfoot alignment.

In the current study we sought to (1) compare ankle and hindfoot alignment of our study cohort with end-stage ankle arthritis with that of a control group; (2) explore the frequency of compensated malalignment between the tibiotalar and subtalar joints in our study cohort; and (3) assess the intraobserver and interobserver reliability of classification methods of hindfoot alignment used in this study.

Patients and Methods

Between March 2006 and September 2013, we performed 419 ankle arthrodesis and ankle replacements (380 patients). We evaluated the radiographs of 226 patients (233 ankles, 56%) ankles who met the following inclusion criteria: (1) no prior subtalar arthrodesis; (2) no previously failed total ankle replacement or ankle arthrodesis; (3) with complete conventional radiographs (all three ankle views were required: mortise, lateral, and hindfoot alignment view). There were 118 men (121 ankles) and 108 women (112 ankles) with a mean age of 58 ± 14 years (range, 18–86 years). The self-identified ethnicities were Caucasian in 195 patients (86%), black in 10 (4%), Hispanic in 17 (8%), and Asian-Pacific Islanders in four (2%).

The patients’ files and radiographs were reviewed by two orthopaedic surgeons (BW, foot and ankle surgeon with 7 years of experience; OC, orthopaedic fellow with 5 years of experience) who did not operate on any of patients. The ankle arthritis etiology and latency time from first injury (in patients with posttraumatic ankle arthritis) or diagnosis to the index surgery were recorded. The most common etiology of end-stage ankle osteoarthritis in our patient cohort was posttraumatic (Table 1).

Weightbearing ankle radiographs including mortise, lateral, and hindfoot alignment views [25] were performed in all patients as described previously [2]. The medial distal tibial angle was measured as described previously [2, 28]. Furthermore the angle between the tibial axis and the articular surface of the talar dome was measured. The talar tilting ankle was calculated as the difference between the medial distal tibial angle and the tibiotalar surface angle. The angle between the tibial axis and calcaneal axis (defined as line parallel to the lateral calcaneal wall) was

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Table 1. Etiology of end-stage ankle arthritis in 233 ankles from 226 consecutive patients

Etiology	Number of ankles	Percentage	Latency time to arthritis (years, range)
Postankle fracture	138	59	15 ± 14 (1–54)
Postankle ligament injury	28	12	16 ± 13 (2–45)
Pes planovalgus	19	8	
Rheumatoid arthritis	17	7	
Primary osteoarthritis	13	6	
Clubfoot or other congenital foot deformity	8	3	
Nontraumatic osteochondral lesion	4	2	
Postinfectious arthritis	3	1	
Charcot-Marie-Tooth disease	2	1	
Hemophilic arthritis	1	1	
Total	233	100.0	16 ± 13 (1–54)

measured as described by Seltzer et al. [27] using the hindfoot alignment view. The moment arm of the calcaneus was measured as described by Saltzman and el-Khoury [25], positive values were defined as valgus alignment [2, 12, 21, 25]. The subtalar joint was assessed using a Kellgren-Lawrence scoring system for arthritis [19].

The control group was identified by searching for a diagnosis of soft tissue mass, nerve entrapment, or contralateral side of ankle instability in the medical database of our institution. Only patients without obvious degenerative changes of the tibiotalar and subtalar joints and without previous surgeries of the ankle or hindfoot were included. There were 27 men (27 ankles) and 33 women (33 ankles) with a mean age of 40 ± 17 years (range, 20–85 years). Demographic data in the arthritis and control groups were comparable (sex, $p = 0.321$; age, $p = 0.087$).

To analyze compensated malalignment between the tibiotalar and subtalar joints, we (BW, OC) calculated correlation between coronal ankle alignment and hindfoot alignment. Varus and valgus coronal ankle malalignment was defined as tibiotalar surface angle smaller or greater than two standard deviations (SD) from the median of that in the control group or absolute values of talar tilting angle greater than 4° [6, 21]: patients with a tibiotalar surface angle less than 83.3° or talar tilting angle less than -4° and with a tibiotalar surface angle greater than 94.9° or talar tilting angle greater than 4° were assigned to the varus and valgus groups, respectively. In either group, the hindfoot alignment (as indicated by tibiocalcaneal axis angle or moment arm of the calcaneus) was compared with the data observed in the

control group. The subtalar joints in the varus or valgus ankle group were defined as compensated when the tibiocalcaneal axis angle or moment arm of the calcaneus was within the same 95% CI statistical cutoffs from the control group. To determine the frequency of compensation between the tibiotalar and subtalar joints, we used two definitions of compensation. First, the tibiocalcaneal axis angle of the calcaneus was greater or smaller than the same 95% CI statistical cutoffs from the control group. Based on our measurements on radiographs from the control subjects, in the varus ankle group it was considered to be compensated when the tibiocalcaneal axis angle was greater than -13.1° . In the valgus ankle group it was considered to be compensated when the tibiocalcaneal axis angle was less than 7.7° . Second, the moment arm of the calcaneus was greater or smaller than the same 95% CI statistical cutoffs from the control group. Based on our measurements on radiographs from the control subjects, in the varus ankle group it was considered to be compensated when the moment arm of the calcaneus was greater than -16.6 mm. In the valgus ankle group it was considered to be compensated when the moment arm of the calcaneus was less than 14.2 mm. We used these two definitions because both were commonly used to measure subtalar joint alignment clinically. The Kellgren-Lawrence score (0–4) [19] was assessed for all subtalar joints and compared between compensated and noncompensated groups. The subtalar joint was defined as no or mild osteoarthritis when the Kellgren-Lawrence score was 0 to 2 and moderate to severe osteoarthritis when the Kellgren-Lawrence score was 3 to 4. A randomly selected 40 ankles were assessed by two orthopaedic surgeons (BW, OC) for interobserver reliability.

All ankle radiographs were independently measured by two orthopaedic surgeons (BW, OC) to determine the interobserver reliability. Neither observer participated in any of the operations. One of the observers (BW) evaluated all images twice at an interval of 4 weeks to determine the intraobserver reliability. The intraclass correlation coefficients (ICC) and their 95% CI were used to summarize the interobserver and intraobserver reliability. ICC values were interpreted as: 1.0, perfect agreement; 0.81 to 0.99 excellent agreement; 0.61 to 0.80 good agreement; 0.41 to 0.60, moderate agreement; 0.21 to 0.40 fair agreement; 0.00 to 0.20 poor agreement [7].

The Shapiro-Wilk test was performed to verify whether our data met the assumptions of a parametric test. Student's t-test and the Mann-Whitney U test were used for comparison of normally and not normally distributed data, respectively. The chi-square test was used for comparison of categorical data. The Pearson correlation coefficient was used to calculate the correlation between ankle alignment and hindfoot alignment. Data were analyzed using SPSS® Version 19.0 (SPSS Inc, Chicago, IL, USA).

Table 2. Radiographic coronal plane assessment

Parameter	Patients with end-stage ankle arthritis	Control subjects	p value
Medial distal tibial angle (°)	86.6 ± 7.3 (66.3–123.7)	89.1 ± 2.9 (83.0–96.3)	< 0.001 ^{††}
Tibiotalar surface angle (°)	84.9 ± 14.4 (45.3–122.7)	89.1 ± 2.9 (83.0–96.3)	< 0.001 [†]
Talar tilting angle (°)	-1.7 ± 12.5 (-41.3–30.3)*	0.0 ± 0.0 (0.0–0.0)	0.003 ^{††}
Tibiocalcaneal axis angle (°)	-7.2 ± 13.1 (-57–33)*	-2.7 ± 5.2 (-13.3–9.0)*	< 0.001 ^{††}
Moment arm of calcaneus (mm)	3.3 ± 19.4 (-88.7–44.4)	-1.2 ± 7.7 (-20.5–14.8)**	0.203 [†]

Data presented as mean ± SD; [†]using independent-samples t test; ^{††}using Mann-Whitney U test; *negative values in talar tilting angle and tibiocalcaneal axis angle indicated varus position; **negative values in moment arm of calcaneus indicated the lowest point of the calcaneus was medial to the bisecting axis line of the tibia.

Table 3. Coronal deformed ankles*

Varus ankles	Number	Percentage	Valgus ankles	Number	Percentage
Tibiotalar surface angle < 83.3° and talar tilting angle < -4°	66	56%	Tibiotalar surface angle > 94.9° and talar tilting angle > 4°	43	75%
Tibiotalar surface angle < 83.3° only	48	41%	Tibiotalar surface angle > 94.9° only	10	18%
Talar tilting angle < -4° only	3	3%	Talar tilting angle > 4° only	4	7%
Total	117	100%	Total	57	100%

* According to the tibiotalar surface angle cutoff values of mean ± 2 SD (95% CI) from the control group and/or absolute value of talar tilting angle.

Results

The medial distal tibial angle in patients with end-stage ankle arthritis and the control groups were 86.6° ± 7.3° (range, 66.3°–123.7°) and 89.1° ± 2.9° (range, 83.0°–96.3°) (Table 2). The inframalleolar malalignment, as measured using the moment arm of the calcaneus, was 3.3 ± 19.4 mm (range, -88.7–44.4 mm) and -1.2 ± 7.7 mm (range, -20.5–14.8 mm) in the end-stage ankle arthritis and control groups, respectively.

According to the cutoff values of mean ± 2 SD (95% CI) from the control group, there were 117 (50%) varus ankles with a tibiotalar surface angle less than 83.3° or talar tilting angle less than -4°, and 57 (25%) valgus ankles with a tibiotalar surface angle greater than 94.9° or talar tilting angle greater than 4° (Table 3). There was a strong correlation between tibiotalar surface angle and tibiocalcaneal axis angle ($r = 0.659$, $p < 0.01$) or moment arm of the calcaneus ($r = 0.797$, $p < 0.01$) (Fig. 1). Ankles with substantial deformity based on the criteria described above were further divided into subtalar compensated (Fig. 2) or noncompensated groups (Fig. 3) according to two hindfoot alignment classification systems. Using the tibiocalcaneal axis angle classification system, there were 62 (53%) and 22 (39%) compensated ankles in the varus and valgus groups, respectively. Using the moment arm of the calcaneus classification system, there were 68 (58%) and 20 (35%) compensated ankles in the varus and valgus groups, respectively. The overall Kellgren-Lawrence score

for the subtalar joint in patients with end-stage ankle arthritis was 2.8 ± 0.9. The reliability of the Kellgren-Lawrence score was 0.815 (0.587–0.917) with the significance level of 0.05 and power of 0.8. The group with subtalar compensation presented with no or mild subtalar arthritis (Kellgren-Lawrence score 0–2) more often than the group without subtalar compensation: tibiocalcaneal axis angle classification system (40% versus 22% [$p = 0.032$] in the varus group [Table 4]; 55% versus 9% [$p < 0.001$] in the valgus group [Table 5]) and moment arm of the calcaneus classification system (40% versus 20% [$p = 0.027$] in the varus group; 50% versus 14% [$p = 0.003$] in the valgus group).

The interobserver and intraobserver reliability for two observers (BW, CO) showed that ankle and hindfoot alignment in the coronal plane could be measured with good to excellent agreement for all four radiographic parameters (Table 6), ranging from 0.855 to 0.920 interobserver reliability and 0.847 to 0.943 intraobserver reliability in the group with ankle arthritis, and 0.820 to 0.910 interobserver reliability and 0.851 to 0.926 intraobserver reliability in the control group.

Discussion

Exact assessment of ankle and hindfoot alignment is crucial for surgical decision making in patients with end-stage ankle arthritis. However, there is a paucity of published

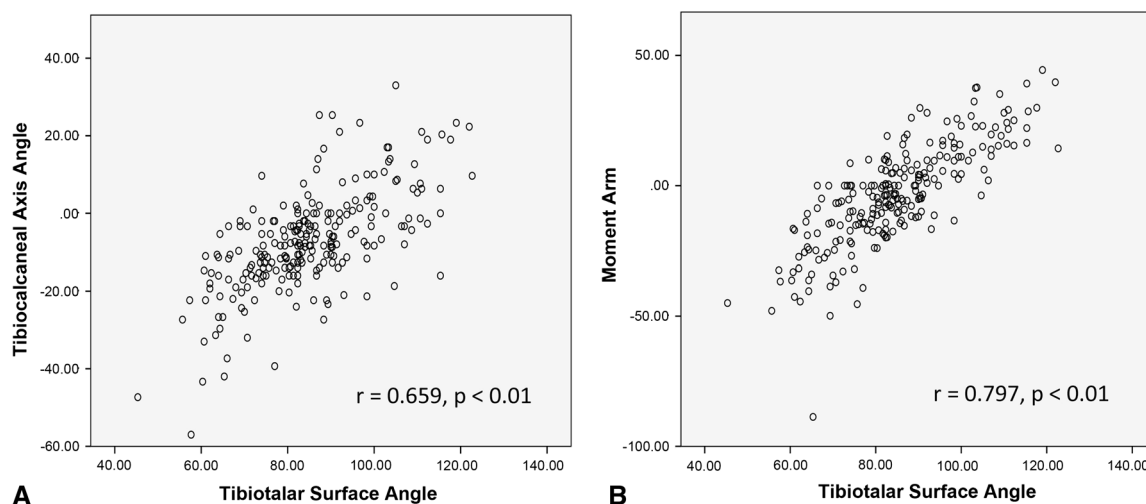


Fig. 1A–B The correlations between the (A) tibiotalar surface angle and tibiocalcaneal axis angle ($r = 0.659$, $p < 0.01$), and between the (B) tibiotalar surface angle and moment arm of the calcaneus ($r = 0.797$, $p < 0.01$) are shown.

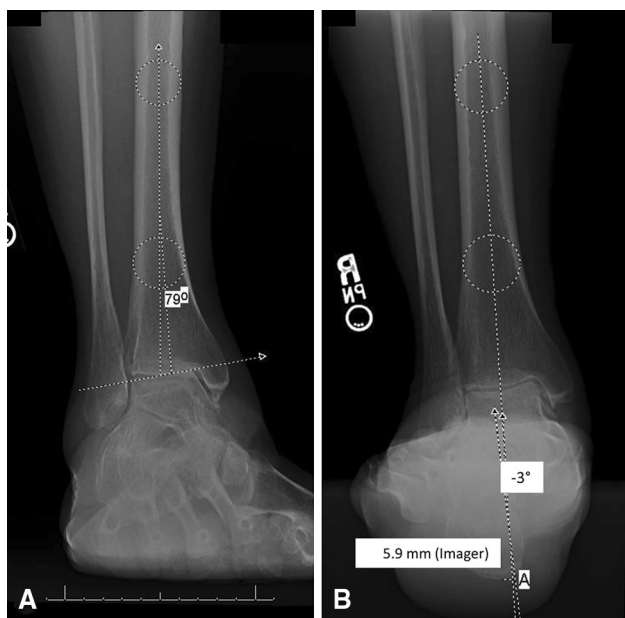


Fig. 2A–B A 61-year-old woman had subtalar compensation of the varus tilting tibiotalar joint. Her (A) tibiotalar surface angle was 79° . (B) The moment arm of the calcaneus was 5.9 mm and the tibiocalcaneal axis angle was -3° .

data describing weightbearing ankle and hindfoot alignment in patients with end-stage ankle arthritis [12, 21]. We therefore (1) compared ankle and hindfoot alignment of our study cohort with end-stage ankle arthritis with those of a control group; (2) explored the frequency of compensated malalignment between the tibiotalar and subtalar joints in our study cohort; and (3) assessed the intraobserver and interobserver reliability of classification methods of hindfoot alignment used in this study.

Our study has some limitations. First the radiographs of 233 ankles studied were selected from all 419 ankle arthrodesis and ankle replacements during the past consecutive $7\frac{1}{2}$ years. They were selected because they met the inclusion criteria mentioned above. Others were excluded mainly because of incomplete radiographs of all three views, or with prior subtalar arthrodesis, converted from a previously failed total ankle replacement, or ankle arthrodesis which made it impossible for all the necessary measurements. Second, the study was retrospective. In a prospective study, it would be possible to correlate radiograph measurements with measured physical examination findings and/or clinical issues. Third, in addition to the arthritis status of the subtalar joint, ligamentous laxity could contribute to ankle and subtalar alignment. However, based on the plain radiographs used in this study, this could not be assessed. We considered using the medical records to determine the clinical alignment and state of periarticular ankle and hindfoot ligaments, but found inconsistent reporting on this; a prospective study seems to be needed to evaluate this potentially important issue. Fourth, the control group used in this study was taken partially from a patient database at our hospital. Although these were patients with soft tissue problems or were the contralateral side of the diseased ankle and strict exclusion criteria of foot and ankle degeneration or deformity were applied, their ankles may not be the same as normal ankles with no symptoms.

We found significant differences in medial distal tibial angle, tibiotalar surface angle, talar tilting angle, and tibiocalcaneal axis angle between patients with ankle arthritis and a control group. Patients with ankle arthritis were more likely to have varus or valgus tibiotalar joint deformity and subtalar joint malalignment than were patients in the control group. In



Fig. 3A–B The radiographs of a 66-year-old man without subtalar compensation of the varus tilting tibiotalar joint are shown. (A) His tibiotalar surface angle was 82°. (B) The moment arm of the calcaneus was -18.8 mm and the tibiocalcaneal axis angle was -35° .

our study, the mean medial distal tibial angle and tibiotalar surface angle in patients with end-stage ankle arthritis were 86.6° (range, 66° – 124°) and 84.9° (range, 45° – 123°), respectively. Horisberger et al. [16] reported a mean tibiotalar surface angle of 88.8° (range, 63° – 110°) in 270 ankles with posttraumatic end-stage ankle arthritis. In total 49% of all ankles had varus malalignment including 10% of patients with varus malalignment greater than 10° , 1% had a valgus malalignment, and only 50% had a neutral alignment [16]. The medial distal tibial and tibiotalar surface angles measured in the control group were 89.1° (range, 83° – 96°). These findings are comparable to those observed by Lee et al. [21] and Barg et al. [2], who used the same measurement method on standard mortise view radiographs. The medial distal tibial angle measured in a cadaver study [17] and in a radiographic study [20] were different, at $93.3^\circ \pm 3.2^\circ$ and $92.4^\circ \pm 3.1^\circ$, respectively. Inman [17] used the angle of the anatomic axis of the tibia and the plafond of the ankle on cadaveric specimens. Knupp et al. [20] used the tibial tuberosity as the proximal reference point and performed all measurements on anteroposterior (AP) views of the ankle. Since there were no AP radiographs of the knee available for most patients, we do not have the tibiofemoral angle for our patients or control subjects. As reported by Stufkens et al. [28], measurement of the medial distal tibial angle depends on radiograph technique and could be different. Our study therefore confirms and quantifies the observations of others

who have indicated the common occurrence of coronal plane deformity compensation through the subtalar joint in patients with end-stage ankle arthritis [12, 14, 21, 23]. It adds to the literature how much the coronal plane deformity is for the tibiotalar joint and subtalar joint in patients of end-stage ankle osteoarthritis, thus guiding physicians in achieving optimal positions of these joints.

There are few studies addressing the possible role of subtalar compensation in patients with ankle arthritis. Takakura et al. [29] speculated that the subtalar joint may have some ability to compensate because it may prevent the progression of ankle arthritis. They postulated that ankle arthritis may progress after the subtalar compensatory function is lost based on their observations of a relatively small cohort with end-stage ankle arthritis [29]. Hayashi et al. [12] documented subtalar joint inclination at the various arthritis stages by measuring the angle between the tibial shaft axis and the articular surface of the posterior facet of the calcaneus. They concluded that the subtalar compensation was found especially in patients with intermediate ankle arthritis [12]. However, the articular surface of the posterior calcaneus facet is not clearly visible on the hindfoot alignment view which may result in substantial measurement bias. Hintermann et al. [13–15] reviewed anatomic and biomechanical characteristics of ankle deformities in patients with peritalar instability. Three different types of peritalar instability were characterized based on load pattern resulting from osseous deformity and/or incompetence of periarticular ligament structures: varus-valgus deformity, valgus-varus deformity, and ankle with neutral alignment and translational peritalar instability [14]. Nosewicz et al. [23] determined talar position in three radiographic planes of varus and valgus tilted ankles. Talar coronal plane alignment did not predict the talar position in the sagittal and horizontal planes indicating that the peritalar instability often results in a complex, three-dimensional malalignment of the talus [23]. Lee et al. [21] described differences in ankle and hindfoot alignment in patients with early stage ankle arthritis. They reported that the patients with a well-preserved subtalar range of motion may better compensate varus tilt of the talus in the arthritic ankles. These findings are comparable to those in our study. In our study, there were 10 patients with clubfoot and Charcot-Marie-Tooth disease, and in these patients, the subtalar joint was less likely to compensate for ankle deformity. Thus the compensation ability of the subtalar joint may be slightly greater than reported. In our patient cohort, there were more patients with no or mild subtalar arthritis in the subtalar compensated group than in the noncompensated group as graded by the Kellgren-Lawrence score. This may indicate that a healthy subtalar joint without or with only mild degenerative changes may have the ability to compensate for talar tilt attributable to ankle arthritis.

Table 4. Subtalar compensation in varus end-stage arthritic ankles

Tibiocalcaneal axis angle classification	Varus ankles	Mild or no subtalar osteoarthritis (Kellgren-Lawrence score ≤ 2)	Moment arm of the calcaneus classification	Varus ankles	Mild or no subtalar osteoarthritis (Kellgren-Lawrence score ≤ 2)
Tibiocalcaneal axis angle $> -13.1^\circ$ (compensated)	62 (53%)	25 (40.3%)	Moment arm of the calcaneus > -16.6 mm (compensated)	68 (58.1%)	27 (39.7%)
Tibiocalcaneal axis angle $\leq -13.1^\circ$ (noncompensated)	55 (47%)	12 (21.8%)	Moment arm of the calcaneus ≤ -16.6 mm (noncompensated)	49 (41.9%)	10 (20.4%)
Total	117 (100%)	$p = 0.032^\dagger$	Total	117 (100%)	$p = 0.027^\dagger$

[†] Using chi-square test for compensated versus noncompensated groups.

Table 5. Subtalar compensation in valgus end-stage arthritic ankles

Tibiocalcaneal axis angle classification	Valgus ankles	Mild or no subtalar osteoarthritis (Kellgren-Lawrence score ≤ 2)	Moment arm of the calcaneus classification	Valgus ankles	Mild or no subtalar osteoarthritis (Kellgren-Lawrence score ≤ 2)
Tibiocalcaneal axis angle $< 7.7^\circ$ (compensated)	22 (38.6%)	12 (54.6%)	Moment arm of the calcaneus < 14.2 mm (compensated)	20 (35.1%)	10 (50%)
Tibiocalcaneal axis angle $\geq 7.7^\circ$ (noncompensated)	35 (61.4%)	3 (8.6%)	Moment arm of the calcaneus ≥ 14.2 mm (noncompensated)	37 (64.9%)	5 (13.5%)
Total	57 (100%)	$p = < 0.001^\dagger$	Total	57 (100%)	$p = 0.003^\dagger$

[†] Using chi-square test compensated versus noncompensated groups.

Table 6. Interobserver and intraobserver reliability for measurement of the ankle and hindfoot alignment*

Parameter	Patients with end-stage ankle arthritis		Control subjects	
	Interobserver reliability	Intraobserver reliability	Interobserver reliability	Intraobserver reliability
Medial distal tibial angle ($^\circ$)	0.912 (0.887–0.931)	0.941 (0.924–0.954)	0.910 (0.854–0.945)	0.926 (0.879–0.955)
Tibiotalar surface angle ($^\circ$)	0.914 (0.890–0.933)	0.943 (0.927–0.956)	0.910 (0.854–0.945)	0.926 (0.879–0.955)
Tibiocalcaneal axis angle ($^\circ$)	0.855 (0.817–0.886)	0.847 (0.806–0.880)	0.820 (0.715–0.888)	0.851 (0.762–0.908)
Moment arm of calcaneus (mm)	0.920 (0.898–0.938)	0.887 (0.856–0.911)	0.844 (0.752–0.904)	0.908 (0.850–0.944)

* Data are presented as interobserver and intraobserver correlation coefficients with 95% CI.

The ICCs for interobserver and intraobserver reliability for measurement of ankle and hindfoot alignment in our study showed good to excellent agreement for all four radiographic parameters. Although measurements of the medial distal tibial angle, tibiotalar surface angle, and talar tilting angle are well-accepted methods for assessment of ankle alignment in the coronal plane, the radiographic assessment of hindfoot alignment remains controversial. The angle between the tibial shaft axis and the calcaneal axis was measured by Cobey [5] and Buck et al. [4] using the hindfoot alignment view, and by Reilingh et al. [24] using long axial view radiographs. However, it is not easy to define specific landmarks of the calcaneus for appropriate definition of the calcaneal axis owing to its irregular shape [26]. We used two methods to assess hindfoot alignment: measurement of the moment arm of the calcaneus as described by Saltzman and el-Khoury [25] and measurement of the tibiocalcaneal axis angle as described

by Seltzer et al. [27]. The moment arm of the calcaneus addresses mechanical alignment of the hindfoot by measurement of the apparent moment arm between the weightbearing axis of the lower leg and point of the heel-floor contact [25]. This method is reliable for assessment of coronal hindfoot alignment and for evaluation of mechanical hindfoot imbalance in patients before and after surgery [8, 9]. In our study the moment arm of the calcaneus was the only parameter not significantly different ($p = 0.203$) in patients with end-stage ankle osteoarthritis from the control group, indicating that the subtalar joint generally compensated to achieve good hindfoot mechanical alignment.

We observed substantial ankle malalignment, mostly varus deformity, in our patients with end-stage ankle arthritis. The patients with no or mild degenerative changes of the subtalar joint may compensate the ankle malalignment resulting in a neutral hindfoot alignment. Future

prospective studies of subtalar joint compensation to tibiotalar joint osteoarthritis at different stages corresponding to the clinical manifestations would offer more understanding of the progression of arthritis at the ankle joint complex.

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