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Acute and chronic aspects of hindfoot trauma

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Chapter 5

Radiological morphology of peritalar instability in varus and valgus tilted ankles

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ABSTRACT

BACKGROUND: Varus and valgus talar tilt in weight-bearing ankles can be explained by loss of peritalar stability allowing the talus to shift and rotate on the calcaneal and navicular surfaces. Little is known about the underlying destabilization process or the resulting talar malpositions. The purpose of this study was to determine talar position in 3 radiographic planes of varus and valgus tilted ankles.

METHODS: Standard weight-bearing radiographs of 126 varus ankles (118 patients [mean age 62 ± 12 years]) and 81 valgus ankles (75 patients [mean age 65 ± 10 years]) were retrospectively evaluated. The tibiotalar surface angle, sagittal talocalcaneal inclination angle, and horizontal talometatarsal I angle were used to determine the frontal, sagittal, and horizontal position of the talus. A control group was used for comparison.

RESULTS: Isolated talar varus malposition was found in 33.3% of the ankles (42/126), and malposition in 1 or both additional planes was found in 49.2% (62/126) and 17.5% (22/126), respectively. In valgus ankles, the percentages were 52% (42/81), 43% (35/81), and 5% (4/81), respectively. Seven out of 9 possible varus and 5 out of 9 possible valgus talar malposition configurations were found. The 4 predominant varus malposition configurations (89.7%, or 113/126) were dorsiflexion or neutral (sagittal plane) combined with neutral/external rotation and neutral/internal rotation (horizontal plane), respectively. The 3 predominant valgus malposition configurations (95%, or 77/81) were neutral or plantar flexion (sagittal plane) combined with neutral/external rotation and neutral (horizontal plane), respectively.

CONCLUSION: In varus and valgus tilted ankles, talar frontal plane alignment does not predict talar sagittal and horizontal position, indicating that peritalar instability leads to various talar malpositions.

CLINICAL RELEVANCE: Prior to operative treatment of varus and valgus tilted ankles, thorough 3-dimensional analysis of talar position may minimize failure in properly balancing the talus within the ankle mortise.

LEVEL OF EVIDENCE: Level III, retrospective comparative series.

KEYWORDS: peritalar instability, varus, valgus, talar tilt, radiological morphology

INTRODUCTION

The ankle is a highly congruent joint in which the articular surfaces provide up to 100% of talar stability in the coronal (frontal) plane when the foot is loaded.^{32,38,39} Given the axis of the subtalar (talocalcaneal) joint and the ball-and-socket-like shape of the talonavicular joint, it is assumed that the peritalar (talocalcaneal and talonavicular) joints may contribute less to talar stability⁶ than does the congruent talocrural joint.^{32,38,39} Consequently, the ligaments of the ankle may significantly contribute to talar stability at the peritalar joints, where a loss of ligament support allows the talus to undergo varus or valgus tilt during loading of the ankle joint complex. The underlying mechanisms of such peritalar instability are not well understood.¹⁶ In varus and valgus ankles,^{4,5,19-21,30,40,41} the tilt of the talus typically increases while the foot is bearing weight (Figure 1). This can be explained by rotation and translation of the talus on the calcaneal and navicular surfaces, resulting in changes of talar position in 1 or more planes.^{2,12,16,28}

This destabilization process, and the subsequent changes of talar position, are poorly understood.¹⁶ The purpose of this study was to assess talar malpositioning in varus and valgus tilted ankles in 3 radiographic planes to determine whether peritalar instability results in a consistent pattern of talar malpositioning.

METHODS

Radiographs from 193 consecutive patients who were treated by supramalleolar osteotomy or total ankle arthroplasty for a varus (118 patients) or valgus (75 patients) tilted ankle between 2006 and 2011 were retrospectively evaluated (Table 1). These patients were part of a larger cohort that presented with various forms of ankle osteoarthritis or instability (Figure 2). Included were ankles with a varus or valgus talar tilt, defined in a weight-bearing mortise view as a tibiotalar surface angle¹⁵ (TTS) of less than 83.8 degrees (varus) or more than 94.2 degrees (valgus), with or without concurrent osteoarthritic changes of the ankle joint. The TTS threshold for varus and valgus talar tilt was determined by subtracting (varus) and adding (valgus) 2 control group standard deviations from and to a TTS control group mean (89.0 ± 2.6 degrees), measured at our institution.²⁸ Also included were ankles that did fall within the normal tilt range²⁸ but which evidenced concurrent osteoarthritic changes in the medial (varus) or lateral (valgus) tibiotalar compartment. Excluded were ankles with neurological disorders or previous surgeries such as an arthrodesis, osteotomies, ligament reconstruction, or tendon transfer of the affected hindfoot (Figure 2). Included in the control group were 30 skeletally mature individuals who were treated at our institution and had not undergone previous ankle surgery (Haglund disease, $n = 10$; contralateral supramalleolar osteotomy, $n = 10$; and contralateral fracture, $n = 10$).²⁸ The institutional review board approved the present study.

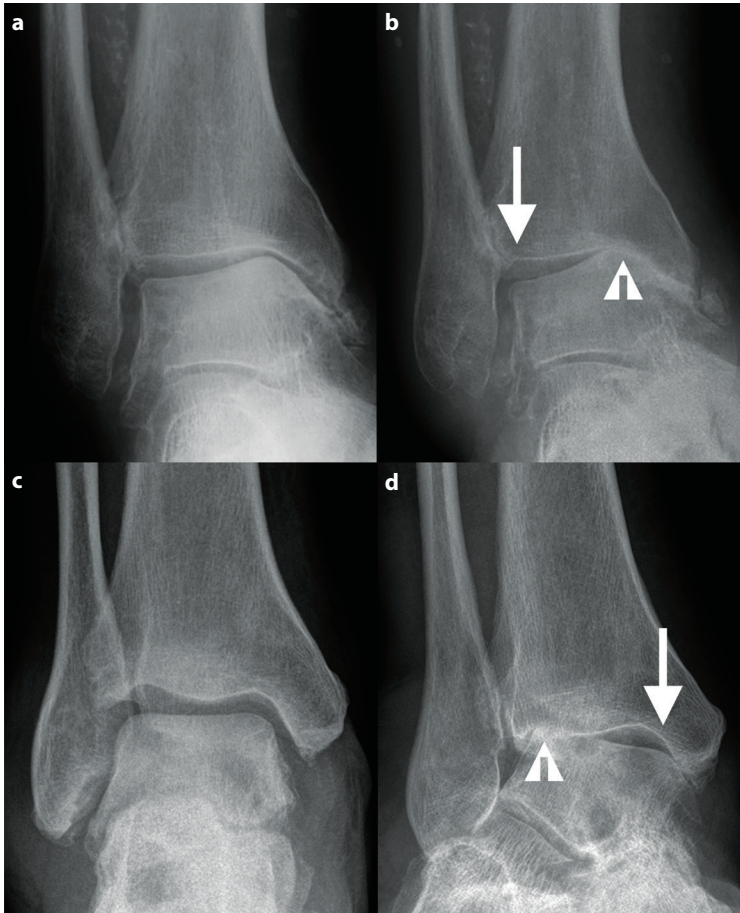


Figure 1. Mortise view of the unloaded ankle (**a** and **c**) and weight-bearing ankle (**b** and **d**), showing increase in varus (**b**) and valgus (**d**) talar tilt upon weight-bearing. Arrows mark increases in the lateral (**b**) and medial (**d**) tibiotalar compartment space; arrowheads mark concurrent decreases in the medial (**b**) and lateral (**d**) tibiotalar compartment space.

All patients had standard weight-bearing radiographs (mortise ankle view, lateral and AP view of the foot). Radiography was performed with the use of the Philips DigitalDiagnost (Philips Research, Eindhoven, the Netherlands). The settings for the radiation source in the mortise, lateral, and AP views of the foot were 5 mAs and 60 kV, 4 mAs and 60 kV, and 3.2 mAs and 57 kV, respectively. In the mortise view the beam was focused on the ankle joint equidistant between both malleoli, in the lateral view on the medial malleolus, and in the AP view on the first cuneiform bone. The beam was parallel to the floor in the mortise and lateral views and inclined 15 degrees caudocranial in the AP view. The film focus distance was 120 cm. All radiographs were taken in weight-bearing stance, with the affected feet bearing approximately 50% of the total weight. To standardize imaging and avoid potential rotational deviations, all radiographs were performed by technicians certified for musculoskeletal imaging. Criteria for proper imaging (taking into account

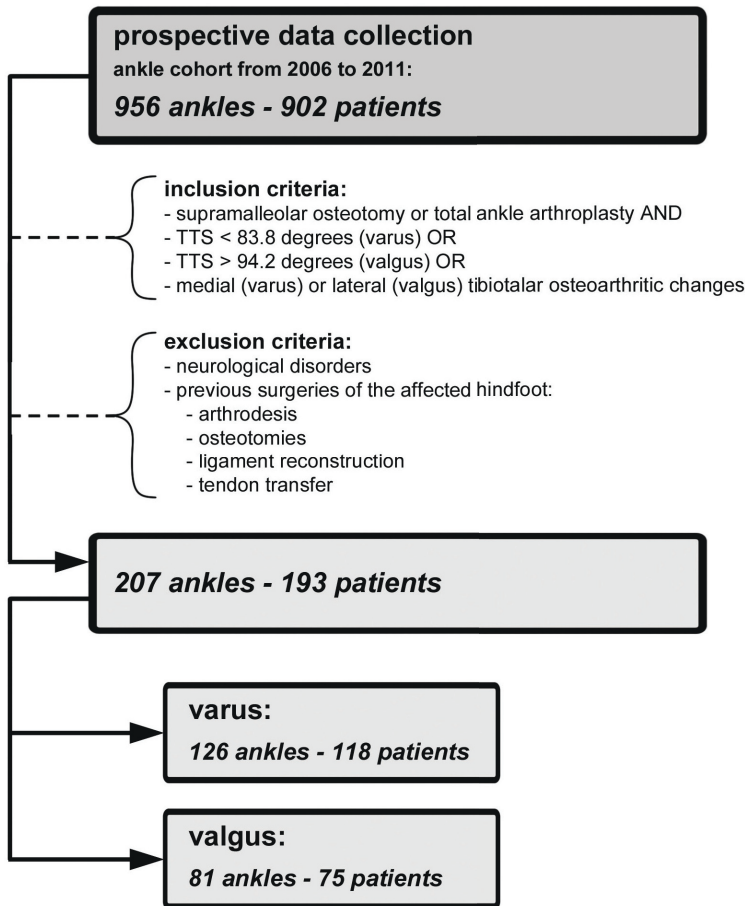


Figure 2. Flow chart displaying the selection of patients and ankles analyzed. TTS, tibiotalar surface angle.

existing talar varus or valgus malpositioning) included the following: for the mortise view, open tibiotalar and lateral joint space, minor tibiofibular overlap, and position of the fifth phalanx on the same vertical line as the distal tibiofibular joint; for the lateral view, parallel aligned tibial domes, open tibiotalar joint space, and overlap of the distal fibula over the tibia; and for the AP view, equal spacing between the second to fifth metatarsal, overlap between the second to fifth metatarsal bases, and an open joint space between the first and second cuneiform.

The mortise view was used to quantify the amount of varus or valgus tilt of the talus according to the TTS¹⁵ (Figure 3). On the lateral and AP views, talar position within the peritalar joints was determined by measuring the sagittal talocalcaneal inclination angle³ and the horizontal talometatarsal I angle⁹ (respectively TCI and TMT I, Figure 3). In the sagittal plane, TCI decreased for dorsiflexion and increased for plantar flexion. In the horizontal plane, TMT I was positive when the talar axis was adducted with respect to the metatarsal axis and negative when the talar axis was abducted with respect to the metatarsal axis. TTS, TCI, and TMT I were chosen after a measurement

reliability and validity analysis, which was performed at our institution to assess the most accurate radiographic method for determining the 3-dimensional position of the talus in varus and valgus tilted ankles.²⁸ In this study, measurement reliability (intraobserver and interobserver) and validity (convergent and discriminant) were determined for 9 different angles. The TTS, TCI, and TMT I angles were found most suitable.²⁸

Table 1. Descriptive patient statistics.

	Varus	Valgus
Number of patients	118	75
Gender (male / female), n	76 / 42	51 / 24
Age in years (mean \pm SD, range)	62 \pm 12, 25 to 85	65 \pm 10, 34 to 85
Number of ankles	126	81
Side (right / left)	75 / 51	49 / 32

All radiographic measurements were performed using Image Access (version 4, Imagic Bildverarbeitung, Glattburg, Switzerland). To improve accuracy in measurements and thereby correctly determine the malposition of the varus and valgus tali in the sagittal and horizontal plane, TCI and TMT I angles were measured by 3 independent observers. Intraobserver reliability was determined by using single measurement, absolute agreement intraclass coefficient (ICC) (2,1). Thereafter, mean TCI and mean TMT I were determined and compared with control group measurements performed within the previously mentioned measurement reliability and validity analysis (TCI, 30.5 \pm 4.5 degrees, and TMT I, 3.7 \pm 7.9 degrees).²⁸

By angle, the neutral position of the talus was defined within 2 standard deviations of the mean of the control group (21.5 to 39.5 degrees for TCI and -12.1 to 19.5 degrees for TMT I).²⁸ Talar malpositioning, in addition to frontal plane varus or valgus tilt (ie, plantar flexion or dorsiflexion [sagittal plane, as measured by mean TCI] and external rotation or internal rotation [horizontal plane, as measured by mean TMT I]) were measures outside the previously defined range. Finally, associations between varus or valgus talar tilt and talar sagittal and horizontal position were analyzed by correlating TTS to TCI and TMT I, respectively (Pearson's correlation coefficient *r*). Normal distribution of data was evaluated by a Kolmogorov-Smirnov test. A P value less than .05 was considered statistically significant. Statistical analyses were performed with SPSS version 17.0 (SPSS Inc, Chicago, IL).

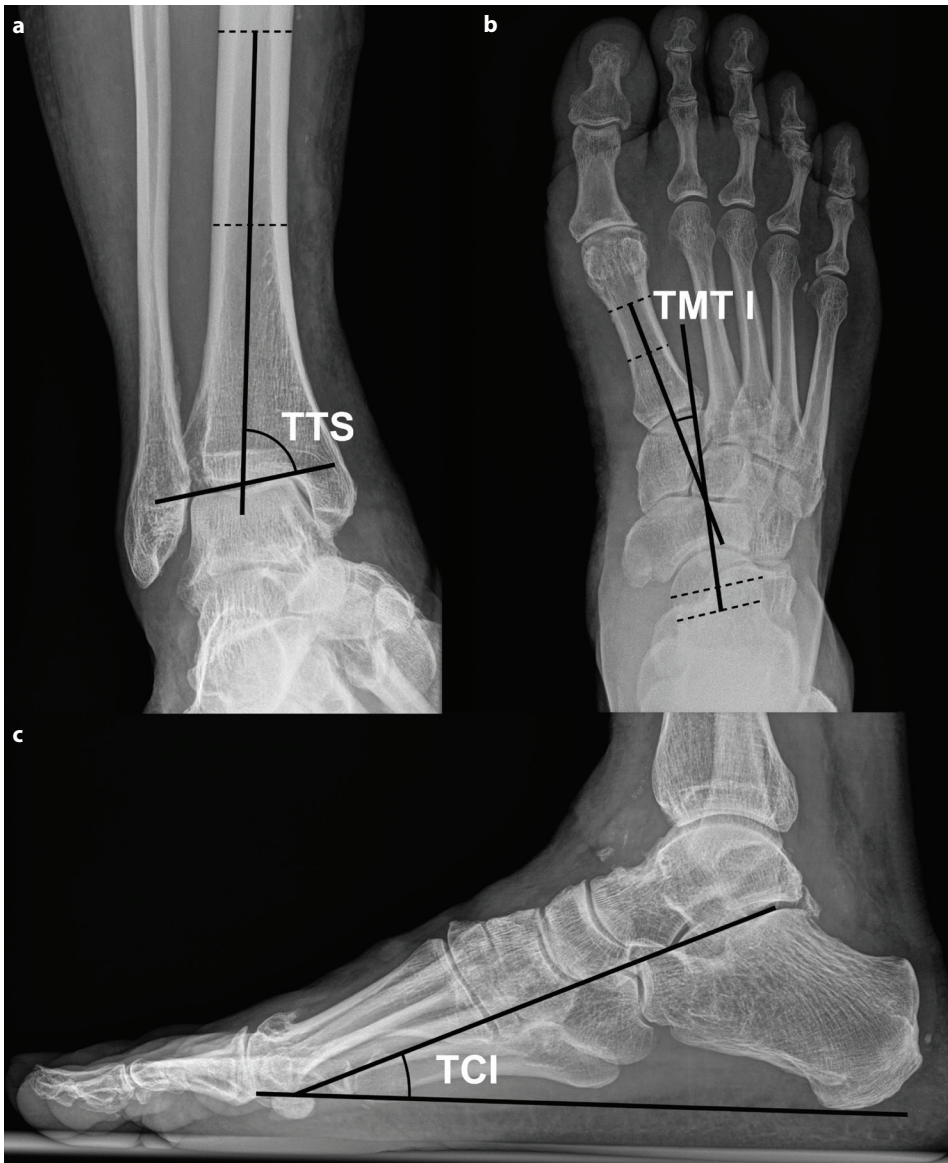


Figure 3. **a** Mortise view of a varus tilted ankle. Talar frontal malposition was measured with the tibiotalar surface angle (TTS), that is, the angle between the tibial midlongitudinal axis and the upper surface of the talus (measured on the medial side). The midlongitudinal tibial axis was formed by a line bisecting the tibia at 8 and 13 cm (horizontal lines on tibia) above the tibial plafond. In the horizontal and sagittal planes, the talometatarsal I (TMT I) angle and the talocalcaneal inclination (TCI) angle were measured on the AP (**b**) and lateral (**c**) view of the foot, respectively. TMT I was defined as the angle between the first metatarsal axis and the talar axis; TCI was defined as the angle between a line connecting the talar axis (from the posterior talar articular surface to the anterior articular surface at the underside of the talar head) and a line representing the base of the foot (from the inferior aspect of the calcaneal tuberosity to the base of the first metatarsal head).

RESULTS

ICCs (2,1) for TCI and TMT I were 0.950 and 0.903, respectively, indicating excellent measurement reliability.²⁸ Isolated varus malposition of the talus (ie, no malposition in the sagittal and horizontal planes) was found in 42 of 126 varus ankles (33.3%). In 62 of 126 ankles (49.2%), the varus talus was malpositioned in 1 additional plane (ie, dorsiflexion or plantar flexion of the talus in the sagittal plane outside the neutral TCI range of 21.5 to 39.5 degrees in $n = 49$, and external rotation or internal rotation of the talus in the horizontal plane outside the neutral TMT I range of -12.1 to 19.5 degrees in $n = 13$). The varus talus was malpositioned in both the sagittal and the horizontal plane in 22 of 126 ankles (17.5%). Isolated valgus malposition of the talus (ie, no malposition in the sagittal and horizontal planes) was found in 42 of 81 valgus ankles (52%). In 35 of 81 ankles (43%), the valgus talus was malpositioned in 1 additional plane (ie, dorsiflexion or plantar flexion of the talus in the sagittal plane outside the neutral TCI range of 21.5 to 39.5 degrees in $n = 18$, and external rotation or internal rotation of the talus in the horizontal plane outside the neutral TMT I range of -12.1 to 19.5 degrees in $n = 17$). The valgus talus was malpositioned in both the sagittal and horizontal plane in 4 of 81 ankles (5%) (Table 2).

Of 9 possible talar malpositions in varus and valgus ankles each, respectively 7 and 5 malpositions were found (Figure 4). The 4 predominant varus malposition configurations were dorsiflexion (sagittal plane) combined with neutral or external rotation (horizontal plane) and neutral (sagittal plane) combined with neutral or internal rotation (horizontal plane), accounting for 89.7% of all ankles (113/126) (Figure 5). The varus talus was dorsiflexed/internally rotated in 6 of 126 ankles (4.8%), plantar flexed/internally rotated in 6 of 126 (4.8%) (Figure 6), and plantar flexed/neutral in 1/126 (0.8%). The varus talus was only externally rotated when also dorsiflexed. When plantar flexed, the talus nearly always was internally rotated (Figure 4). The 3 predominant valgus malposition configurations were neutral (sagittal plane) combined with neutral or external rotation (horizontal plane) and plantar flexion (sagittal plane) combined with neutral (horizontal plane), accounting for 95% of all ankles (77/81) (Figure 7). The valgus talus was plantar flexed/internally rotated in 3 of 81 ankles (4%) and dorsiflexed/externally rotated in 1 of 81 ankles (1%) (Figure 8). When sagittal neutral, the valgus talus was not internally rotated, whereas when sagittal plantar flexed, the talus was not externally rotated (Figure 4).

Evident continuity between the talar malposition configurations in both varus and valgus ankles was seen (Figure 9). A significant correlation was found between varus tali and talar dorsiflexion (Pearson's $r = 0.378$, $P < .001$). No correlation was found between valgus tali and talar sagittal position (Pearson's $r = 0.099$, $P = .379$). A significant correlation was found between valgus tali and talar external rotation (Pearson's $r = -0.545$, $P < .001$). No correlation was found between varus tali and talar horizontal position (Pearson's $r = -0.101$, $P = .260$).

Table 2. Angular measurements by plane and talar malpositioning.

		Varus (n = 126 ankles)	Valgus (n = 81 ankles)	
Angle in degrees (mean ± SD, range)	TTS (frontal plane)	74.6 ± 7.7, 51 to 95	100.6 ± 7.2, 90 to 127	
	TCl (sagittal plane)	22.7 ± 8.4, 5 to 45 [§]	35.0 ± 7.6, 19 to 54	
	TMT I (horizontal plane)	7.8 ± 15.4, -55 to 44	-3.3 ± 14.7, -48 to 45 [¶]	
Malpositioning in addition to frontal varus or valgus (number and (%))	One additional plane	Sagittal	49/126 (38.9)	18/81 (22)
		Horizontal	13/126 (10.3)	17/81 (21)
	Sagittal and horizontal plane	22/126 (17.5)	4/81 (5)	
	No additional plane	42/126 (33.3)	42/81 (52)	

Abbreviations: TTS, tibiotalar surface angle; TCl, talocalcaneal inclination angle; TMT I, talometatarsal I angle.
[§]Significant correlation between varus tali and talar dorsiflexion (Pearson's $r = 0.378, P < .001$). [¶]Significant correlation between valgus tali and talar external rotation (Pearson's $r = -0.545, P < .001$).

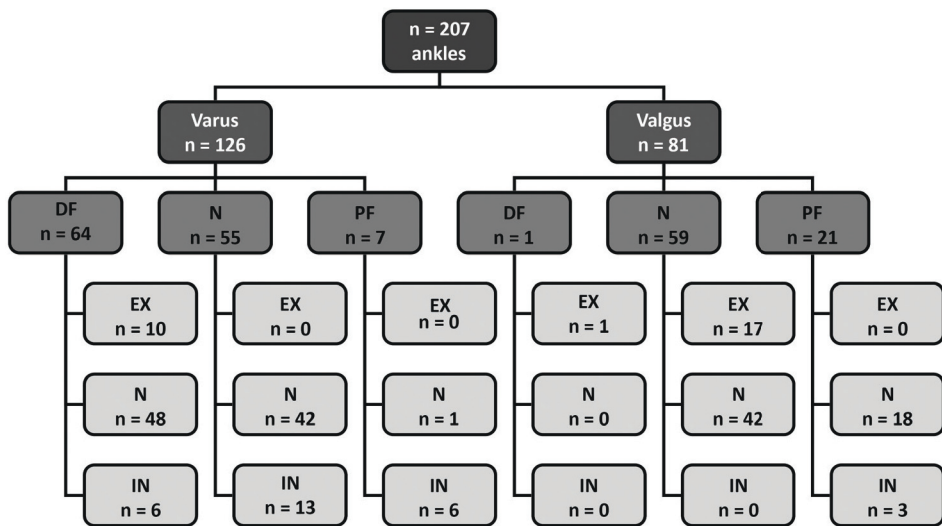


Figure 4. Talar radiological morphology in varus and valgus tilted ankles. DF, dorsiflexion; N, neutral; PF, plantar flexion (sagittal plane); EX, external rotation; N, neutral; IN, internal rotation (horizontal plane). Significant correlation was found between varus tali and talar dorsiflexion (Pearson's $r = 0.378, P < .001$). Significant correlation was found between valgus tali and talar external rotation (Pearson's $r = -0.545, P < .001$).

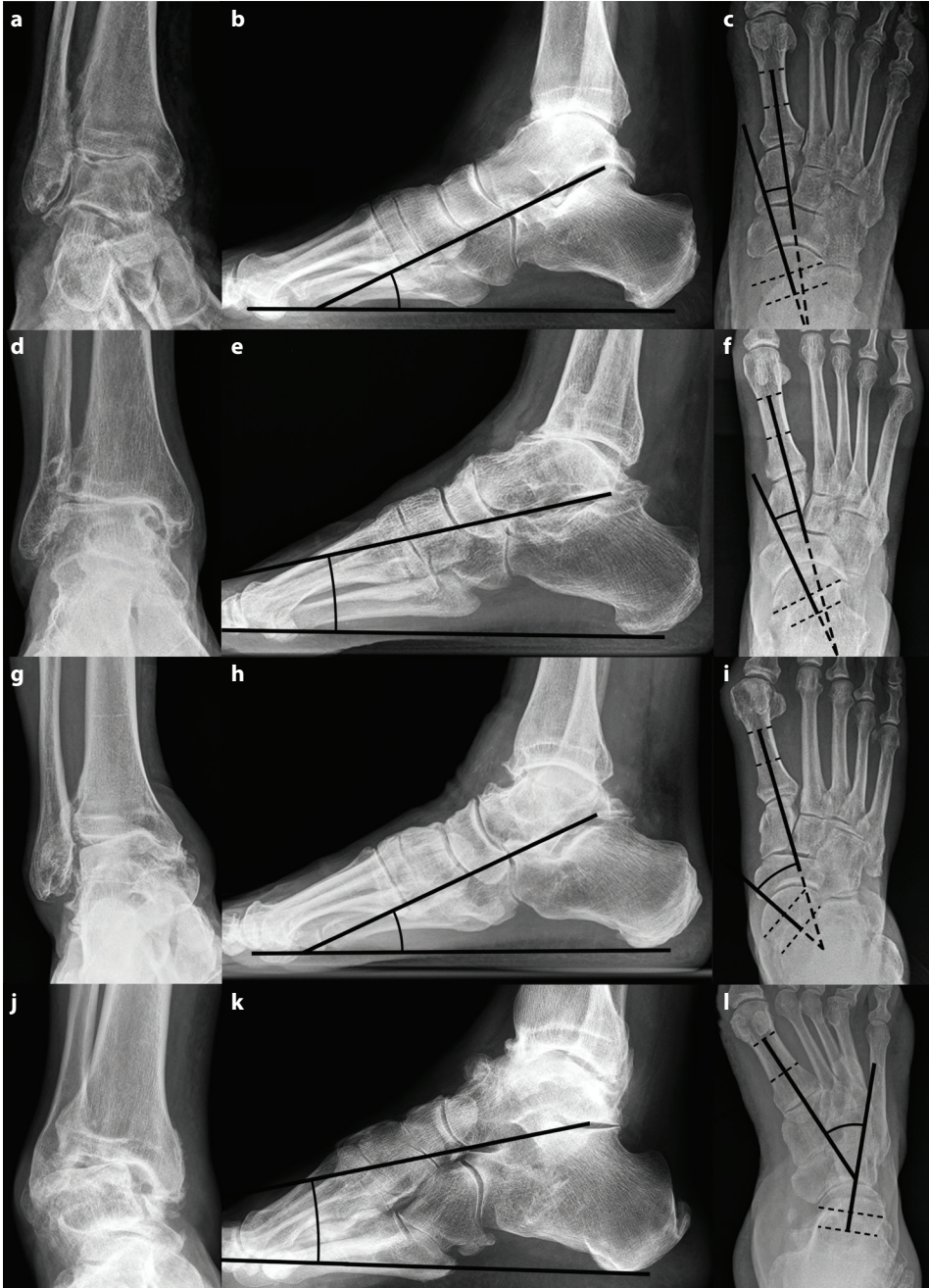


Figure 5. Weight-bearing radiography representing the 4 predominant talar varus malposition configurations. The angles marked in **b, e, h, and k** relate to the sagittal talocalcaneal inclination angle and in **c, f, i, and l** to the horizontal talometatarsal I angle. **a-c** 70-year-old male with varus talar tilt (**a**) following recurrent sprains. Talar sagittal (**b**) and horizontal (**c**) position was neutral. **d-f** 53-year-old female with varus talar tilt (**d**) after a trimalleolar ankle fracture 23 years earlier. The talus was dorsiflexed (**e**) and horizontally neutral (**f**). **g-i** 73-year-old male with

talar varus tilt (**g**) after recurrent childhood sprains. Talar position was neutral in sagittal plane (**h**) and internally rotated (**i**) in horizontal plane. **j-l** 58-year-old male following recurrent severe ankle sprains, resulting in varus talar tilt, talar dorsiflexion (**k**), and external rotation (**l**).

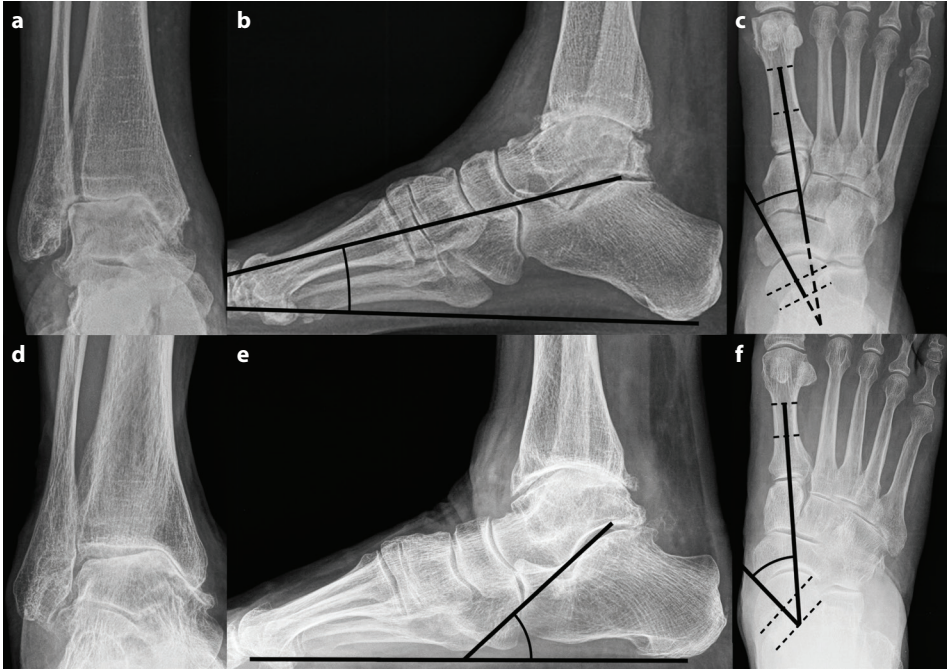


Figure 6. Weight-bearing radiography. The angles marked in **b** and **e** relate to the sagittal talocalcaneal inclination angle and in **c** and **f** to the horizontal talometatarsal I angle. **a** 68-year-old female with varus talar tilt following recurrent ankle sprains. The talus was dorsiflexed (**b**) and internally rotated (**c**). **d** 79-year-old female with varus talar tilt following recurrent sprains. Talar position was plantar flexed (**e**) and internally rotated (**f**).



Figure 7. Weight-bearing radiography showing the 3 predominant valgus talar malposition configurations. The angles marked in **b, e, and h** relate to the sagittal talocalcaneal inclination angle and in **c, f and i** to the horizontal talometatarsal I angle. **a-c** Male, 66 years old, presenting with valgus talar tilt following hemochromatosis-related valgus ankle osteoarthritis (**a**). Talar position was neutral in sagittal (**b**) and horizontal (**c**) plane. **d-f** Male, 57 years old, with valgus talar tilt (**d**) following recurrent childhood ankle sprains. The talus was neutral in sagittal plane (**e**) and horizontally externally rotated (**f**). **g-i** 73-year-old male with painful primary valgus ankle osteoarthritis (**g**). The talus was plantar flexed (**h**) and neutral in horizontal plane (**i**).

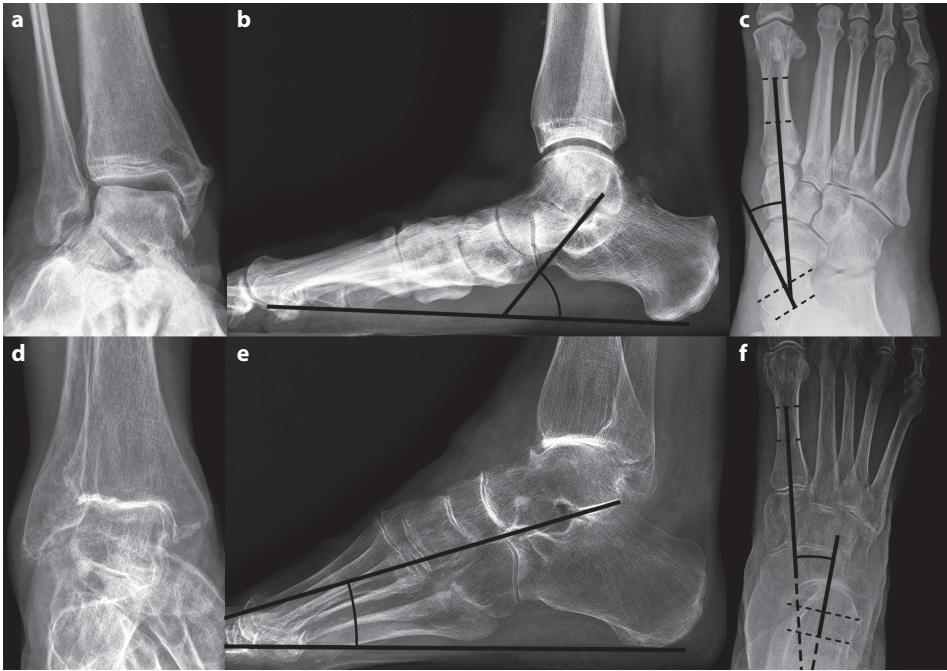


Figure 8. Weight-bearing radiography. The angles marked in **b** and **e**, and those in **c** and **f**, relate to the sagittal talocalcaneal inclination angle and the horizontal talometatarsal I angle, respectively. **a-c** 53-year-old female with valgus talar tilt following recurrent sprains and posterior tibial tendon deficiency. The talus was plantar flexed (**b**) and internally rotated (**c**). **d-f** 60-year-old female with painful primary valgus ankle osteoarthritis (**d**). The talus was dorsiflexed (**e**) and externally rotated (**f**).

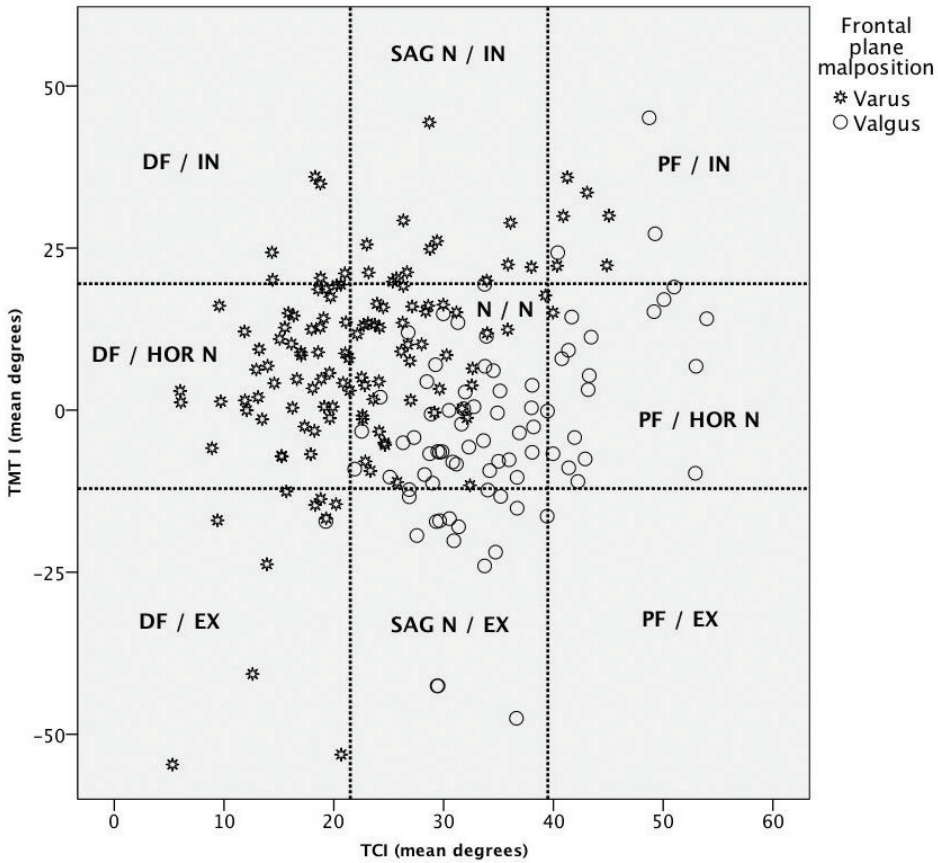


Figure 9. Scatter plot of all 126 varus and 81 valgus ankles. Horizontal and vertical dashed lines represent the neutral position range for the horizontal talometatarsal I angle (TMT I) and sagittal talocalcaneal inclination angle (TCI). DF, dorsiflexion; PF, plantar flexion; EX, external rotation; IN, internal rotation; SAG N, neutral in sagittal plane; HOR N, neutral in horizontal plane; N/N, neutral in both the sagittal and horizontal plane. Varus tali were significantly correlated to talar dorsiflexion (Pearson’s $r = 0.378$, $P < .001$). Valgus tali were significantly correlated to talar exorotation (Pearson’s $r = -0.545$, $P < .001$).

DISCUSSION

In the unstable varus and valgus ankle,^{4,5,19-21,30,40,41} talar tilt typically increases when loading the ankle joint complex. This may be caused by loss of stability at the peritalar joints, which allows the talus to rotate and/or translate,^{2,16} and by the specific articular configuration of the peritalar joints for which the articular surfaces may not provide stability by containment.^{32,38,39} To obtain more insight into the potential outcomes, talar position in 3 radiographic planes was analyzed to determine whether an unstable varus or valgus ankle resulted in consistent talar malpositioning. In 42 of 126 varus ankles (33.3%) and 42 of 81 valgus ankles (52%) the talus was only malpositioned in the frontal plane, indicating that when loaded the talus rotated with regard to the subtalar joint

axis.¹² The malposition in the frontal plane was toward inversion in varus and eversion in valgus, along the curved posterior surface of the subtalar joint.¹⁶ In as many as 84 of 126 varus ankles (66.7%) and 39 of 81 valgus ankles (48%), talar malpositioning in the sagittal and/or horizontal plane was found in addition to frontal tilt. In these ankles, the talus did not solely rotate with regard to the subtalar joint axis¹² but also rotated in craniocaudal direction (sagittal plane) and medial-lateral direction (horizontal plane), suggesting a complex destabilization process in the peritalar joints.

In addition to frontal varus and valgus, respectively 6 and 4 different talar positions were found (dorsiflexed or plantar flexed, and/or internal or external rotation). For instance, the varus talus only externally rotated when dorsiflexed, while the valgus talus was not able to externally rotate when plantar flexed. This indicates that the specific joint geometry did not allow the talus to become malpositioned in all directions. The specific ligament instability pattern may also contribute to the fact that not all possible talar malposition configurations were found. The significant correlation between talar varus and talar dorsiflexion may indicate that in peritalar instability, a radiographic association between varus tali and cavovarus feet⁴² may exist. On the contrary, talar valgus was significantly correlated with talar external rotation but not with talar plantar flexion. This may indicate that in peritalar instability, on radiographs, valgus tali are not necessarily associated with planovalgus feet.⁴

It remains speculative as to why the talus tilts into various malpositions. Subtalar joint congruency and contact area are low⁶ as the talus rests on the convex posterior and flat intermediate and anterior calcaneal facets.¹⁶ In vivo weight-bearing tomography of symptomatic flatfeet shows considerable talar subluxation¹⁰ of the morphologically different subtalar joint surfaces.³¹ Any combination of bony instability^{4,19,25,26,28,29,33–36,39} with ligamentous instability or peritalar muscle-tendon complex imbalance (eg, posterior tibial tendon deficiency, triceps surae contracture, or peroneus longus muscle overpull)^{1,7,11,13,14,17,18,21,22,24,27,37,38,42–44} can result in talar malpositioning with respect to the talocalcaneal, talonavicular, or tibiotalar joints. This may result in the uncoupling of talocalcaneal motion¹² and the observed talar malposition configurations. However, the pattern of this peritalar instability and its interplay with the ankle is not yet understood.

This study indicates that careful radiographic analysis of talar positioning in peritalar instability is important when considering reconstructive surgery of an unstable varus or valgus ankle joint complex. Rebalancing of the talus within the ankle mortise in the frontal plane may fail as long as the talar position is not fully corrected in the horizontal and sagittal plane as well. This may be particularly true if the muscular balance is not restored and applied joint forces are not normalized. Despite appropriate hindfoot balancing following ligament reconstructions and triple arthrodesis, supramalleolar and calcaneal osteotomies, or total ankle replacement,^{5,8,20,21,30,33,42} residual talar tilt may occur. This may indicate persistent peritalar instability, caused by advanced wear of the medial or lateral tibiotalar joint, resulting in changes of articular geometry, coupled with subtalar joint changes and overuse injury of supporting ligamentous structures.

There are some limitations to this study. No validity analysis was performed on the control group, which might have influenced our results. However, control group measurements were consistent with the literature.²⁸ Even though we used a validated measurement protocol,²⁸ the anatomic landmarks used for analysis of standard radiographs may have undergone changes due to osteoarthritis. Additionally, 2-dimensional plane radiographs were used to describe 3-dimensional positions of the talus. Weight-bearing computed tomography, although potentially more accurate, is rarely available and must first prove to be more reliable.²³ The TMT I⁹ may not accurately indicate the horizontal position of the talar head to the navicular. However, considering the horizontal position of partially subluxated tali, the TMT I did reflect talar malposition within the talonavicular joint. Finally, ankles with concomitant calcaneal, forefoot and midfoot, and tibial plafond deformities were not excluded, and this may have influenced the talar position. However, in most instances, such deformities may have been the result of the tilt of the talus at the tibiotalar joint.

CONCLUSION

In varus and valgus tilted ankles, malposition of the talus in the frontal plane does not reliably predict malposition in the sagittal or horizontal planes, as loss of peritalar stability leads to various talar malposition configurations. Therefore, conclusions about peritalar malposition and stability on the basis of talar frontal plane alignment (TTS) are difficult to make. Before treatment is initiated, careful radiographic assessment of talar position in varus or valgus tilted ankles may be important to properly balance the talus within the ankle mortise. Further studies are needed to clarify the precise mechanism of destabilization in peritalar instability, the accompanying morphological changes, and the resulting peritalar instability configurations and to establish possible relations between preoperative radiographic assessment and postoperative results.

DECLARATION OF CONFLICTING INTERESTS

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