CLINICAL RESEARCH

Does Alignment in the Hindfoot Radiograph Influence Dynamic Foot-floor Pressures in Ankle and Tibiotalocalcaneal Fusion?

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Abstract

Background   The Saltzman-el-Khoury hindfoot alignment view (HAV) is considered the gold standard for assessing the axis from hindfoot to tibia. However, it is unclear whether radiographic alignment influences dynamic load distribution during gait.

Questions/purposes   We evaluated varus-valgus alignment by the HAV and its influence on dynamic load distribution in ankle and tibiotalocalcaneal (TTC) arthrodesis.

Patients and Methods   We clinically assessed 98 patients (ankle, 56; TTC, 42) with SF-36 and American Orthopaedic Foot and Ankle Society (AOFAS) scores, visual hindfoot alignment, HAV angle, and dynamic pedobarography using a five-step method. For comparison, 70 normal feet were evaluated. Minimum followup was 2 years (average, 4.11 years; range, 2–6 years).

Results   The mean HAV angle was $-0.8° \pm 7.8°$ for ankle and $-1.2° \pm 6.9°$ for TTC arthrodesis. The HAV angle correlated with pedobarographic load distribution (r = 0.35–0.53). Radiographic alignment did not influence SF-36 or AOFAS scores; however, load distribution correlated to qualities of these scores. Visual alignment only predicted the corresponding HAV angle in 48%. To reproduce the dynamic load of healthy subjects, HAV angles of 5° to 10° valgus were needed.

Conclusions   Visual positioning is inadequate to determine intraoperative positioning and resulted in a varus position with a relatively large SD. The HAV should be used to assess the hindfoot alignment correctly. HAV angles of 5° to 10° valgus are needed to reproduce a physiologic gait pattern.

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Introduction

Frontal plane alignment of the hindfoot can be assessed visually [5, 7, 38], on AP radiographs [21, 31, 37], or with posterior radiographs such as those described by Saltzman and el-Khoury (hindfoot alignment view or HAV) [37] or Cobey and Sella [10, 11]. Although the reliability of clinical measurement is improved by using a goniometer and weightbearing position, several studies showed clinical measurements are less reliable than radiographic approaches [5, 13, 38]. AP radiographs are difficult to measure because of superimposition of the midfoot and the 20° internal rotation that mimics the heel lateral to the tibia. The HAV is taken at a 20° angle from the horizontal (Fig. 1) and allows measurement of the mechanical axis of the hindfoot to the tibia (Fig. 2) [37]. Although we

Fig. 1A–B (A) The HAV is taken at a 20° angle to the floor. (B) The foot is placed with its medial border parallel to the radiographic beam (the so-called straight position).
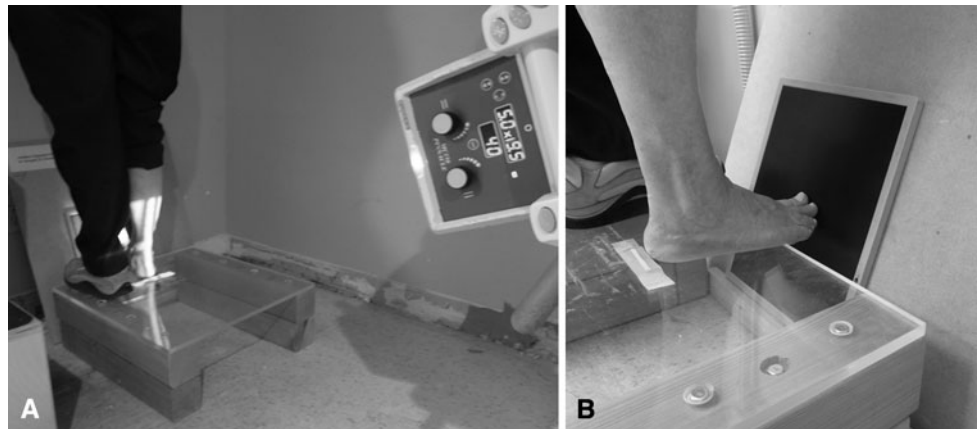
Fig. 2 A radiograph shows the HAV in a patient after a medial ankle fracture. The lowest contact point of the calcaneus is 3 mm medial to the tibial axis corresponding to the varus position.

consider the HAV the gold standard to assess hindfoot alignment [15, 18, 21, 31], this view was used in only one study [12].

Radiographs reflect only static alignment of the foot in the standing position. However, physiologic heel strike occurs in varus on the lateral heel followed by the hindfoot turning in pronation for the rollover process [15]. It therefore is unclear whether static alignment measured on radiographs also predicts dynamic load distribution during gait, ie, dynamic alignment. This dynamic alignment can be measured by pedobarography, allowing measurement of pressure distribution of the foot during the rollover process [6, 7, 9, 23, 32]. Barefoot pedobarography has been used to observe correlation of foot pain and abnormally high pressure areas in clubfeet [6, 14], to identify high pressure areas at risk for ulceration [2, 16, 41], and to investigate the mechanical change in patients with rheumatoid arthritis in the feet [28, 40], metatarsalgia [19], hallux valgus [20], and cavovarus deformity [26].

The hindfoot position can be divided into neutral (0° angle from hindfoot to tibial axis), valgus (lateral deviation), and varus (medial deviation). There are different definitions to assess the hindfoot axis radiographically because of the variable shape of the calcaneus, including lateral calcaneal wall, superimposition of 2:1 ellipsis, and lowest contact point of the calcaneus [10, 11, 21, 37]. Numerous authors [4, 5, 12, 15, 27, 29] have stated, based on visual and radiographic measurements, the hindfoot should be in 5° to 7° valgus. However, in a study of 57 healthy subjects Saltzman and el-Khoury [37] found the average contact point of the calcaneus was 3.2 mm medial to the tibial axis, corresponding to a varus position of approximately 1° to 2°. Although some consider 0° to 10° valgus the best position in ankle arthrodesis [5], the only study assessing ankle arthrodesis with the HAV reports a varus position with medial calcaneal displacement of 1.5 mm [12].

The aims of our study were to (1) assess hindfoot alignment with the HAV in patients with ankle and TTC arthrodesis visually positioned in 5° to 7° valgus, (2) determine if radiographic varus/valgus alignment measured in the HAV influences dynamic load distribution, (3) determine if the AOFAS and SF-36 scores are influenced by HAV alignment and pedobarographic load, (4) evaluate how hindfoot alignment measured by visual means predicts HAV alignment, and (5) determine the best position in the HAV for ankle arthrodesis to reproduce the load distribution of healthy subjects.

Patients and Methods

We retrospectively reviewed all 236 patients who underwent ankle or TTC arthrodesis from 2003 to 2006. For this study we included patients meeting the following criteria: (1) with unilateral successful ankle or TTC fusion performed at the authors' institution with a minimal followup

of 2 years, (2) with complete preoperative and postoperative radiographs available on a DICOM/PACS system, and (3) living in the city or a maximum 1-hour drive away. We excluded patients with persistent painful nonunion (n = 5), who were bedridden (n = 22), deceased (n = 6), had amputations during followup (n = 8), with comorbidities that precluded walking over the pedobarograph (eg, blindness, neuromuscular diseases, paralysis of the lower extremity) (n = 7), with incomplete preoperative radiographs (n = 13), with incomplete data during followup (n = 8), living outside the city or more than 1 hour away (n = 23), refused to participate in the study (n = 32), or moved away to unknown addresses (n = 14). These exclusions left 98 patients with arthrodesis of the ankle (n = 56) or TTC (n = 42). The comorbidity score of Charlson et al. [8] was 0.8 ± 1.1. There were 65 men (66%) and 33 women (34%). Their average (± SD) age was 63 ± 11 years. Radiographic evidence of osteoarthritis according to the criteria of Giannini et al. [17] was found in the subtalar and midfoot joints in 93% of patients. Minimum followup was 2 years (average, 4 ± 1 years; range, 2–6 years).

To determine the physiologic varus-valgus load distribution, the pedobarographic data of 35 healthy subjects (70 feet) with no history of foot problems or disorders seen on clinical examination were used. No radiographs of the healthy subjects were available. There were 17 men (49%) and 18 women (51%) with an average age of 37 ± 12 years. All subjects provided informed consent to participate in the study. The study was approved by the ethical board of the authors' university. The study was performed in accordance with the World Medical Association Declaration of Helsinki.

Indications for surgery were osteoarthritis of the ankle and/or subtalar joint. Ankle fusions were performed using a transfibular approach using two 6.5-mm screws for tibiotalar fixation and two 3.5-mm screws for fixation of the fibula. TTC fusions were performed using a transfibular approach and a straight retrograde intramedullary nail (Biomet, Warsaw, IN; Stryker, Kalamazoo, MI). Alignment was adjusted by the surgeons' using visual judgment and intraoperative AP radiographs of the ankle.

Postoperatively, patients wore a cast and were nonweightbearing using crutches. After 2 weeks, the sutures were removed and the cast was changed. At 6 weeks, the cast was exchanged, radiographs were taken, and patients then were allowed to begin feather weightbearing. The cast was removed at 12 weeks and radiographs repeated. The criteria for union was radiographic evidence of complete bridging of the joint line/osteotomy site by trabeculae and absence of a visible joint line or gap as read by the hospital radiologist and the treating surgeon. If satisfactory union had occurred, the patient was permitted to ambulate with

full weightbearing. Otherwise, the patient was kept partial weightbearing and clinical and radiographic followups were performed at 4-week intervals until there was evidence of fusion. Thereafter, patients were followed clinically and radiographically at 1 and 2 years postoperatively and additional visits according to clinical needs.

The followup consisted of four parts: (1) AOFAS [22] and SF-36 scores [43]; (2) visual assessment of hindfoot alignment; (3) radiographic followup with AP view, lateral view, and HAV; and (4) dynamic pedobarography. Hindfoot alignment was judged visually using a goniometer. The patient was standing full weightbearing on both legs. The upper arm of the goniometer followed the axis of the calf, and the lower arm followed a parallel line of the lateral heel. One of three observers (AF, LH, LD) made measurement on the patients. According to the AOFAS score [22] and Chang et al. [7], hindfoot alignment was divided into five groups: neutral (0 to < 5° valgus); valgus (5°–10° valgus); severe valgus malalignment (> 10° valgus); varus (< 0 to −10° varus); and severe varus malalignment (< −10° varus).

The HAV was obtained as described by Saltzman and el-Khoury [37] (xray beam orientated 20° from the horizontal at a distance of 40 inches, 62 kV) (Fig. 1). The straight position (medial border of the feet parallel, knees in extension facing the film) was used as it was more reproducible than the natural position in which patients are xrayed in their natural amount of rotation [37]. A 6-cm lead strip was placed tangent to the most posterior aspect of the heel to assess radiographic magnification. Radiographs were evaluated by one blinded observer (AF, not a treating surgeon) trained in skeletal radiology on a high-resolution wide screen using a DICOM/PACS system. The intraobserver test revealed an intraclass correlation coefficient of 0.998 for distances and 0.996 for angles. As the film-object distance was larger on the HAV compared with on the AP view, we measured an average 16% magnification in the HAV, which was included in the measurements.

The following measurements were made on the HAV: HAV distance (HAVD), HAV angle (HAVA), lateral heel angle (LHA), frontal tibial ground angle (FTGA), and frontal strike angle (FSA). The HAVD was the distance from the most inferior point of the calcaneus to the tibial axis (lowest point lateral = positive value = valgus; lowest point medial = negative value = varus) (Fig. 3A) [37]. The HAVA was the angle created by a line drawn from the most inferior point of the calcaneus to the intersection of the tibial axis with the joint line, which was reconstructed in fused ankles using the medial malleolus as a reference from preoperative radiographs (valgus = positive, varus = negative values) (Fig. 3A). The LHA, which correlates best in the clinical setting with the visual impression, was the angle measured between the lateral calcaneal wall and
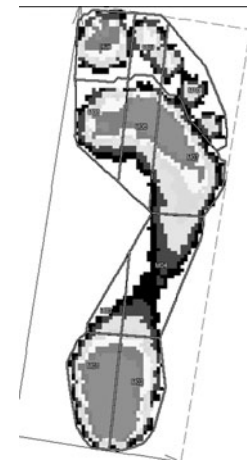
Fig. 3A–B The radiographs show the HAV of a right TTC arthrodesis. (**A**) The HAVD and HAVA are shown; white line = reconstruction of the joint line based on the length of the medial malleolus. (**B**) The FTGA and LHA are shown. A 6-cm lead strip at the bottom is used to assess radiographic magnification.

tibial axis (Fig. 3B). The FTGA was the angle between the tibia and the ground measured on the lateral side (Fig. 3B). The FSA was the angle at which the hindfoot ultimately hits the ground adding the FTGA to the HAVA (FSA = FTGA + HAVA − 90°).

All patients were examined using dynamic pedobarography on a 10-m runway made of hard plastic (Novel emed m/E, St Paul, MN, USA). To avoid effects of acceleration and deceleration, patients took five steps before and after hitting the platform (five-step method) [23]. Footprints outside the platform were excluded by the software. To obtain eight footprints accepted by the software, patients performed eight or more runs per foot. These footprints then were averaged by the software. The feet were analyzed barefoot in a Peter Richard Cavanagh (PRC) mask from the Novel scientific software (Fig. 4) [39]. The PRC mask divides the foot into 10 masks: lateral and medial heel; lateral and medial midfoot; forefoot consisting of first, second, and lateral metatarsal heads, hallux, second toe, and lateral toes. Boundaries between heel to midfoot and midfoot to forefoot were defined as 45% and 73% of length. The lateral and medial sections were defined by an axis drawn from the center of the heel to the center of the second toe. The first, second, and lateral metatarsal heads were separated by straight lines drawn parallel to the foot axis, which divided the forefoot region vertically from the medial to the lateral side into sections of 30%, 25%, and 45% [39].

Fig. 4 The PRC mask for pedobarographic evaluation divides the foot into lateral and medial heel, lateral and medial midfoot, and forefoot consisting of first, second, and lateral metatarsal head, hallux, second toe, and lateral toes.

The following parameters were calculated (Table 1): heel index (HI), strike point (SP, Fig. 5), coronal index (CI), lateral medial force-time integral index (LAMFIN, Fig. 6), lateral medial area index (LAMAI, Fig. 6), and gait line integral (GLI, Fig. 7). Data were extracted from pedobarography producing ASCII files, which then were reorganized into Excel® files (Microsoft Corp, Redmond, WA, USA) with custom-made software written in MATLAB® (The Mathworks Inc, Natick, MA, USA). The radiographic parameters were correlated by calculating the Pearson correlation coefficients (r). The significance level of r was corrected for multiple testing by dividing the significance level of 0.05 by the number of tests. The correlations of radiographic to pedobarographic parameters and SF-36 and AOFAS scores were calculated the same way. For comparison of visual and radiographic parameters, patients were grouped according to their HAVA in the same groups as for visual judgment. To evaluate the physiologic load pattern in patients with ankle and TTC arthrodesis, only pedobarographic parameters showing a correlation with r > 0.4 to HAVA were used. We used STATISTICA® Version 8.0 (StatSoft Inc, Tulsa, OK, USA) for all analyses.

Results

The average HAVA was −0.8° ± 7.8° for ankle and −1.2° ± 6.9° for TTC arthrodesis. The radiographic alignment measured by HAVA was neutral in 24%, varus in 53% (average varus for ankle, −7.1 ± 4°; for TTC, −5.8 ± 3°), and valgus in 24% (average valgus for ankle, 7.5 ± 5°; for TTC, 6.9 ± 4°). The average LHA was −10.5° ± 10.2° for ankle and −8.2° ± 12.6° for TTC arthrodesis.

The radiographic alignment on heel strike correlated (r = 0.35–0.42; p < 0.05 in all cases) with the HI in ankle

Table 1. Pedobarographic parameters, definitions, and clinical meaning

Pedobarographic parameter	Definition	Meaning
Heel index (HI)	= PTI ([medial heel − lateral heel]/total heel) (Fig. 4)	Medial load (positive value); lateral load (negative value)
Strike point (SP)	= initial heel contact measured on a line perpendicular to the anatomic axis of the foot through the initial heel contact; the medial border was defined as −100%, the lateral border as +100%, the middle of the heel as 0% (Fig. 5)	Positive value = lateral contact; negative value = medial contact
Coronal index (CI)	= PTI midfoot and forefoot ([medial − lateral]/total) (Fig. 4)	The CI shows loading of the foot medially (positive value) or laterally (negative value) divided by the anatomic axis of the foot
Lateral medial force-time integral index (LAMFIN)	= FTI ([lateral − medial]/total) (Fig. 6)	The LAMFIN shows if the load is more medial (negative value) or lateral (positive value) in relation to the gait line
Lateral medial area index (LAMAI)	= area ([lateral − medial]/total) (Fig. 6)	Gait line progresses medially (= more lateral area, positive value) or laterally (= more medial area, negative value)
Gait line index (GLI)	= area between the gait line and anatomic axis ([medial − lateral]/total) (Fig. 7)	GLI shows how the gait line progresses in relation to the anatomic axis of the foot (positive value = lateral, negative value = medial progression of the gait line)

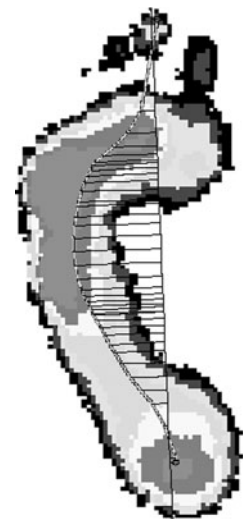PTI = pressure-time integral, FTI = force-time integral.

Fig. 5 The initial foot contact on heel strike (SP) was measured, defining the middle of the heel as 0%, the medial border as −100%, and the lateral border as +100% using the bisection of the plantar angle.

Fig. 7 GLI, the area between the gait line and the anatomic axis defined from the center of the heel to the center of the second toe during the rollover process of the foot, is shown in a patient with a TTC fusion.

Fig. 6 Pedobarography of a patient with a TTC arthrodesis revealed an isobaric pressure picture and division of the foot by the gait line, which is created by the center of pressure during the rollover process, into medial foot and lateral foot. This is used to calculate the LAMAI and LAMFIN.

(Table 2) but not in TTC arthrodesis (Table 3). Radiographic alignment had no influence on the SP in ankle (Table 2) or TTC arthrodesis (Table 3). During the rollover process, the HAVA had correlations with different pedobarographic parameters in ankle arthrodesis (CI, LAMFIN, GLI: r = |0.42–0.53|; p < 0.001 in all cases) (Table 2). In TTC arthrodesis, radiographic alignment also correlated (r = |0.48–0.49|; p < 0.001) with the CI and LAMFIN in all cases (Table 3). However, with the fused hindfoot, the GLI correlation was weaker (r = −0.35; p = 0.02). The LHA also correlated (r = |0.34–0.6|; p = 0.01 to < 0.001) with pedobarographic load parameters in ankle (Table 2) and TTC arthrodesis (Table 3). The

Table 2. Correlations of radiographic and pedobarographic parameters in ankle arthrodesis (n = 56)

Parameter	HAVD	HAVA	LHA	FTGA	FSA	Visual
HI	0.42*	0.40*	0.38*	0.09	0.35*	0.15
SP	−0.05	−0.06	−0.24	0.02	−0.04	−0.12
CI	0.43*	0.42*	0.34*	0.18	0.40*	0.04
LAMFIN	−0.50[*,†]	−0.48[*,†]	−0.43[*,†]	0.01	−0.38*	−0.05
LAMAI	−0.27	−0.26	−0.28	−0.07	−0.23	−0.09
GLI	−0.51[*,†]	−0.53[*,†]	−0.50[*,†]	−0.25	−0.51[*,†]	−0.05

* Significant correlations; [†]significant correlations after correction for multiple testing; HAVD = hindfoot alignment view distance; HAVA = hindfoot alignment view angle; LHA = lateral heel angle; FTGA = frontal tibial ground angle; FSA = frontal strike angle; HI = heel index; SP = strike point; CI = coronal index; LAMFIN = lateral medial force-time integral index; LAMAI = lateral medial area index; GLI = gait line index.

Table 3. Correlations of radiographic and pedobarographic parameters in TTC arthrodesis (n = 42)

Parameter	HAVD	HAVA	LHA	FTGA	FSA	Visual
HI	0.02	−0.01	0.08	0.17	0.07	−0.10
SP	0.09	0.10	0.03	0.12	0.14	0.12
CI	0.44*	0.48*	0.51[*,†]	−0.18	0.32*	0.40*
LAMFIN	−0.45*	−0.49[*,†]	−0.60[*,†]	0.26	−0.30	−0.42*
LAMAI	−0.29	−0.32*	−0.47*	0.14	−0.20	−0.23
GLI	−0.34*	−0.35*	−0.54[*,†]	0.01	−0.29	−0.35*

* Significant correlations; [†]significant correlations after correction for multiple testing; TTC = tibiotalocalcaneal; HAVD = hindfoot alignment view distance; HAVA = hindfoot alignment view angle; LHA = lateral heel angle; FTGA = frontal tibial ground angle; FSA = frontal strike angle; HI = heel index; SP = strike point; CI = coronal index; LAMFIN = lateral medial force-time integral index; LAMAI = lateral medial area index; GLI = gait line index.

Table 4. Correlations (r values) of radiographic parameters of hindfoot alignment

Parameter	Visual	HAVD	HAVA	LHA	FTGA
HAVD	0.48[*,†]				
HAVA	0.50[*,†]	0.99[*,†]			
LHA	0.52[*,†]	0.67[*,†]	0.69[*,†]		
FTGA	0.11	0.27*	0.27*	0.19	
FSA	0.45[*,†]	0.91[*,†]	0.92[*,†]	0.63[*,†]	0.63[*,†]

* Significant correlations; [†]significant correlations after correction for multiple testing; HAVD = hindfoot alignment view distance; HAVA = hindfoot alignment view angle; LHA = lateral heel angle; FTGA = frontal tibial ground angle; FSA = frontal strike angle.
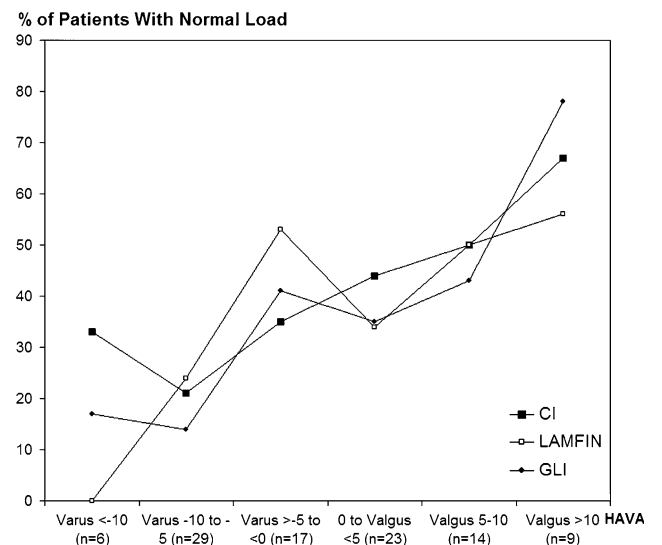

Fig. 8 A graph shows the percentages of patients with a normal dynamic load pattern, defined in the range of the mean and ± one SD of each parameter, after ankle and TTC arthrodesis. The amount of valgus position correlated (r = 0.84–0.9; p < 0.05) with the percentage of patients with a normal load distribution.

FSA did not correlate as well with pedobarographic data as the HAVA (Tables 2, 3).

There was no correlation of radiographic alignment with AOFAS or SF-36 scores. The dynamic load distribution correlated with AOFAS and SF-36 scores in ankle arthrodesis: The LAMAI correlated with gait abnormality of the AOFAS score in ankle arthrodesis (r = 0.41; p = 0.02), showing the more medially the gait line runs, the better the observed gait. LAMAI also correlated with Body Pain (r = 0.42; p = 0.001) and Vitality of the SF-36 (r = 0.44; p = 0.001), showing a more medial gait line results in less pain and better vitality. For TTC arthrodesis, no correlation of pedobarography with SF-36 or AOFAS scores was noted.

The visual alignment was neutral in 45%; 39% had a varus, whereas 16% had a valgus position. Visual alignment correlated with HAVA (r = 0.5; p < 0.001) and LHA

(r = 0.52; p < 0.0001) (Table 4). However, visual judgment predicted radiographic alignment correctly in only 48% of cases (accuracy, 5.5° ± 4°). Radiographically, the HAVA correlated (r = 0.69; p < 0.001) with LHA. The HAVD correlated (r = 0.99; p < 0.0001) with HAVA.

Pedobarographic measurements from healthy subjects showed the load during the rollover process was greater medially than laterally (CI, 0.33 ± 0.11; LAMFIN, −0.053 ± 0.11) and the center of pressure ran more medially (GLI, −0.54 ± 0.31). The amount of valgus positioning correlated with the percentage of patients with a normal load distribution measured by the CI, LAMFIN, GLI (r = 0.84–0.9; p < 0.05). In ankle and TTC arthrodesis, an HAVA of 5° to 10° or greater valgus was needed to reproduce the dynamic values of normal subjects in more than half the patients (Fig. 8).

Discussion

The HAV according to Saltzman and el-Khoury [37] is considered the best view to assess alignment of the hindfoot toward the tibia. In this view, healthy subjects showed medial displacement of the calcaneus corresponding to the varus position [15]. However, Buck et al. [5] suggested a valgus position was best for ankle arthrodesis. As radiographs only show so-called static alignment and the initial heel strike occurs laterally, it is unclear how radiographic alignment influences dynamic load during gait. Therefore, we assessed the hindfoot position in ankle or TTC arthrodesis by HAV, evaluated the influence of radiographic alignment on pedobarographic load and SF-36 and AOFAS scores, evaluated the prediction of radiographic alignment by visual judgment, and measured the pedobarographic varus/valgus load of healthy subjects to determine which is the best HAV position for ankle and TTC arthrodesis.

The study has several limitations. First, as this study was the first to correlate radiographic to pedobarographic alignment, we had no previous data to make a power analysis. Final sample size was one of convenience determined by the size of the cohort from 2003 to 2006. Second, as healthy subjects were recruited in an earlier study, there was no age or gender match as neither obviously influenced varus/valgus load patterns [3]. Third, one could argue, in the straight position for obtaining the HAV radiographs, there is an unnatural amount of internal rotation. However, no difference between the amount of external rotation and hindfoot alignment was found, but the straight position was more reproducible [37]. Fourth, we did not obtain radiographs of the contralateral side, which would have helped to determine the influence of built-in external rotation of 5° to 10° in ankle arthrodesis [5]. Fifth, visual judgment was made by three different observers as patients were seen for followups. Because visual judgment is inaccurate [1, 36, 38, 44], a certain variance must be assumed which may have reduced the correlation of visual with radiographic alignment. Sixth, measurements were made with the patients in bare feet. Even though we rarely walk barefoot, because there is such a wide variety of shoe wear and shoes alter the pedobarographic examination to such a degree that meaningful results cannot be measured, measurements frequently are made with the patient barefoot [2, 6, 14, 16, 19, 20, 26, 28, 40, 41]. We cannot presume we would have the same findings were the patients wearing shoes.

Intraoperative positioning by visual means resulted in a slight varus position of −1° and a relatively large SD of 7° to 8°. This is consistent with the findings of Coester et al. [12] who also measured a medial calcaneal displacement of 1.5 mm in a 22-year followup of 23 patients with ankle arthrodesis. Navigation [34, 35] and intraoperative pedobarography [33] are the only tools described to enhance the precision of intraoperative positioning of the hindfoot. However, the load distributions of ambulatory and anesthetized subjects are not comparable. In addition to inadequacy of visual positioning, the varus position might have resulted from the use of straight intramedullary nails in TTC arthrodesis, which forces the hindfoot into varus making intramedullary nails with built-in valgus preferable.

Our data suggest radiographic alignment of the HAV influences the dynamic load distribution. Chang et al. [7] found a correlation of the visual hindfoot position with dynamic load in spastic feet in patients with cerebral palsy.

We found no correlation of radiographic hindfoot alignment with SF-36 or AOFAS scores. However, to conclude a fusion in any position is acceptable cannot be made because of the short followup of the study; with a longer followup, differences might be discovered. In a 10-year followup of ankle arthrodesis, Buck et al. [5] found a valgus position is more advantageous and provides a more normal gait. The missing correlation of radiographic alignment with SF-36 and AOFAS scores also might be explained by the facts that almost all patients had comorbidities (eg, rheumatoid arthritis, heart disease, pulmonary disease, obesity, mental illness, postspinal or shoulder surgery), which decreased AOFAS and SF-36 scores unrelated to any foot condition and that 93% of patients had arthritis in the subtalar and/or midfoot joints at the time of followup.

Visual judgment only predicted radiographic alignment in 48%. The inaccuracy of visual judgment also has been reported by others [1, 36, 38, 44]. Although the reliability of clinical measurement is improved by using a goniometer and a weightbearing position, clinical approaches are less reliable than a radiographic approach [5, 13, 38].

Our findings of healthy subjects show 33% more load medially related to the anatomic axis of the foot. Richter et al. [33] assumed a 50:50 medial:lateral force distribution for intraoperative pedobarography without measuring healthy subjects. Others have found a medial displacement of the hindfoot in healthy subjects corresponding to a slight varus position of 1° to 6° [21, 37, 42]. This raises the question of why the best position of an ankle arthrodesis should be in 0° to 10° valgus according to Buck et al. [5], Morrey and Wiedeman [29], and our results. Support for hindfoot valgus is based on the concept that valgus position causes pronation of the foot that unlocks the midtarsal joints, allowing more natural motion of the hindfoot, whereas varus locks the midtarsal joints [25, 30]. Another rationale might be that the ankle exhibits inversion/eversion of 5° [24], which is not possible with arthrodesis; thus the hindfoot must be in slight valgus.

We believe the HAV should be performed routinely to assess hindfoot alignment. Ankle and TTC arthrodesis should be fused in valgus of 5° to 10° in the HAV to reproduce a physiologic load pattern. Better means for intraoperative positioning are needed to obtain a valgus hindfoot position and greater precision, as for example in TKA. New alignment techniques, such as navigation, intraoperative pedobarography, or extramedullary alignment guides, should be developed further. Varus position occurs because visual judgment is not accurate and because the use of a straight nail in TTC may force the hindfoot into varus. Therefore, intramedullary nails with built-in valgus may be preferable to straight nails.

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