Static Rearfoot Alignment

A Comparison of Clinical and Radiographic Measures

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Foot structure is typically evaluated using static clinical and radiographic measures. To date, the literature is devoid of a correlation between rearfoot frontal plane radiographic parameters and clinical measures of alignment. In a repeated-measures study comparing radiographic and clinical rearfoot alignment in 24 healthy subjects, radiographic angular measurements were made from standard weightbearing anteroposterior, lateral, long leg calcaneal axial, and rearfoot alignment views. Clinical measurements were made using a jig and scanner to assess the malleolar valgus index and a goniometer to evaluate the resting and neutral calcaneal stance positions. There was a significant correlation between frontal plane radiographic angles (long leg calcaneal axial and rearfoot alignment views) ($r = 0.814$). Similarly, there was a significant correlation between clinical measures (resting calcaneal stance position and malleolar valgus index) ($r = 0.714$). A multivariate stepwise regression showed that resting calcaneal stance position can be accurately predicted from 3 of the 15 clinical and radiographic measurements collected: malleolar valgus index, rearfoot alignment view, and long leg calcaneal axial view ($r = 0.829$). In summary, a commonly used clinical measure of static rearfoot alignment, resting calcaneal stance position, was correlated closely with the malleolar valgus index and both frontal plane radiographic parameters. (J Am Podiatr Med Assoc 95(1): 26-33, 2005)

Surgeons typically perform hand-held goniometric clinical measurements to obtain segmental alignment data, joint range-of-motion measures, and radiographic angles to assist in the diagnosis and treatment of most foot and ankle pathologies. However, routine radiographic evaluations of the rearfoot frequently ignore a frontal plane examination to assess the varus or valgus alignment. Frontal plane radiographs are usually thought to be more difficult to obtain because of the specialized equipment and techniques required and, therefore, are used less frequently. Foot and ankle surgeons commonly use their clinical evaluation to determine frontal plane rearfoot and ankle alignment.

Although radiographs have been well documented for identification of the level and extent of osseous deformity, the literature shows only limited use in the frontal plane.[1] Harris and Beath[2] were the first to develop a frontal plane radiograph of the heel, and it was later refined by Kleiger and Mankin[3] into what is now known as a long leg calcaneal axial view. This radiograph shows the relationship of the calcaneus to the leg and best visualizes the subtalar joint space (Fig. 1A). Another frontal plane technique was de-

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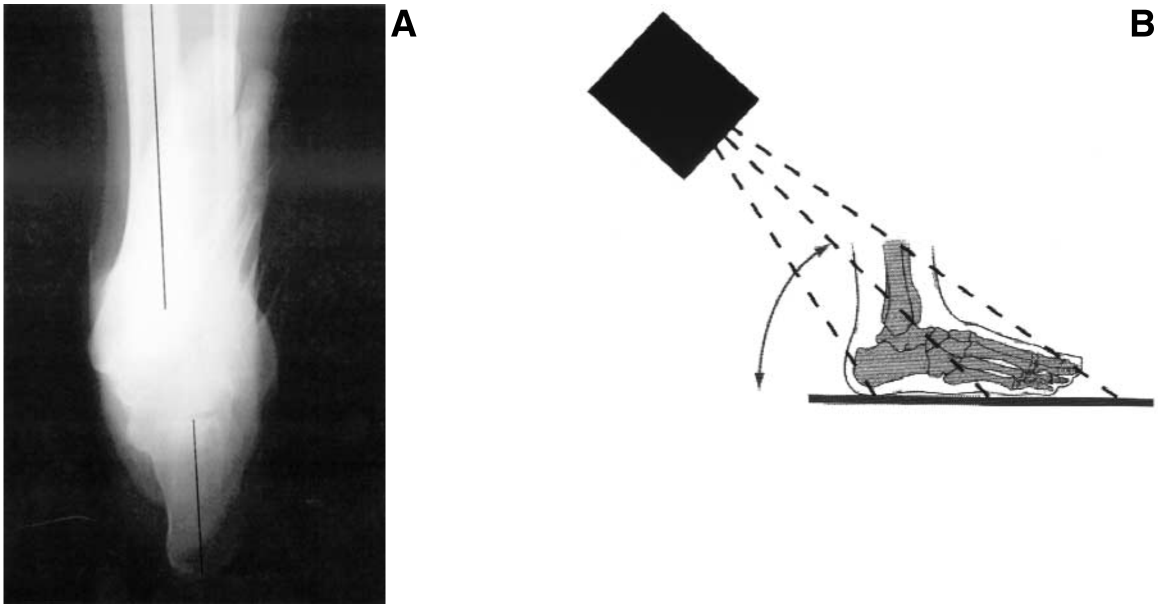

A B

Figure 1. Long leg calcaneal axial view. A, This radiograph captures the distal one-third of the tibia, the subtalar joint, and the calcaneus. B, This view is taken with the subject standing in a ski-jumping position, with the involved limb centered on the film (14 × 17 inches) (the uninvolved limb is in front of the film). The heel is closest to the edge of the film that faces the tube head (the central beam is centered at the subtalar joint). The involved ankle is dorsiflexed 10° (maximum dorsiflexion), and the knee is extended. The tube head is positioned posterior to the involved limb, 40 inches from the heel, is declinated at a 45° angle to the vertical, and is set at 6 mA sec and 70 kVp.

scribed by Cobey[4] in 1976 and was later modified by Buck et al,[5] Saltzman and el-Khoury,[6] and Johnson et al.[7] This rearfoot alignment view best visualizes the ankle joint space and, like the long leg calcaneal axial view, shows the relationship of the calcaneus to the leg (Fig. 2A).

Several studies[6, 8, 9] have determined that radiographic measurements are more reliable than goniometric assessments. Unlike goniometric measures, which are variable, the malleolar valgus index is a clinical technique that quantitatively measures rearfoot position during static stance. Because the malleolar valgus index is a static measure that has been correlated to dynamic measures, it has been called a measure of static rearfoot function.[10] The malleolar valgus index incorporates a computerized scanned image of the foot and transmalleolar axis. The resulting footprint allows one to calculate the center of the ankle and the center of the foot (forefoot and rearfoot). In contrast to resting calcaneal stance position, a well-accepted clinical measure of frontal plane rearfoot alignment, the malleolar valgus index technique accounts for the influence of the forefoot and structures proximally up the kinetic chain.[10, 11]

Resting calcaneal stance position has been the primary measurement for rearfoot alignment. However, with the increased use of long leg calcaneal axial and rearfoot alignment frontal plane radiographs, we believe that these radiographs might be a more accurate, repeatable measurement of rearfoot alignment. The purpose of this study was to objectively evaluate static rearfoot alignment by correlating frontal plane radiographic and clinical measurements in healthy adults.

Materials and Methods

A random sample of 24 healthy adults was evaluated at the Foot and Ankle Institute of Western Pennsylvania, Pittsburgh. The right foot of each subject was assessed clinically and radiographically. Standard weightbearing foot radiographs (anteroposterior and lateral to include the tibia) were obtained for each subject. In addition, long leg calcaneal axial and rearfoot alignment views were obtained (Figs. 1B and 2B). Note that long leg calcaneal axial and rearfoot alignment frontal plane radiographs are taken in two different postures. The long leg calcaneal axial view is measured while the subject stands with one limb anterior and the other limb posterior in a “wall push-up” posture (Fig. 1B). The posterior limb is dorsiflexed approximately 10° and is imaged in a posteroanterior

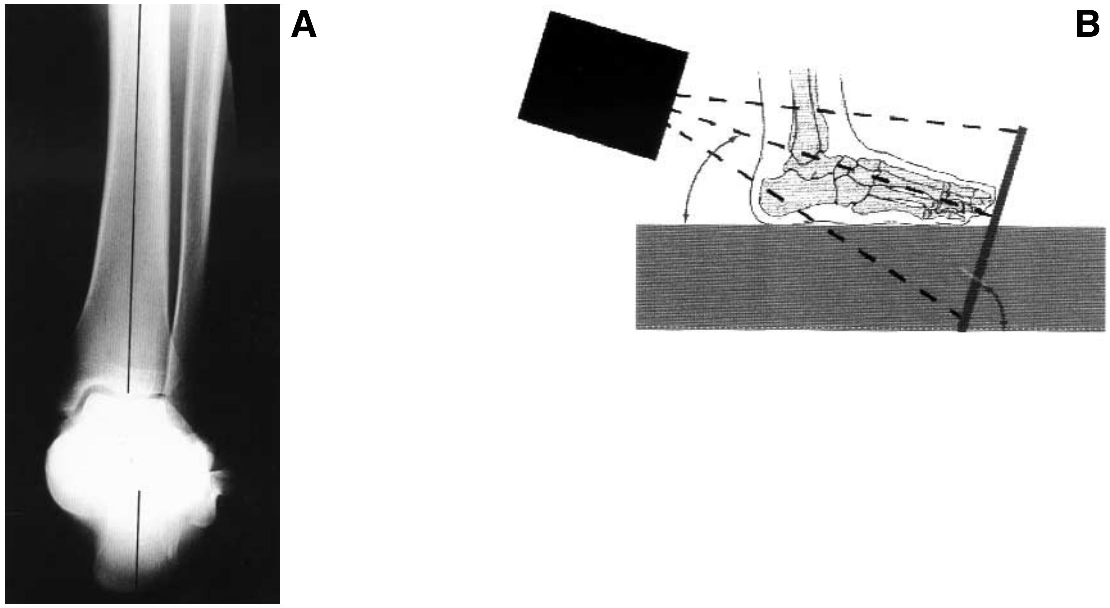

Figure 2. Rearfoot alignment view. A, This radiograph captures the distal one-third of the tibia, the ankle joint, the calcaneus, and the horizontal reference line (the floor), which is represented by the Plexiglas jig. B, This view is taken with the subject standing in the angle and base of gait on a Plexiglas box with the involved limb perpendicular to the film (14 × 17 inches), which is placed anterior to the box at a 15° angle to the vertical. The first digit rests against the film and the tube head (the central beam is centered at the ankle joint), which is set at 40 inches posterior to the involved limb, is declinated at a 15° angle to the horizontal (perpendicular to the film), and is set at 6 mA sec and 70 kVp.

orientation. The rearfoot alignment view is also captured in a posteroanterior orientation but with the subject standing in comfortable angle and base of support (Fig. 2B).

From the aforementioned multiplanar weightbearing foot and ankle radiographs, the following angles were measured: calcaneal inclination angle, talar declination angle, anatomical anterior distal tibial angle, talar–first metatarsal angle (in the sagittal and transverse planes), angle between the mid-diaphyseal line of the tibia and the calcaneal bisection line (long leg calcaneal axial or rearfoot alignment pending posture), anatomical lateral distal tibial angle, and talocalcaneal angle (Kites) (Figs. 3–5). The calcaneal bisection line, the frontal plane axis of the posterior heel, was obtained from the bisector of the radiographic silhouette of the calcaneus.[4, 7] All corresponding radiographic angles were measured using an X-Caliper digital measuring device (Eisenlohr Technologies, Davis, California). For each subject, the senior author (B.M.L.) collected all radiographic and clinical measurements twice, and the average was calculated.

A standard biomechanical foot and ankle examination was performed on each subject using the methods described by Root et al.[11] Nonweightbearing measures of the subtalar joint in the maximum eversion, maximum inversion, and neutral positions were collected while the subject lay prone with the contralateral foot behind the ipsilateral knee (Fig. 6). The forefoot-rearfoot relationship was also assessed in the nonweightbearing prone position by loading the fourth and fifth rays (varus, rectus, or supinatus). The resting and neutral calcaneal stance positions were determined while the subject stood in the angle and base of gait (Fig. 7).

An Epson Perfection 636U scanner (Epson, Long Beach, California) and malleolar valgus index jig was used to collect and calculate the malleolar valgus index. The malleolar valgus index is determined from a scanned image of the plantar aspect of the foot during quiet standing. In the barefoot condition, each subject stood on a $^{7}/_{8}$-inch-thick Plexiglas (Röhm, Darmstadt, Germany) platform that straddled a flatbed scanner. The malleolar valgus index jig, adjusted to fit and be aligned with each subject's transmalleolar axis, registered the medial and lateral malleoli to the scanned image of the foot (Fig. 8).[10] The scanned footprint was imported into a public domain program from the National Institutes of Health (NIH Image, version 1.55) and was expressed in eight levels of gray. A foot coordinate system was developed from each image to calculate the bisections of the

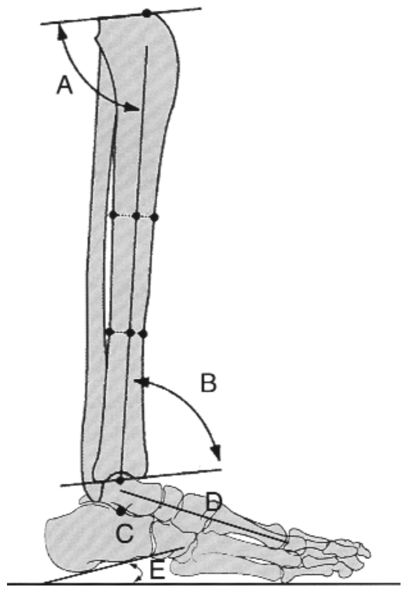

Figure 3. The following angles and distances were measured on a lateral weightbearing radiograph of the foot, ankle, and leg: anatomical posterior proximal tibial angle (normal = 81°) (A), anatomical anterior distal tibial angle (normal = 80°) (B), talar declination angle (normal = 21°) and talar–first metatarsal angle (normal = 0°) (D), and calcaneal inclination angle (normal = 21°) (E). The anterior or posterior distance between the extended mid-diaphyseal line of the tibia and the lateral process of the talus (C) is also measured (normal = 0 mm). In addition, the angle between the mid-diaphyseal line of the tibia and the plantar aspect of the foot is measured (plantargrade angle) (normal = 90°).

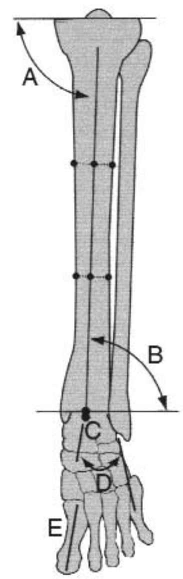

Figure 4. The following angles and distances were measured on an anteroposterior weightbearing radiograph of the foot, ankle, and leg: anatomical medial proximal tibial angle (normal = 87°) (A), anatomical lateral distal tibial angle (normal = 89°) (B), talocalcaneal angle (normal = 21°) (D), and talar–first metatarsal angle (normal = 0°) (E). The medial or lateral distance between the mid-diaphyseal line of the tibia and the center of the talar dome (C) is also measured (normal = 0 mm).

forefoot and rearfoot (foot bisection) and the transmalleolar axis. The malleolar valgus index was defined as the difference between these parameters divided by the transmalleolar width and multiplied by 100 to yield a percentage (Fig. 9). After repositioning (marching in place), each subject was scanned a second time, and the two resultant malleolar valgus index percentages were averaged. Originally developed by Song et al,[10] the malleolar valgus index provides investigators with an objective measure of each subject's static rearfoot function.

A simple linear regression was performed in StatView, version 5.0 (SAS Institute Inc, Cary, North Carolina) to determine the relationship (correlation coefficient) and its significance for all radiographic angular and clinical goniometric measures and the malleolar valgus index. In addition, a multivariate stepwise regression was used for predicting the resting calcaneal stance position and the malleolar valgus index.

Results

The right feet of 24 healthy individuals (5 women and 19 men) were evaluated. The mean age of this cohort was 28 years (range, 24–40 years). The mean malleolar valgus index (static rearfoot function) was 8.95%, and the mean resting calcaneal stance position was 1.7° of valgus. The rearfoot alignment averaged 0.8° of varus and the long leg calcaneal axial view averaged 2.1° of varus. A simple linear regression showed that the long leg calcaneal axial and rearfoot alignment radiographic measurements demonstrated a significant correlation ($r = 0.814$; $P < .0001$).

Linear regression values between resting calcaneal stance position and the clinical and radiographic parameters are summarized in Table 1. Poor correlations were associated with $r < 0.5$; fair correlations, $r = 0.5$ to 0.69; good correlations, $r = 0.7$ to 0.89; and excellent correlations, $r = 0.9$ to 1.0. Only one parameter had a good correlation (malleolar valgus index). The multivariate stepwise regression showed that resting calcaneal stance position could be predicted from 3 of the 15 aforementioned clinical

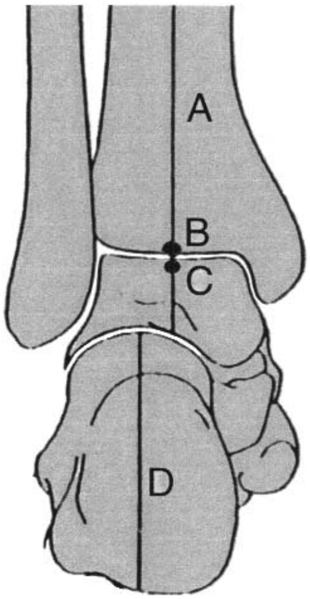

Figure 5. The angles measured on an axial or rearfoot alignment weightbearing radiograph of the foot, ankle, and leg include the angle between the mid-diaphyseal line of the tibia (A) and the calcaneal bisection line (D) (normal = 0°–2° valgus). As on the anteroposterior radiograph of the ankle, the center of the talar dome (C), the mid-diaphyseal line of the tibia (A), and the center of the tibial plafond (B) should all coincide.

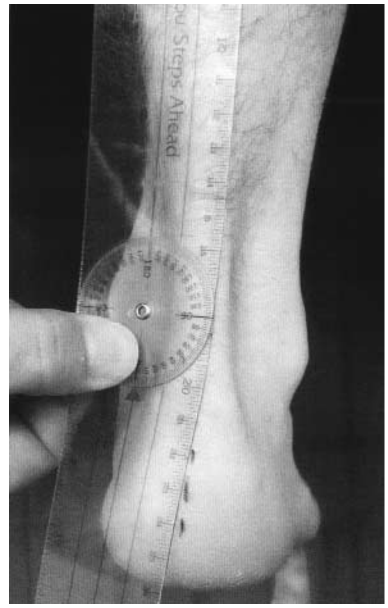

Figure 6. The clinical nonweightbearing goniometric measurement of the subtalar joint neutral position is shown. The bisection of the heel to the bisection of the leg (the bisection of the medial and lateral heads of the gastrocnemius muscle) is measured while the patient's ankle is held in the neutral position (the foot at 90° to the leg and after palpation of talar-navicular congruity).

and radiographic measurements (malleolar valgus index, rearfoot alignment view, and long leg calcaneal axial view) (r = 0.829; P < .0001). An improved correlation coefficient was obtained by using four parameters (malleolar valgus index, rearfoot alignment view, long leg calcaneal axial view, and anatomical anterior distal tibial angle) for the prediction of resting calcaneal stance position (r = 0.852; P < .0001).

Linear regression values between the malleolar valgus index and the clinical and radiographic parameters are summarized in Table 2. Only the long leg calcaneal axial view and resting calcaneal stance position had good correlations with the malleolar valgus index. A multivariate stepwise regression was conducted to determine whether the malleolar valgus index could be predicted from a subset of the linear regression parameters. When only 2 of the 15 aforementioned clinical and radiographic measurements were used (resting calcaneal stance position and rearfoot alignment view), a good correlation was obtained (r = 0.857; P < .0001). When long leg calcaneal axial view was substituted for rearfoot alignment view in this model, a good correlation was obtained as well (r = 0.835; P < .0001). This correlation

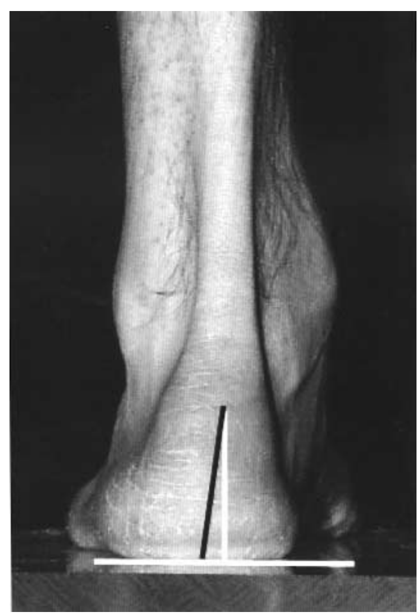

Figure 7. Resting calcaneal stance position is measured while the patient is standing in the angle and base of gait. As shown, this measurement is the angle formed between the bisection of the heel and a line parallel to the floor (the white line represents a vertical heel or 0°).

Figure 8. Malleolar valgus index data are collected while the subject is in barefoot static stance. Subjects stood on a $^{7}/_{8}$-inch-thick Plexiglas platform that straddled a flatbed scanner. An additional jig, adjusted to fit and be aligned with each subject's transmalleolar axis, registered the medial and lateral malleoli.

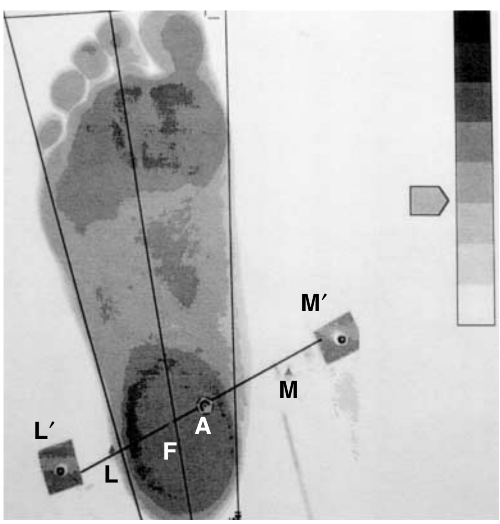

Figure 9. The scanned footprint was imported into a public domain program from the National Institutes of Health (NIH Image, version 1.55) and was expressed in eight levels of gray. A foot coordinate system was developed from each image to calculate the bisections of the transmalleolar axis and the width of the rearfoot. The malleolar valgus index was defined as the difference between these parameters divided by the transmalleolar width, as originally developed by Song et al.[10] L′ and M′ indicate the locations of the lateral and medial malleolar jig; L, the lateral malleolus; M, the medial malleolus; F, the center of the rearfoot; and A, the center of the ankle.

Table 1. Predictions of Resting Calcaneal Stance Position Using Linear and Multivariate Regressions

Parameter	r	P Value
	Linear Regression Model	
MVI	0.714	<.0001[a]
STJN	0.577	.0031[a]
STJ_{ev}	0.457	.0247[a]
STJ_{inv}	0.139	.5183
NCSP	0.549	.0055[a]
RA	0.084	.6949
LLCA	0.433	.0347[a]
aLDTA	0.269	.2034
aADTA	0.113	.5989
Kites	0.248	.2433
$T1M_{trans}$	0.024	.911
$T1M_{sag}$	0.161	.4511
CIA	0.183	.3928
TDA	0.191	.4811
	Multivariate Regression Model	
MVI + STJN	0.757	<.0001[a]
MVI + STJN + NCSP	0.769	<.0001[a]
MVI + RA	0.795	<.0001[a]
MVI + RA + LLCA	0.829	<.0001[a]
MVI + RA + LLCA + aADTA	0.852	<.0001[a]

Abbreviations: MVI, malleolar valgus index; STJN, subtalar joint neutral; STJ_{ev}, subtalar joint maximum eversion; STJ_{inv}, subtalar joint maximum inversion; NCSP, neutral calcaneal stance position; RA, rearfoot alignment view; LLCA, long leg calcaneal axial view; aLDTA, anatomical lateral distal tibial angle; aADTA, anatomical anterior distal tibial angle; Kites, talocalcaneal angle; $T1M_{trans}$, talar–first metatarsal angle (transverse plane); $T1M_{sag}$, talar–first metatarsal angle (sagittal plane); CIA, calcaneal inclination angle; TDA, talar declination angle.

[a]Statistically significant.

could be improved to an excellent rating by using five variables (resting calcaneal stance position, rearfoot alignment view, calcaneal inclination angle, talar–first metatarsal angle in the transverse plane, and anterior distal tibial angle) to predict the malleolar valgus index ($r = 0.901$; $P < .0001$).

Discussion

The mean malleolar valgus index (static rearfoot function) was 8.95%. Similarly, Song et al[10] found an average malleolar valgus index of 7.3% in their rectus population. In addition, the mean resting calcaneal stance position was 1.71° of valgus, which correlates to the rectus foot type.

Table 2. Predictions of Malleolar Valgus Index Using Linear and Multivariate Regressions

Parameter	r	P Value
	Linear Regression Model	
RCSP	0.714	<.0001[a]
STJN	0.505	.0119[a]
STJ_{ev}	0.462	.0229[a]
STJ_{inv}	0.034	.8749
NCSP	0.402	.0516
RA	0.533	.0074[a]
LLCA	0.699	.0001[a]
aLDTA	0.276	.1921
aADTA	0.32	.127
Kites	0.293	.1644
$T1M_{trans}$	0.22	.3025
$T1M_{sag}$	0.085	.6932
CIA	0.457	.0249[a]
TDA	0.11	.6095
	Multivariate Regression Model	
RA + LLCA	0.702	.0008[a]
RCSP + LLCA	0.835	<.0001[a]
RA + RCSP	0.857	<.0001[a]
RA + RCSP + LLCA	0.858	<.0001[a]
RA + RCSP + CIA + $T1M_{trans}$ + aADTA	0.901	<.0001[a]

Abbreviations: RCSP, resting calcaneal stance position; STJN, subtalar joint neutral; STJ_{ev}, subtalar joint maximum eversion; STJ_{inv}, subtalar joint maximum inversion; NCSP, neutral calcaneal stance position; RA, rearfoot alignment view; LLCA, long leg calcaneal axial view; aLDTA, anatomical lateral distal tibial angle; aADTA, anatomical anterior distal tibial angle; Kites, talocalcaneal angle; $T1M_{trans}$, talar–first metatarsal angle (transverse plane); $T1M_{sag}$, talar–first metatarsal angle (sagittal plane); CIA, calcaneal inclination angle; TDA, talar declination angle.

[a]Statistically significant.

This pilot study demonstrated a significant correlation between the long leg calcaneal axial and the rearfoot alignment radiographs ($r = 0.814$; $P < .0001$). These results indicate that the arc formed by the mid-diaphyseal line of the tibia to the calcaneal bisection line is basically unchanged whether the patient is in the wall push-up position (as measured on the long leg calcaneal axial radiograph) or their angle and base of gait (as measured on the rearfoot alignment radiograph). No previous study has correlated these frontal plane radiographic views (long leg calcaneal axial and rearfoot alignment), and most noteworthy is the fact that the angular measure is essentially unchanged between these two frontal plane radiographs.

The long leg calcaneal axial radiograph demonstrated a stronger correlation to the malleolar valgus index ($r = 0.699$) than did the rearfoot alignment radiograph ($r = 0.533$). Because the malleolar valgus index and rearfoot alignment radiographs are both collected while the subject is standing in the angle and base of gait, this seems counterintuitive because the long leg calcaneal axial radiograph is collected while the subject is in a wall push-up posture. However, the long leg calcaneal axial radiograph and the malleolar valgus index are potentially more sensitive to forefoot and midfoot contributions to rearfoot alignment. The long leg calcaneal axial radiograph was also better correlated with resting calcaneal stance position ($r = 0.433$).

Resting calcaneal stance position showed a good correlation to the malleolar valgus index ($r = 0.714$), which is consistent with the results of Song et al[10] ($r = 0.82$). The multivariate stepwise regression showed that resting calcaneal stance position could be predicted from 3 of the 15 aforementioned clinical and radiographic measurements (malleolar valgus index, rearfoot alignment view, and long leg calcaneal axial view) ($r = 0.829$; $P < .0001$). Therefore, using a basic goniometric measurement (resting calcaneal stance position), the two frontal plane radiographs (long leg calcaneal axial and rearfoot alignment views) and a static clinical measure (malleolar valgus index) are all closely interrelated.

Altering foot structure by using conservative methods (orthoses, taping, splinting, and bracing) or surgical realignment is a common goal for the correction of most foot and ankle dysfunction. Accurate evaluation of static foot structure is important for the correct treatment to produce good outcomes. The frontal plane radiographs (long leg calcaneal axial and rearfoot alignment views) evaluated in this study were related to clinical rearfoot alignment. Given the greater availability of radiographs, we stress the importance of using and understanding these typically ignored frontal plane radiographs. The inexactness of goniometric measurement and the difficulty in acquiring specialized instrumentation required to measure the malleolar valgus index make these standard frontal plane radiographs essential to an accurate analysis. Both frontal plane radiographic views may be performed intraoperatively, an option that is not available with the malleolar valgus index or not accurate with resting calcaneal stance position. These measures are also not as likely to be subject to soft-tissue errors such as those imposed by the calcaneal fat pad on resting calcaneal stance position. Ultimately, we anticipate that the rearfoot alignment and long leg calcaneal axial radiographs will help us better evaluate the origin and severity of rearfoot and ankle pathologies.

Conclusion

Clinical and radiographic measures are the foundation from which surgeons evaluate and preoperatively plan a patient's treatment. This preliminary study of healthy individuals demonstrated that resting calcaneal stance position, a common clinical goniometric measure, can be predicted from the malleolar valgus index, a reliable measure of static foot alignment, and both frontal plane radiographs (long leg calcaneal axial and rearfoot alignment views). Therefore, this study proved that frontal plane clinical and radiographic measurements are closely related. These results designate frontal plane radiographic measurement as a critical assessment. The malleolar valgus index is an accurate instrument that quickly characterizes and classifies foot types, but it is not easily accessible to the clinical community. Although goniometric measures are commonly performed, they are generally less reliable than radiographic measures. Frontal plane radiographs are simple to obtain and provide quantitative measures that document malalignments and deformities about the rearfoot and ankle.

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