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Interobserver Analysis of Standard Foot and Ankle Radiographic Angles

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ABSTRACT

Standard foot and ankle radiographs have long been studied and averages formulated in an attempt to provide a common framework for understanding the relationships of the foot and ankle, not only for surgical planning but also to determine normal versus abnormal relationships. The authors describe 8 angles measured on 100 patients by up to 18 observers (4 attending physicians, 12 residents, and 2 students). This study validates the previously documented normal angles using a significantly larger observer group as well as a greater number of analyzed angles. Additionally, this study reveals the tibio-second metatarsal angle on the calcaneal axial view is not a reliable radiographic angle for evaluation of foot and ankle deformity. Intraclass correlation coefficients were also analyzed, which displayed variability in measurements based on level of training, with residents being the most accurate, followed by attending physicians and then students. Foot and ankle radiographs are essential for surgical planning, and understanding normal versus abnormal is key before any surgical planning can be accurately performed.

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Foot and ankle radiology has provided the means to perform arthrometric measurements or measurements of the mobility of joints. Comparison of one osseous structure to another provides foot and ankle surgeons with the ability to distinguish normal versus abnormal relationships between the osseous structures of the foot and ankle (1). Standard radiographic values have been documented in multiple articles (2–6) published within both the podiatric and the orthopedic literature (Table 1). Normal values have been established by using weightbearing radiographs to show the foot in a locked and static position, while also exhibiting the kinetic and functional condition to provide a true notion of the bony and soft tissue complex under stress (2). The use of a single static position also allows for consistent and accurate measurements. There has been a significant amount of published data on the validation of the commonly acceptable radiographic standards, but very little data currently exist that compare the variability between observers, as well as variations among training levels of the observers.

This radiographic evaluation is important to physicians and surgeons, because these data are frequently used to evaluate and to determine treatment plans for foot and ankle deformities. Preoperative surgical planning is key in identifying the underlying structural deformities, as well as in selecting the most appropriate surgical procedures to be performed. Selecting the appropriate procedure before performing any operative intervention is beneficial to the patient, because it decreases operating time and increases surgical outcomes.

Foot and ankle surgeons routinely use radiographs of the lower extremity to make clinical and surgical decisions based on data obtained from those radiographs. The widespread use of these quantitative measures hinges on an unstated belief in the reliability of the radiographic parameters routinely used (7). Saltzman et al (7) published data on the reliability of standard foot radiographic measurements. They followed 50 patient radiographs, evaluated by 6 experienced examiners, to determine the reliability of the measurements and the interobserver variability of 8 common foot measurements. They examined the hallux-metatarsophalangeal angle, first intermetatarsal angle, metatarsophalangeal-5 angle, fourth intermetatarsal angle, dorsal-plantar (DP) talo-calcaneal angle, lateral talo-calcaneal (TCL) angle, sesamoid station, and forefoot width. The study authors determined that there was always some intrinsic error involved in the process of measuring angles. The authors did not publish the actual averages, because they were more focused on the 80% and 95% bounds for each angle evaluated.

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Table 1
Standard radiographic values established in multiple studies and the present study

Angle	Fuson and Smith (3)	Steel et al (4)	Graham et al (1)	Bryant et al (8)	Thomas et al (6)	Berquist (9)	Lamm and Stasko (5)	Present study
CC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	17.2
CIL	19 ± 4.07	22 ± 2.46	N/A	24.2 ± 5.8	19.6 ± 6.2	11 to 38	17.9 ± 5.3	20.5
T1L	N/A	N/A	N/A	N/A	N/A	N/A	5.5 ± 3.9	9.6
T2	N/A	6 to 42	18.61 ± 7.21	N/A	N/A	15 to 63	N/A	18.7
TCL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48.2
TTL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	115.5
T2H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11
TCH	N/A	N/A	N/A	N/A	N/A	N/A	1.5 ± 3.4	1.5

Data presented as average ± standard deviation and ranges.
Abbreviations: CC, calcaneal-cuboid; CIL, lateral calcaneal inclination; N/A, not applicable; T1L, lateral talo-first metatarsal; T2, talo-second metatarsal; TCL, lateral talo-calcaneal; TTL, lateral tibio-calcaneal; T2H, tibio-second metatarsal; TCH, tibio-calcaneal.

Steel et al (4), in what is one of the more comprehensive reviews, evaluated 41 feet with DP and lateral radiographs. In this study, they evaluated the range, percentile distribution, standard distribution, and averages for 31 different variables, including the talo-second metatarsal (T2) angle on the DP view (6° to 42°) as well as the calcaneal inclination (CI) angle on the lateral view (11° to 38°). This study evaluated the normal range of radiographic angle but did not attempt to evaluate observer reliability. Thomas Berquist's *Imaging of the Foot and Ankle* (9) also lists the averages for the CI as 11° to 38° on the lateral view. Berquist, however, obtained a slightly different range for the T2 angle on the DP view, finding 15° to 63°. Siddiqui and Lamm (7) found normal values for the calcaneal pitch (CI), 17° (11° to 23°); lateral tibio-talar (TTL), 70° (66° to 74°); and lateral talo-first metatarsal (T1L), 5° (1° to 9°). Furthermore, on the calcaneal axial, they list the tibio-calcaneal angle as 0° (±4°).

According to Graham et al (1), evaluation of the T2 angle in 35 participants (21 to 78 years old) revealed 2.95° in the neutral calcaneal stance position and 18.61° in the resting calcaneal stance position. Three subjects were used to also evaluate the variance between the observers and determined by using Bland-Altman plots created with MedCalc 11.4.1.0. The authors determined that based on the results, the DP T2 angle can be measured with very high accuracy, reproducibility, and consistency, thereby providing clinicians with a reliable tool to measure rearfoot-to-forefoot alignment on the transverse plane. Taranto et al (10), authored an intrarater and interrater reliability study using 6 subjects. They evaluated first metatarsal protrusion distance, hallux abductus, first intermetatarsal, CI, and lateral intermetatarsal angles. Two raters measured all parameters independently, and measurements were repeated on 3 separate occasions. The authors were able to determine that the selected measurement parameters from weightbearing foot radiographs were found to exhibit high intrarater and interrater reliability, which correlated with the results of Graham et al (1).

The aim of the present study was to reevaluate some of the most common radiological angles used in foot and ankle surgery, specifically CI, TTL, lateral talo-calcaneal (TCL), T1L, calcaneal-cuboid (CC), T2, and talo-calcaneal angulation (TCH). The tibio-second metatarsal (T2H) on the calcaneal axial view was analyzed in this study to determine if it has any viability in evaluating the foot and ankle, as well as for surgical planning. The interobserver reliability of the previously stated angles on a much larger scale was also evaluated.

Patients and Methods

After a full review, institutional review board approval was obtained from our institution (Geisinger Health Systems, Protocol: 2016-0308) before this research was performed. A total of 8 angles and reference points were measured using 100 rectus feet without obvious deformity and collected from January 2005 to March2016. Digital patient radiographs were collected by the primary author (M.D.G.) from the secondary author's (G.A.L.) practice. The radiographic measurements were performed by hand on printed radiographs using standard weightbearing DP, lateral, and calcaneal axial views. Two measurements were made from the DP, 4 from the lateral, and 2 from the calcaneal axial (Tables 1 and 2) (Figs. 1 through 8). Radiographic angles were measured by 4 third-year residents, 4 second-year residents, 4 first-year residents, 2 fourth-year podiatry students, and 4 podiatric surgeon-attending physicians. Patients on whom the radiographs were obtained had an age range of 18 to 63 years and a 63:27 male:female ratio. Patients who reported having experienced trauma, fracture, pain, history of any osseous surgery, or any other relevant medical history were excluded. Additional exclusion criteria included congenital deformity, rheumatoid arthritis, osteoarthritis, and paralysis. Inclusion criteria included minimum age of 18 years and closed epiphysis. The secondary author (G.A.L.) examined all subjects, and no gross abnormalities were noted.

All data obtained were recorded using Excel spreadsheet (Microsoft Office®, 2011; Microsoft, Redmond, WA). All statistical analyses were performed using SAS 9.4 (Cary, NC) or R 3.0.3 (Vienna, Austria) statistical software. The intraclass correlation coefficients were calculated for each angle to determine the level of agreement between the observers (interobserver reliability). Reliability was scored using the method reported by

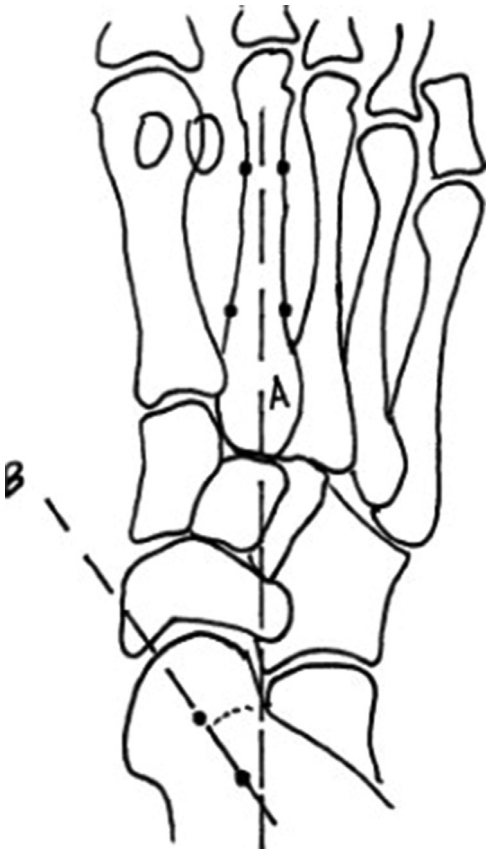

Fig. 1. Talo-second metatarsal angle (drawn by Drs Gibboney and Dreyer).

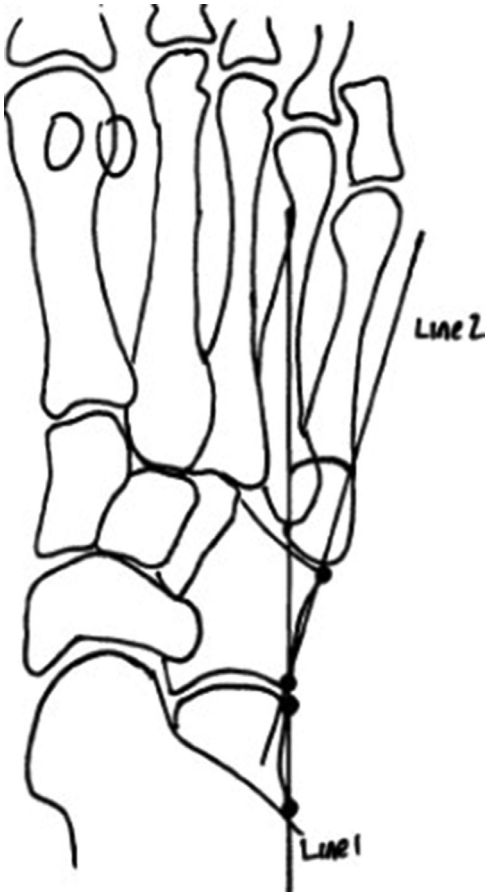

Fig. 2. Calcaneo-cuboid angle (drawn by Drs Gibboney and Dreyer).

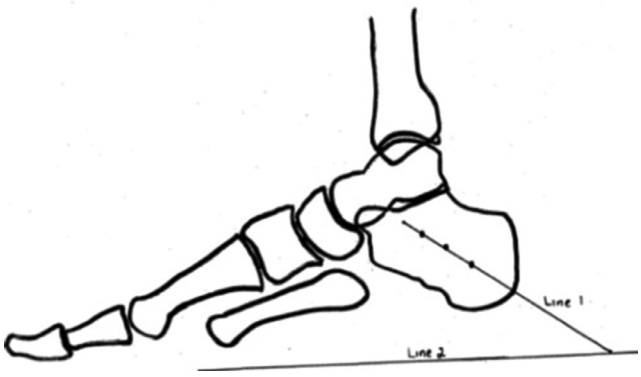

Fig. 3. Calcaneal inclination angle (drawn by Drs Gibboney and Dreyer).

Altman (9): a score of 0.81 to 1 was rated very good, 0.61 to 0.8 as good, and 0.41 to 0.6 as moderate.

Radiographs

DP and lateral radiographs were obtained in the standard fashion as described by Lamm and Stasko (6). The calcaneal-cuboid angle and the T2 angles were measured on the DP view. The following angles were measured from the lateral view: CI, tibio-talar angle, talo-first metatarsal, and talo-calcaneal. The calcaneal axial weightbearing radiographs were taken with the foot and heel flat on the weightbearing surface with the x-ray beam centered on the ankle joint and 45° from the weightbearing surface

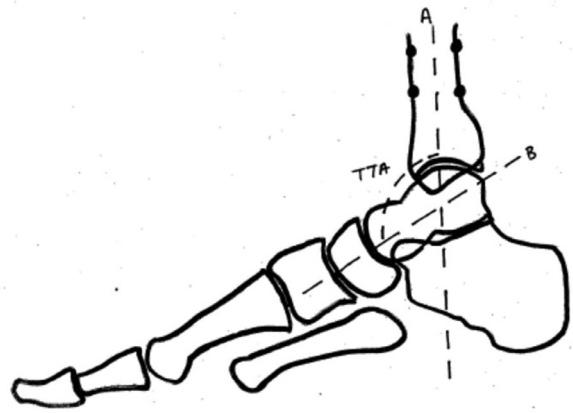

Fig. 4. Tibio-talar angle (drawn by Drs Gibboney and Dreyer).

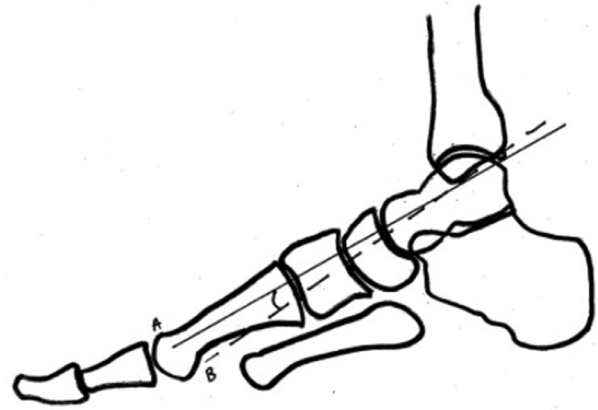

Fig. 5. Talo-first metatarsal angle (drawn by Drs Gibboney and Dreyer).

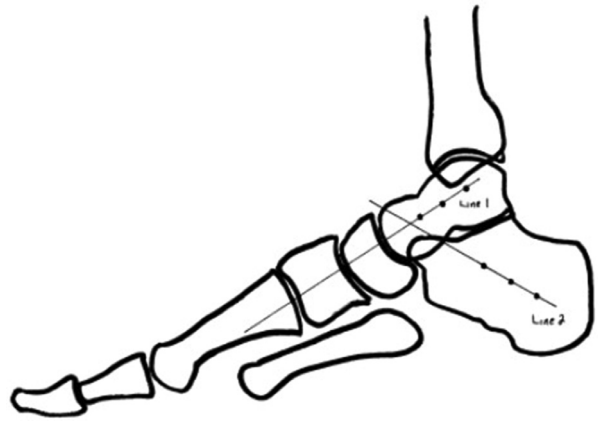

Fig. 6. Talo-calcaneal angle (drawn by Drs Gibboney and Dreyer).

posterior to the foot. The tibio-second metatarsal and tibio-calcaneal angles were measured from this view.

Measurement Technique

A detailed explanation of the 8 measured angles used in this study is provided in Table 2. Additionally, measured angles are shown in Figures 1 through 8.

Fig. 7. Tibio-calcaneal angle (drawn by Drs Gibboney and Dreyer).

Fig. 8. Tibio-second metatarsal angle (drawn by Drs Gibboney and Dreyer).

Results

One hundred radiographs were measured by up to 18 investigators leading to 9414 measured angles examined and statistically analyzed (Table 3). The data obtained found a mean calcaneal-cuboid angle of 17.2° (range 5.3° to 30.6°), a mean CI angle of 20.5° (range 13.2° to 27.5°), a mean T1L angle of 9.6° (range 2.8° to 21.5°), a mean T2L angle of 11.0° (range 3.4° to 28.8°), a mean TTL angle of 115.5° (range 105.0° to 126.9°), a mean TCL angle of 48.2° (range 40.4° to 56.7°), a mean calcaneal axial talo-second metatarsal angle of 18.7° (range 5.6° to 33.8°), and a mean calcaneal axial talo-calcaneal angle of 1.5° (range −6.6° to 10.0°). Note these ranges refer to the inner 90% range.

Table 4 shows the intraclass correlation coefficients (ICCs), where ICC near +1 indicates good interrater agreement. Reliability was scored using the method reported by Altman (11): a score of 0.81 to 1 was rated as very good, 0.61 to 0.8 as good, and 0.41 to 0.60 as moderate. Only 2 angles rated in the good category for all physicians: the T2L angle (0.634) and the calcaneal axial talo-second metatarsal angle (0.664). No angles were rated as very good. The remaining angles, with

Table 2
Description of each measured radiographic angle

	Description
Radiographic Angle – Dorsal-Plantar	
T2	Angle formed between the bisection of the neck of the talus and the anatomic axis of the second metatarsal
CC	Angle formed by the intersection of the line formed by the lateral border of the calcaneus and the lateral border of the cuboid
Radiographic Angle – Lateral	
CI	Angle formed between the bisection of the calcaneus and the weightbearing surface
TTL	Angle formed by the bisection of the tibia and the bisection of the talus
T1L	Angle formed by the bisection of the talus and the bisection of the first metatarsal
TCL	Angle formed by the bisection of the talus and the calcaneus
Radiographic Angle – Calcaneal Axial	
TCH	Angle formed by the bisection of the tibia and the calcaneus
T2H	Angle formed by the bisection of the tibia and the bisection of the second metatarsal

Abbreviations: CC, calcaneal-cuboid; CIL, lateral calcaneal inclination; N/A, not applicable; T1L, lateral talo-first metatarsal; T2, talo-second metatarsal; TCL, lateral talo-calcaneal; TTL, lateral tibio-calcaneal; T2H, tibio-second metatarsal; TCH, tibio-calcaneal.

Table 3
Mean, median, and range of the 9414 measured radiographic angles

Angle	Mean (°)	Median (°)	Inner 90% Range (°)	Width of Inner 90% Range (°)
CC	17.2	17.1	5.3 to 30.6	25.3
CIL	20.5	20.4	13.2 to 27.5	14.3
T1L	9.6	7.3	2.8 to 21.5	18.7
T2H	11.0	8.1	3.4 to 28.8	28.1
T2	18.7	19.1	5.6 to 33.8	28.2
TCH	1.5	0.9	−6.6 to 10.0	16.6
TCL	48.2	47.7	40.4 to 56.7	16.3
TTL	115.5	114.6	105.0 to 126.9	21.9

Abbreviations: CC, calcaneal-cuboid; CIL, lateral calcaneal inclination; N/A, not applicable; T1L, lateral talo-first metatarsal; T2, talo-second metatarsal; TCL, lateral talo-calcaneal; TTL, lateral tibio-calcaneal; T2H, tibio-second metatarsal; TCH, tibio-calcaneal.

Table 4
Intraclass correlation coefficients arranged by observer group

Angle	ICC (all physicians)	ICC (attendings only)	ICC (residents only)	ICC (students only)
CC	0.565	0.031	0.557	0.455
CIL	0.485	0.500	0.506	0.162
T1L	0.555	0.711	0.545	0.726
T2	0.634	0.763	0.628	0.254
T2H	0.664	0.414	0.641	0.578
TCH	0.593	0.260	0.605	0.439
TCL	0.183	0.013	0.180	−0.150
TTL	0.352	0.688	0.357	0.204

Abbreviations: CC, calcaneal-cuboid; CIL, lateral calcaneal inclination; ICC, intraclass correlation coefficient; N/A, not applicable; T1L, lateral talo-first metatarsal; T2, talo-second metatarsal; TCL, lateral talo-calcaneal; TTL, lateral tibio-calcaneal; T2H, tibio-second metatarsal; TCH, tibio-calcaneal.

the exception of the TCL, were rated as moderate. The TCL was rated as below moderate with an ICC of 0.183.

Discussion

Significant published data exist regarding many of the standard radiographic angles that are commonly used in podiatry and orthopedics; however, the current published data focus on only a small group of subjects with relatively few observers. There is also another group of data, which focus on specific deformities commonly seen in the foot and ankle. The published data are comprehensive but lack large-volume patient population studies.

The present study does have its limitations, which should be addressed. First, the primary author was a member of the angle analysis team. Ideally, the author would not be a part of the group that measures or collects the angles to prevent data corruption. A second limitation is the relatively few number of angles evaluated. This study did an excellent job of collecting and measuring >1000 data points per angle, but it was limited to a set of 8 angles. Last, the data analysis broke the ICCs down into residents, attendings, students, and all participants; it would have improved the study to break the resident group down into individual resident years.

One of the major accomplishments of this study is the large size of data collection. There were >9400 data points collected, which is significantly higher than in any previous study.

This report was able to differentiate how angles were measured and the reliability of the measurements based on level of training. Using the ICC values of each angle, data subsets were measured to reflect whether the observer was a student, resident, or attending (Table 4). Results demonstrates that measured angles appear to be more reliable during residency as data ICCs range from −0.150 to 0.726, while residents' ICCs range from 0.180 to 0.641 and the ICC for the attendings ranges from 0.013 to 0.763, with averages of 0.401 for attendings, 0.502 for residents, and 0.333 for students. These data may reflect the fact that many attendings no longer measure radiographs due to experience and that residents are trained to be more attentive to surgical planning as they do not have the experience to determine normal versus abnormal based on visual acuity.

One angle, the calcaneal axial talo-second metatarsal, was found to be unreliable in this study. It was noted that a standard position was not always obtained during radiographic examination and much of the data collected for that measurement had to be discarded due to inability of observers to accurately measure the angles. This leads to our conclusion that, as currently studied, this is not a reliable angle for preoperative surgical planning.

Table 1 summarizes data that have previously been performed in determining radiographic normal in relation to our data collected during this experiment. As expected, our data do not deviate from the previously identified normal values. The one exception is the TTL angle, which deviates from Siddiqui and Lamm's (12), findings. This is likely because the posterior angle was measured by Siddiqui and Lamm, but in the current study, the anterior aspect of the angle was measured. Therefore, when the data are compared, it appears that the angles are supplementary and represent the same averages.

The data collected contain a wealth of information based on the 8 radiographic angles that were measured, which can be extrapolated to include how each angle relates to each other and changes that may or may not correlate.

As expected, students have much more variability in analyzing radiographic angles, but, surprisingly, attending physicians also appear to have more variability than residents, which, as discussed previously, could be due to no longer formally drawing angles during surgical planning. It was also determined that the tibio-second metatarsal as studied is not a viable option for evaluation and surgical planning.

The data collected during this research have solidified the current knowledge of normal foot and ankle radiographic angles and provided some insight into variability, which occurs as training progresses.

Acknowledgment

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