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Foot and ankle radiographic angles in a normal saudi population

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ABSTRACT

Objectives: Radiographic reference lines, angles, and measures comprise the foundation for accurate evaluation and surgical planning of orthopedic surgeries, especially when it comes to foot and ankle deformities. To date, no study has evaluated the average parameters for foot and ankle radiography in the Saudi population. This study aimed to establish reference values of foot and ankle angles for the general Saudi population.

Methods: We included 100 participants (200 feet) in this study, with 50 males and 50 females aged 21–30 years. We recruited subjects who had no history of foot or ankle pain, surgery or fracture, no evidence of ligamentous laxity, and no history of systemic disease. Bilateral anterior-posterior (AP) and lateral weight-bearing radiographs were obtained using standardized angles. A total of 19 angles on AP and 9 angles on lateral radiographs were evaluated. Radiographic parameters were compared between genders.

Results: A total of 400 radiographs from 200 normal feet were evaluated. The mean ± SD age of the subjects was 22.7±1.7 years. Statistically significant differences in mean radiographic parameters were found between males and females in both radiographic projections.

Conclusion: Significant variation exists between the normal foot and ankle reference angles between the Saudi population included in our study and other ethnicities. Moreover, significant differences are found between genders in our study. Considering the lack of other studies involving the Saudi population, the results of this study can help serve as a reference when evaluating Saudi patients.

Keywords: Ankle, Foot, Ethnic groups, Radiographic angles, Reference values

INTRODUCTION

Radiographic measurements play a substantial role in guiding surgical planning of orthopedic surgeries when assessing the need to correct deformed angles and choose appropriate surgical procedures. Standard sets of radiographic angles provide a solid reference for surgeons in preoperative planning and postoperative follow-up.

Many studies on isolated radiographic measurements of adult feet do not provide details on how the angles are produced.[1–3] Thus, variations are seen in radiographic measurements owing to

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inter- and intra-observer errors.[4] In Saudi Arabia, antero-posterior (AP) bilateral radiographs of 333 normal knees were studied by El Fouhil *et al.*[5] Some angles in Saudis were significantly different from the same angles in the corresponding groups in Japanese and Australian Caucasians. Correspondingly, Khoshhal *et al.*[6] provided normal ranges for Böhler's angle (BA) and Gissane's angle (GA) among a population in Saudi Arabia. The mean BA was 31.21°, while the mean GA was 116.16°.

Excluding the Khoshhal *et al.* study, which only reviewed BA and GA, no other dedicated studies have identified the average value of radiographic measurements of foot and ankle angles in normal Saudi adults. Moreover, no previous study looked at the ethnic Arabic group from which Saudis originally descend. Since it is important to understand radiographic variations in adults, the results of this study can help establish baseline data for Saudi adults' foot and ankle, which might subsequently assist orthopedic surgeons. Therefore, this study aimed to report radiographic angles of the foot and ankle in a standardized Saudi population.

MATERIALS AND METHODS

A total of 176 adults attending the medical school at King Saud bin Abdul-Aziz University for Health Sciences (KSAU-HS) were asked to join our study.

Male and female Saudi Arabian nationals with an Arabic ethnic background between the ages of 21 and 30 years, and body mass index (BMI) between 18.5 and 24.9 were included. These parameters were chosen to try to limit any confounding variables that might skew our data. Each participant's ankle and feet were assessed in King Abdelaziz Medical City (KAMC)'s orthopedic clinic and they completed a survey form. The survey form consisted of questions that helped us exclude any participants that did not meet our inclusion criteria.

Participants with foot and ankle deformities, degenerative osteoarticular disease, muscular imbalance, alterations in foot load distribution, foot and ankle pain, previous related surgery, partial amputation, injuries requiring casting or operation, previous ankle sprains, any evidence of ligamentous laxity or neurological problems, muscle paralysis or skeletal problems, systemic disease, or current pregnancy, were excluded. Based on the inclusion and exclusion criteria, a total of 100 participants (50 male and 50 female) were recruited over a period of four weeks. The sample size was not derived from statistical grounds instead of convenience, as the study's main goal was descriptive.

Bilateral weight-bearing, AP and lateral radiographs were obtained using a standardized technique. The AP view was aimed at the center of the navicular bone, while the lateral view was aimed at the medial aspect of the foot. The central beam was oriented at 90° to the cassette and aimed at the first cuneiform bone.

Nineteen angles on AP and nine angles on lateral views were obtained. All measurements and reference lines were defined based on Thomas *et al.*[7] and can be found in the supplementary material.

All radiographs were stored and obtained using a workstation provided by the radiology department. To ensure anonymity of the participants, a system of random numbering was used. Digital software was used to obtain radiographic measurements (Carestream Vue, Carestream Health, 2015, Rochester, NY, USA; v 11.4).

With a minimum 2-week interval between sessions, all angles were measured twice by two senior investigators, an orthopedic foot and ankle consultant and a board-certified orthopedic senior registrar, independently of each other.[8,9] Interobserver reliability was measured using intraclass correlation coefficients (ICCs) in order to determine the level of agreement between the investigators. An ICC value of >0.8 indicated excellent reliability.[10,11] Inter-observer measurement errors and reliability were found to be within acceptable standards for all measurements.

Statistical Analysis System (SAS® version 9.2, SAS Institute Inc., 2008, Cary, NC, USA) software was used for data management and analysis. Descriptive statistics were presented as mean and standard deviation (SD), and differences between males and females were calculated using independent *t*-tests. The level of statistical significance was set at $P \leq 0.05$.

RESULTS

In this study, 400 radiographs from 100 participants with 200 normal feet and ankles were evaluated. Results of the study are summarized in Tables 1 and 2. Table 1 lists the Mean, SD, and range of all 200 feet. The mean±SD age was 22.7±1.7 years. The BMI was 21.2±3.7 for females and 22.0±2.8 for males [Table 1].

Radiographic parameters for males and females are shown in Table 1. A *t*-test was used for each pairing between males and females. Statistically significant differences in mean radiographic parameters were found between males and females in both projections.

In the AP view, there was a statistically significant difference between males and females in the following measurements: the first proximal and first distal phalanx angle (IPJ) with a mean angle of 11.7° in females and a male mean angle of 14.6° ($P = 0.001$). The mean angle between the first metatarsal and proximal phalanx (M1P1) was 12.7° in females and 10.8° in males ($P = 0.019$). The second and first metatarsals angle (M2M1) had a female mean of 3.7° and a male mean of 2.9° ($P = 0.019$). A similar significant difference was found ($P < 0.001$) in the angles between the second and third metatarsals (M2M3), second and fourth metatarsals angle (M2M4) and second and fifth metatarsals (M2M5).

Supplementary material based on the Thomas *et al* study.[1]

Radiographic measurements definitions: anterior-posterior (AP) and lateral view.

Radiographic measurement definitions	
IPJ	Angle created by the bisection of the first proximal and first distal phalanx. Positive equals abduction. Negative equals adduction.
M1P1	Angle created by the bisection of the first metatarsal and first proximal phalanx. Positive equals abduction. Negative equals adduction.
M2P2	Angle created by the bisection of the second metatarsal and second proximal phalanx. Positive equals abduction. Negative equals adduction.
M3P3	Angle created by the bisection of the third metatarsal and third proximal phalanx. Positive equals abduction. Negative equals adduction.
M4P4	Angle created by the bisection of the fourth metatarsal and fourth proximal phalanx. Positive equals abduction. Negative equals adduction.
M5P5	Angle created by the bisection of the fifth metatarsal and fifth proximal phalanx. Positive equals abduction. Negative equals adduction.
M2M1	Angle created by a line perpendicular to the second metatarsal bisection at the distal most aspect of the second metatarsal head and another line from that point tangent to the most distal aspect of the first metatarsal head. Positive if the first metatarsal is shorter than the perpendicular line off the distal end of the second metatarsal bisection. Negative if the first metatarsal is longer than the perpendicular line off the distal end of the second metatarsal bisection.
M2M3	Angle created by a line perpendicular to the second metatarsal bisection at the distal most aspect of the second metatarsal head and another line from that point tangent to the most distal aspect of the third metatarsal head. Positive if the third metatarsal is shorter than the perpendicular line off the distal end of the second metatarsal bisection. Negative if the third metatarsal is longer than the perpendicular line off the distal end of the second metatarsal bisection.
M2M4	Angle created by a line perpendicular to the second metatarsal bisection at the distal most aspect of the second metatarsal head and another line from that point tangent to the most distal aspect of the fourth metatarsal head. Positive if the fourth metatarsal is shorter than the perpendicular line off the distal end of the second metatarsal bisection. Negative if the fourth metatarsal is longer than the perpendicular line off the distal end of the second metatarsal bisection.
M2M5	Angle created by a line perpendicular to the second metatarsal bisection at the distal most aspect of the second metatarsal head and another line from that point tangent to the most distal aspect of the fifth metatarsal head. Positive if the fifth metatarsal is shorter than the perpendicular line off the distal end of the second metatarsal bisection. Negative if the fifth metatarsal is longer than the perpendicular line off the distal end of the second metatarsal bisection.
IM 1–2	Angle created by the bisections of the first metatarsal and second metatarsal. Positive if the metatarsal shafts diverge distally. Negative if the metatarsal shafts converge distally.
IM 2–3	Angle created by the bisections of the second metatarsal and third metatarsal. Positive if the metatarsal shafts diverge distally. Negative if the metatarsal shafts converge distally.
IM 3–4	Angle created by the bisections of the third metatarsal and fourth metatarsal. Positive if the metatarsal shafts diverge distally. Negative if the metatarsal shafts converge distally.
IM 4–5	Angle created by the bisections of the fourth metatarsal and fifth metatarsal. Positive if the metatarsal shafts diverge distally. Negative if the metatarsal shafts converge distally.
T-M1	Angle created by a line perpendicular to a line connecting the anterior-medial and anterior-lateral extremes of the talar head and the bisection of the first metatarsal. Positive if the lines diverge distally. Negative if the lines converge distally.
T-M2	Angle created by a line perpendicular to a line connecting the anterior-medial and anterior-lateral extremes of the talar head and the bisection of the second metatarsal. Positive if the lines diverge distally. Negative if the lines converge distally.
C-M2	Angle between a line parallel to the lateral aspect of the calcaneus and the bisection of the second metatarsal. Positive if the lines diverge distally. Negative if the lines converge distally.

(*Continued*)

Supplementary material based on the Thomas *et al* study.[1]	
Radiographic measurements definitions: anterior-posterior (AP) and lateral view.	
Lateral	
Talocalcaneal	Angle created by a line perpendicular to a line connecting the anterior-medial and anterior-lateral extremes of the talar head and a line parallel to the lateral aspect of the calcaneus.
Forefoot to rearfoot	Angle created between the forefoot and rearfoot reference lines. Positive if the forefoot is abducted to rearfoot.
Calcaneal inclination	Angle created between the supporting surface and a line from the most anterior plantar point of the calcaneal tubercle to the most anterior plantar point of the calcaneus at the calcaneal cuboid joint.
Böhler's angle	Angle created between a line from the peak of the anterior process to the peak of the posterior articular surface and a line from the peak of the tuberosity to the peak of the posterior articular surface.
Talar declination	Angle created between the supporting surface and a line perpendicular to a line connecting the anterior-dorsal and anterior-plantar extremes of the talar head.
Talocalcaneal	Angle formed by a line perpendicular to a line connecting the anterior-dorsal and anterior-plantar extremes of the talar head and line from the most anterior-plantar point of the calcaneal tubercle to the most anterior-plantar point of the calcaneus at the calcaneal-cuboid joint.
M1 Base	Angle created between the supporting surface and the bisection of the first metatarsal.
M5 Base	Angle created between the supporting surface and the bisection of the fifth metatarsal.
M1 Talus	Angle created between the bisection of the first metatarsal and a line perpendicular to a line connecting the anterior-dorsal and anterior-plantar extremes of the talar head. Positive if the talus is plantarflexed to the first metatarsal.
M1P1	Angle created by the bisection of the first metatarsal and the bisection of the first proximal phalanx. Positive if the proximal phalanx is dorsiflexed to the first metatarsal.
P1D1	Angle created by the bisection of the first proximal phalanx and a line parallel to the dorsa central cortex of the distal phalanx.

There was also a statistically significant difference between the second and third metatarsals angle (IM2-3) (P = 0.002), the fourth and fifth metatarsals angle (IM 4-5) (P = 0.001), the talar head and the second metatarsal (T-M2) (P = 0.036), and the angle between the calcaneus and the second metatarsal (C-M2) (P = 0.001).

As for the lateral view, there was a significant difference between males and females when it came to: the talocalcaneal angle (P = 0.002) with a female mean of 24° and a male mean of 26.7°, the forefoot to rearfoot angle (FF-RF) (P = 0.001) with a mean of 14.6° in females and 9.9° in males. A similar significant difference was found (P < 0.001) in the calcaneal inclination angle, the talar declination angle, and the proximal-to-distal phalanx (P1-D1) angle. As for the Bohler's angle, the female mean was 33° and a 34.9° mean in males (P = 0.012).

DISCUSSION

Radiographic reference lines, angles, and measures build the foundation for precise assessment of deformities in orthopedics in general and in foot and ankle service in precise. These also play an integral part in the subsequent surgery planning. These measurably based standards arise from a set of average radiographic angles. Paley *et al*.[12] described a set of standardized measurements based on radiographs using the aforementioned principles. However, although these lines and angles can be standardized for all ethnicities, their values cannot. Most of the studies that established the normal values for these angles either did not report participants' ethnicity or did not look into the Arabic ethnicity in specific. Variations among ethnicities is an established fact and ignoring it might lead to over or underestimation of one given deformity. This has been reinforced by multiple studies, including the one published by El Fouhil *et al*.[5] that looked into the normal knee angles in the Saudi population and found a significant difference between Arabs and other ethnicities.[1–3,7,13,14] Another study showed statistically significant differences in the calcaneal pitch, lateral talocalcaneal, and metatarsal span foot angles among different ethnic groups.[3]

As for our study, when compared to the study conducted by Thomas *et al*., which looked into 100 participants (50 male and 50 female) in Alabama, United States, without specifying the ethnicity, males in our group had greater values in most of the measured angles (21 out of 28). Similar findings were also found in our female group with greater values in 19 out of the 28 measured angles. However, most of the differences were relatively small (<5°, 10%).[7] Similar Findings can be found when comparing the values in our study with Lamm *et al*. study, with higher values in 6 out of the 9 angles measured in both views in our population compared to theirs.[14]

Moreover, the structural and functional differences of foot and ankle among genders have also been established before.[15] Several radiographic indices varied significantly according to

Table 1: Normal foot and ankle angles and descriptive statistics with comparative analysis of 100 female feet and 100 male feet measurements.

Angles	Mean	SD	Range	Gender				P value
				Male		Female		
				Mean	SD	Mean	SD	
Age	22.7	1.7	8.0	22.9	2.0	22.5	1.3	0.151
IPJ	13.2	4.7	27.7	14.6	4.1	11.7	4.8	<0.001
M1P1	11.7	5.6	28.7	10.8	5.2	12.7	5.9	0.019
M2P2	5.9	4.4	23.9	5.8	4.2	6.0	4.6	0.791
M3P3	7.2	5.2	30.7	6.6	4.8	7.7	5.6	0.145
M4P4	4.9	3.9	20.6	4.8	4.0	5.0	3.8	0.664
M5P5	7.9	5.1	21.7	8.8	5.1	7.0	5.0	0.012
M2M1	3.3	2.4	9.7	2.9	2.1	3.7	2.6	0.019
M2M3	5.2	2.0	12.1	5.7	2.0	4.8	1.8	<0.001
M2M4	14.1	3.2	17.5	15.3	2.8	12.9	3.1	<0.001
M2M5	28.1	4.5	23.5	30.2	3.9	26.0	4.1	<0.001
IM 1–2	10.4	2.4	15.1	10.6	2.2	10.1	2.5	0.097
IM 2–3	3.5	1.5	7.4	3.8	1.5	3.2	1.4	0.002
IM 3–4	6.3	1.8	11.2	6.4	1.7	6.3	2.0	0.808
T-M 2	17.2	7.9	37.3	18.3	9.0	16.0	6.5	0.036
C-M2	8.7	6.0	25.6	10.4	6.3	7.0	5.1	<0.001
Talo-Calcaneal	25.4	6.3	33.2	26.7	7.1	24.0	4.9	0.002
FF-RF	12.3	7.7	39.2	9.9	6.1	14.6	8.4	<0.001
Calc. Inc.	20.9	4.6	33.8	23.0	4.6	18.9	3.6	<0.001
Bohler's	34.0	5.1	25.4	34.9	4.8	33.0	5.3	0.012
Talar Dec.	22.8	3.8	19.3	21.1	3.4	24.5	3.3	<0.001
Talo-Calc.	42.7	5.7	36.0	43.9	5.3	41.6	5.9	0.004
M1-Base	18.8	2.7	15.3	18.9	3.2	18.7	2.2	0.675
M5-Base	8.6	2.8	21.9	8.2	2.7	8.9	2.8	0.062
M1-Talus	5.1	3.5	18.0	5.0	3.7	5.3	3.4	0.483
M1-P1	9.3	4.3	20.2	10.0	4.3	8.6	4.3	0.023
P1-D1	14.5	7.5	36.8	16.3	7.1	12.7	7.5	0.001

IPJ: Interphalangeal joint, M: Metatarsal, P: Phalanx, IM: Intermetatarsal, T: Tarsal, C: Calcaneus, FF-RF: Forefoot to rear foot angle, Cal. Inc: Calcaneal inclination, D: Distal phalanx gender or age in a sample of healthy Koreans.[16] We did not investigate the variations with age in our study since the age range in our group was small (21–30 years).

As for gender differences, there was a statistically significant difference between males and females in our group with the male group having higher values compared to females in 18 out of the 28 measured angles. Gender differences were also reported in both Lamm *et al*. and Thomas *et al*. study population.

One of the limitations of this study is that although we recruited more participants compared to previous studies, the sample size was insufficient to represent the entire normal Saudi population. In addition, the age range in our study was narrow. However, when we compared our study to others, ours was based on a young adult and healthy population. Moreover, axial parameters were not investigated in our study. Furthermore, human error may still have resulted in variations, although we used computer-aided design software, which decreases the chance of measurement variation.[17] Despite these limitations, we do believe that these results contribute to scientific literature, particularly when foot and ankle angles are the measures of interest.

CONCLUSION

Significant variation exists between the normal foot and ankle reference angles between the Saudi population included in our study and other ethnicities. Moreover, significant differences are found between genders in our study. Considering the lack of other studies involving the Saudi population, the results of this study can help to serve as a reference when evaluating Saudi patients.

RECOMMENDATIONS

Although the results of this study can help serve as a reference value in measuring foot and ankle angles in the Saudi population in the meantime, further studies with larger sample size and wider inclusion criteria taking into consideration the ethnic diversity in Saudi Arabia are needed with a wider age range.

AUTHORS' CONTRIBUTIONS

SA, NA, AA and BA conceived and designed the study conducted research, provided research materials and collected data. MA, AA and NA organized data, analyzed and interpreted data. OA and FA wrote final draft and provided logistic support. AA, TA and NA reviewed and approved the final draft. All authors have critically reviewed and approved the final draft and are responsible for the manuscript's content and similarity index.

ETHICAL APPROVAL

Consent was obtained by all participants in this study. The study was reviewed and approved by the Institutional Review Board at King Abdullah International Medical Research Centre (issued approval RSS17/016/R).

Declaration of patient consent

The authors certify that they have obtained all appropriate patients consent forms. In the form, the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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