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Original Article

Determination of Foot Angles in Healthy Adult Turkish Population

Sağlıklı Yetişkin Türk Popülasyonunda Ayak Açılarının Belirlenmesi

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Abstract

Background: It is well known that morphometric measurements taken from the foot are related to foot biomechanics. Radiographic angle and measurements of the certain parameters of the foot are reference sources in the treatment and surgical planning of foot and ankle deformities. This study has focused on measuring and evaluating the angular variables of the foot in terms of age and gender on foot radiographs of healthy adults.

Materials and Methods: A total of 300 individuals (150 females and 150 males) between the ages of 25 and 55 were grouped according to age and gender. Four angular variables were measured on lateral radiographs of the right foot taken with weight. The variables measured are as follows: Gissane Angle, Bohler Angle, Medial Arch Angle and Lateral Arch Angle. Statistical analyses were conducted with R (version 4.3.2 64-bit (2023-10-31 ucrt)) software.

Results: As a result of the analyses, the difference between genders was found to be statistically significant in the variables of Gissane Angle and Bohler Angle. While statistically significant difference was found only between the individuals in the third group in terms of Lateral Arch Angle variable, no significant result was found between the groups and the genders forming the groups for the variable of Medial Arch Angle.

Conclusions: Conclusion: The morphometric data acquired in this study with the use of the lateral radiographs of the foot can serve as a reference value for healthy Turkish population.

Keywords: Gissane Angle, Bohler Angle, Medial arch angle, Lateral Arch Angle, Reference values.

ÖZ

Amaç: Ayaktan alınan morfometrik ölçümlerin ayak biyomekaniği ile ilişkili olduğu bilinmektedir. Ayak ve ayak bileği deformitelerinin tedavi ve cerrahi planlama süreçlerinde radyografik açı ve ölçüler referans kaynağı olmaktadır. Bu çalışmanın amacı, sağlıklı yetişkin bireylere ait ayak radyografi görüntüleri üzerinden ayağa ait açısal değişkenlerin yaşa ve cinsiyete göre değerlendirilmesini yapmaktır.

Gereç ve Yöntem: 25-55 yaş aralığındaki 300 kişi (150 kadın ve 150 erkek) yaşa ve cinsiyete göre gruplandırılmıştır. Bu kişilere ait vücut yüküyle çekilmiş sağ ayak lateral radyografi görüntüleri üzerinde belirlenen dört açısal değişken ölçülmüştür. Ölçümü yapılan değişkenler şu şekildedir: Gissane açısı, Bohler açısı, Medial ark açısı ve Lateral ark açısı. İstatistiksel analizler R (version 4.3.2 64-bit (2023-10-31 ucrt)) yazılım programı ile yapılmıştır.

Bulgular: Analizler sonucunda Gissane açısı ve Bohler açısı değişkenlerinde cinsiyetler arası farklılık istatistiksel olarak anlamlı bulunmuştur. Lateral ark açısı değişkeni için sadece 3. grubu oluşturan bireyler arasında istatistiksel açıdan anlamlı farklılık bulunurken, Medial ark açısı değişkeni için hiçbir grup ve grupları oluşturan cinsiyetler arasında anlamlı sonuç bulunmamıştır.

Sonuç: Ayağa ait lateral radyografi görüntülerinin kullanıldığı bu çalışmada, sağlıklı Türk popülasyonu ile ilgili referans oluşturabilecek morfometrik verilere ulaşılmıştır.

Anahtar kelimeler: Gissane açısı, Bohler açısı, Medial ark açısı, Lateral ark açısı, Referans değerler.

Highlights

- Foot biomechanics has a complex anatomy formed by joint formations and muscles.
- The data obtained as a result of this study with a healthy group may be guiding in clinical processes.
- The available data can also be useful for age and sex determination in forensic and anthropological sciences.

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Introduction

The maintenance of the arch in the static foot is utilized by a complex anatomy through perfect biomechanics and its stability is provided through the joint capsule, joint faces, ligaments, and muscles (1,2). Studies have documented data affecting foot biomechanics (3,4), are classified according to population specific ethnicity, gender, and age (5,6,7). Likewise, international data obtained from the angular measurements of the foot are used in interpretation of deformities such as pes planus (8), pes cavus (9), pes equinovarus (10), and in the detection and treatment of calcaneus (11) and talus (12) fractures. On the other hand, studies conducted in documenting the reference values of these angles to be used in the diagnosis and treatment follow-up in the clinics, have been limited in the healthy Turkish population (24-27). This study has therefore been designed to determine the varieties of angular measurements taken from the lateral foot radiographs of healthy adults living in the northwest of Turkey, focusing Bolu region.

The relationship between the shape of the foot and its bones varies in relation to whether the foot bears the weight of the body or not. Weight-bearing radiographs give better results than isolated bones to obtain functional relationships among the peculiarities of the foot. For this reason, weight-bearing foot radiographs were used in this study. The results will surely give profound contribution to the literature in terms of age and gender differences.

Material and Methods

Study design

The study was initiated after the 2023/410 numbered approval of Bolu Abant İzzet Baysal University Clinical Research Ethics Committee. (number: 2023/410. date:19.12.2023). Informed consent was obtained from all groups. It was conducted by using the right foot radiographs of 150 women and 150 men between the ages of 25 and 55, randomly selected from the Picture Archiving and Communication Systems (PACS) archive of Bolu Abant İzzet Baysal University Training and Research Hospital between November and December 2023. Patients with a history of surgery or fracture of the foot or ankle and those with a systemic disease were excluded from the study. The participants were divided into 3 groups as the first group (G1) between the ages of 25-34, the second group (G2) between the ages of 35-44 and the third group (G3) between the ages of 45-55 and each group consisted of 50 women and 50 men. The images taken in Dicom format were transferred to personal workstation Radiant Dicom Viewer (RDV) program from the system. The variables measured on the images are as follows: Gissane Angle (GA), Bohler Angle (BA), Medial Arch Angle (MAA) and Lateral Arch Angle (LAA). The variables were shown in **Figure 1.**

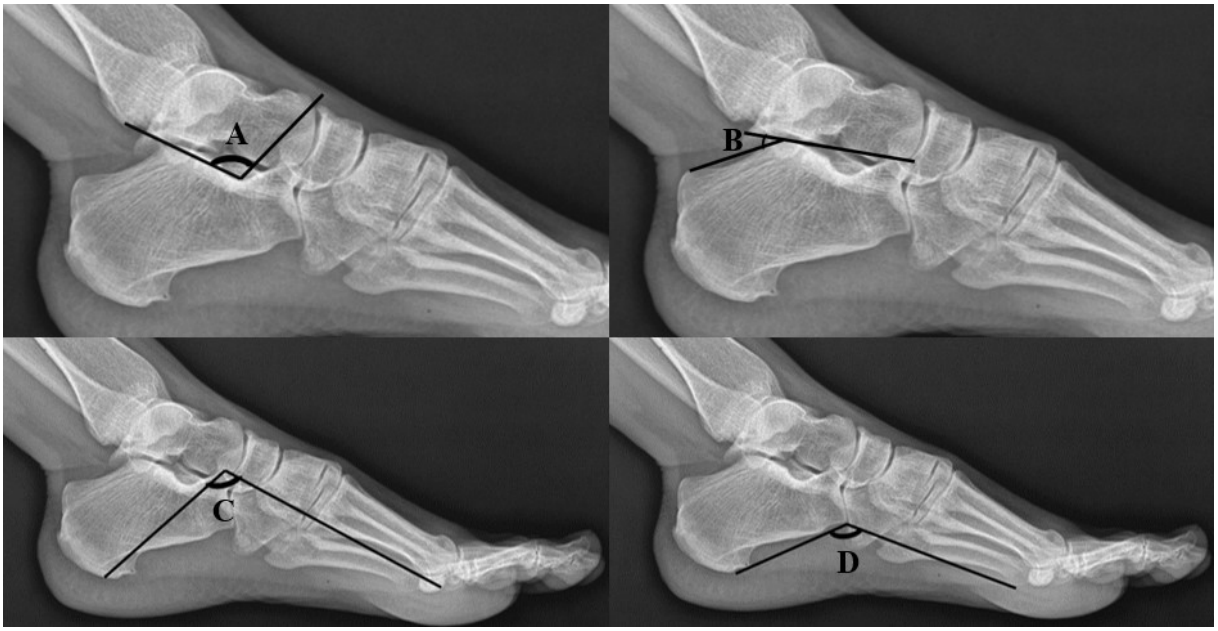

Figure 1. Demonstration of the variables; A- GA, B- BA, C-MAA, D- LAA (GA: Gissane Angle, BA: Bohler Angle, MAA: Medial Arch Angle, LAA: Lateral Arch Angle).

Bohler Angle is defined as the integral of the angle between the line combining the highest point of the tuber calcanei and the posterior facet of the calcaneus and the line uniting the highest point of the anterior calcanei

process and the posterior facet of the calcaneus (12). A decrease in the angle and negative measurement of the angle indicates the clinical picture of calcaneus fracture as documented by the literature (12,13). Likewise, GA is described as the angle between the anterior facet of the calcaneus and the lateral of the posterior facet (11).
Medial Arch Angle is defined as the angle between the lowest point of the talus head and the lines drawn to the lowest points of the first metatarsal head and calcaneal tuberosity (15). The value of the angle changes in pes planus and pes cavus deformities in which the medial longitudinal arch height is affected (8,9,15). Lateral Arch Angle is described as the angle between the lines drawn from the lowest point of calcaneocuboid joint to the lowest point of tuber calcanei and the apex of the 5th metatarsal bone (16).
Since a high prevalence of right foot dominance was found in Turkish population in the literature, lateral radiographs of the right foot were used in this study as suggested by the literature (17).

Statistical Analysis

Statistical analyses were conducted with R (version 4.3.2 64-bit (2023-10-31 ucrt)) software. Conformity of the data to normal distribution was tested with Anderson Darling Test. In order to control the normality test, normal distribution of residuals was checked and evaluated by drawing four in one (normal probability plot, versus fit, histogram, versus order) graph. As a result of the analysis, the variables were found to be normally distributed. For this reason, no transformation was required. Two-way Anova was performed to find out the difference between groups. Post-hoc tests were not needed since no statistically significant result was found between groups as a result of variance analysis. Two Sample T Test was used to analyse differences between genders. Descriptive statistics of the data were calculated, and boxplot graphs were drawn to show the changes resulting from groups and gender.

Results

The variables were found to conform normal distribution. Variance analysis determined a statistically significant difference between the genders for the age (p=<0.001). Hence, the two-sample t test found statistically significant difference between the first (p=0.013) and second groups (p=<0.001) regarding the gender variance while no statistical significance was found for the third group (p=0.131). In terms of the variance analysis for GA variable, the difference between genders was found to be statistically significant (p=<0.001) while the interaction among the groups and the interaction between the groups and gender were shown not to be statistically significant (p=0.507). Two-sample t test determined the difference between the genders of the three groups to be statistically significant. For the BA variable, no statistically significant result was found among the groups (p=0.204) while significant difference was obtained between genders (p=0.001) in terms of the interaction between the gender and groups. According to the results of the two-sample t test conducted to find out the differences between genders, while no statistically significant result was found between the genders in the first (p=0.304) and third (p=0.121) groups, statistically significant result was acquired between the genders in the second (p=0.004) group. Regarding the results of the variance analysis and two-sample t test for MAA variable, no statistically significant results were determined among the groups (p=0.516), in terms of the interaction between the groups and gender, and between the genders (p=0.688). As a result of the variance analysis for LAA variable, while no statistically significant result was found among the groups (p=0.602), in terms of the interaction between the groups and gender, and between the genders, the difference between the genders of the individuals in the third (p=0.017) group was found to be statistically significant as a result of the two-sample t test. The results of descriptive statistics, variance analysis, and two-sample t test were shown in **Table 1.** Boxplot graph depicting the comparison of the variables in terms of the group and gender was shown in **Figure 2**.

Table 1.Descriptive statistics of the data, the results of variance analysis and two-sample t test analysis.

Varaibles		G1 (n=100)	G2 (n=100)	G3 (n=100)	P value
Age	M (n=50)	37.8±3.5	51.3±2.7	37.8±3.5	0.570*
	F (n=50)	41.3±2.6	52.1±2.3	41.3±2.6	0.406**
	P value	0.013ǂ	<0.001ǂ	0.131ǂ	<0.001#
GA (º)	M (n=50)	130±9.5	128.4±9.5	130±9.5	0.507*
	F (n=50)	117.3±10.9	118.8±10	117.3±10.9	0.406**
	P value	<0.001ǂ	<0.001ǂ	<0.001ǂ	<0.001#

BA (º)	M (n=50)	32.9±5.6	32.9±4.9	32.9±5.6	0.204*
	F (n=50)	29.5±6	31.2±5.9	29.5±6	0.392**
	P value	0.308ǂ	0.004ǂ	0.121ǂ	0.001#
MAA (º)	M (n=50)	105.5±7.9	104.3±7.9	105.5±7.9	0.516*
	F (n=50)	104.1±8.8	105.3±9	104.1±8.8	0.597**
	P value	0.653ǂ	0.414ǂ	0.575ǂ	0.688#
LAA (º)	M (n=50)	137.1±9.1	133.9±8.9	137.1±9.1	0.602*
	F (n=50)	135.7±10.5	138.2±8.8	135.7±10.5	0.094**
	P value	0.679ǂ	0.458ǂ	0.017ǂ	0.267#

Abbreviations: The data were displayed as mean ±standard deviation. *p value as a result of the analysis of difference between groups. ** p value showing the interaction of gender and group factors. # p value as a result of the analysis of difference between genders. ǂ p value showing the difference between genders forming the groups. (GA: Gissane Angle, BA:Bohler Angle, MAA: Medial Arch Angle, LAA: Lateral Arch Angle).

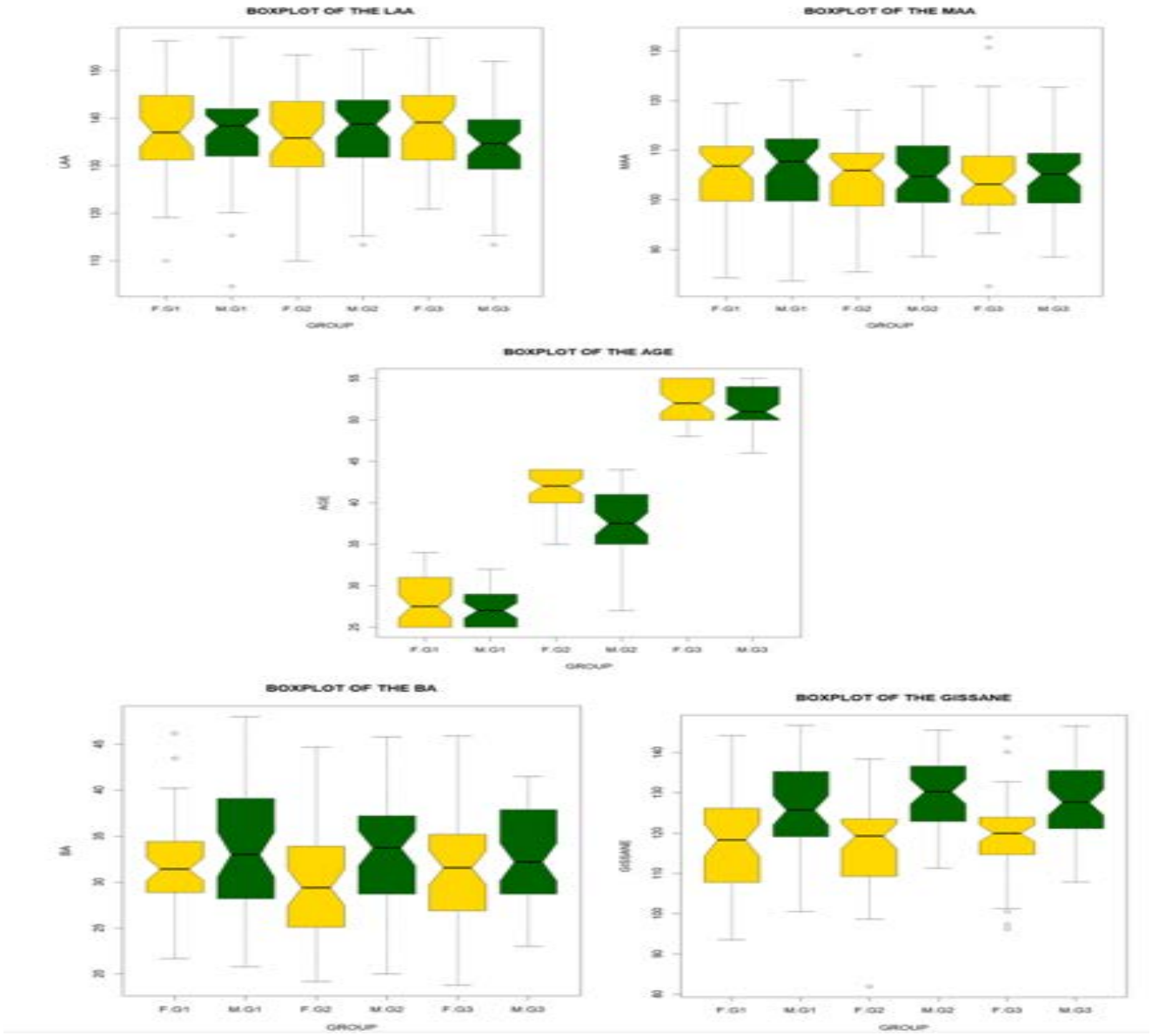

Figure 1. Boxplot illustrating the changes in variables in terms of genders and groups (GA: Gissane Angle, BA: Bohler Angle, MAA: Medial Arch Angle, LAA: Lateral Arch Angle).

Discussion

This study was designed to contribute to the accumulation of literature on the angular functional morphology of the foot in healthy adults. The results revealed statistically significant differences in all the groups for the variables of

GA and BA, taken from the lateral foot radiographs of healthy adults living in the northwest of Türkiye, focusing particularly on the data in terms of age and gender parameters.

Calcaneus is the most frequently fractured tarsal bone (11) and the values of BA and GA are taken as key reference during the diagnosis and treatment process of calcaneus fracture (12,18). Therefore, knowing the physiological range of these angles, which are also known as calcaneal angles, is very essential in terms of determining the degree of deformity and prognosis follow-up (18). The related literature has accumulated different reference ranges given for calcaneal angles in different populations (19-23).

A literature report has aimed to evaluate the relationship of calcaneal angles with age, gender and body side in healthy individuals in Egypt population, using foot radiographs of 220 individuals (5). This report has obtained similar mean values on these parameters as compared to those of our study except the fact that no relationship has been indicated between the calcaneal angles and age and gender. This may be due to the differences in the number and variation of population used, and age ranges and gender groups as well. A similar study has been designed to determine the reference values of foot and ankle angles in Saudi Arabia, using the radiographs of both feet of 100 individuals between the ages of 21 and 30, showing statistically significant difference between the genders, which is in parallel with the results of the present study (6). Another study conducted to reveal the relationship of BA with age, gender and laterality in adult Croatians, has reported higher BA values than those acquired in the present study, suggesting that BA value may not be associated with age, gender and laterality (11). Again, it is of valuable to stress the fact that this difference can also be due to different population and fewer participants used in the study. Research conducted on Chinese population to determine the physiological value of BA and to evaluate the possible factors that may affect the angle, has reported similar BA values as compared to the findings of our study, indicating no correlation with age, gender, and body side; thus, emphasizing that objective results cannot be obtained in individuals younger than 10 years of age (19). Similarly, a study to determine the physiological BA and GA values in Brazilian population, has found parallel results, indicating no significant correlation in terms of gender and age (20). Yet, another study performed on adults living in Serbia in terms of age and gender, has found the normal values of BA higher than the present study, indicating the effect of age and gender on the angles as statistically significant (21). Another research in Kwara population has documented similar BA and lower GA values as compared to the results of our study, suggesting no usage of the data in gender determination studies (22). Finally, another research conducted to show the relationship of calcaneal angles with gender, age, body mass index (BMI) and calcaneus morphometry on healthy adults living in India, has revealed significant correlation between calcaneal angles and BMI while documenting no significant correlation between calcaneal angles and age and gender (23). This research also has emphasized that calcaneal angles are associated with calcaneus morphometry and therefore surgical repairs of calcaneal fractures should be individualized. This report thus has found BA value similar to the present study in individuals with normal BMI but GA value is lower, which is probably due to the usage of different population studied and the fact that BMI has not been taken into account in the evaluations.

Few studies have evaluated calcaneal angles in healthy Turkish population by using foot radiographs (24-27). A literature report designed to determine the mean values of angular variables of the foot, and to show the relationship of these with age, gender and body size, has documented parallel mean calcaneal angles, as is the case the present study, highlighting no significant correlation between the angles and age and gender, which may again be due to the fact that age and gender have not been grouped homogenously (24). Another study examining the relationship of calcaneal angles with pes planus deformity, has reported no statistically significant correlation between the calcaneal angles and pes planus, and different mean values of the angles from those in the present study (25). This difference may be because the sample group of the study consists of unhealthy individuals. Another research done to compare the reliability of a smart phone application iPinPoint and computer based SECTRA program in the measurement of calcaneal angles, has shown both their reliabilities and reproducibility in the evaluation of angles, and BA was found to be lower than that of the present study (26). This difference may be due to the fact that the study has been conducted on the patients and different measurement techniques have been applied. Another report performed to evaluate the radiological and demographic characteristics of patients diagnosed with plantar calcaneal spur in terms of age and BMI, and to show the differences between these patients and the control group, has found no significant difference, revealing higher mean values than those of the present study (27). This difference may be since the present study has been performed on healthy individuals and BMI has not been calculated. It is important to know and maintain the physiological values of calcaneal angles for quick and painless healing of calcaneus and talus fractures during and after surgery. Yet, angular values are lower in the present study than in the reports used patients diagnosed with talus and calcaneus fracture (13,28,29).

Several static and dynamic methods have been developed to define and evaluate the medial arch structure of the foot such as calcaneal inclination angle and calcaneus 1st metatarsal angle (3), dynamic plantar pressure measurement (30), arch index (31), and navicular drop test (32). The methods are applied mostly to the clinical cases of the related anatomical structures. On the other hand, there are very limited studies examining the LAA in healthy individuals (35, 36). This study has attempted to constitute reference values of arch angles in healthy adults, stressing particularly the fact that while he difference between genders was statistically significant in LAA variable in individuals in the third group, no difference was found between genders in MAA variable.

In a study examining the correlation of MAA with foot length in healthy individuals by using foot radiograph, no statistically significant difference has been found between MAA and gender, parallel to the results of the present study (3). Sample group of another study (30) which has aimed to compare dynamic plantar measurement system and radiographic measurements in MLA evaluation has consisted of healthy adults, reporting the dynamic and static methods given consistent results for MLA evaluation. In addition, parallel with the present study, no significant correlation has been achieved between the MLA angle and gender. Likewise, another report (31) searching for the relationship between the arch structure of the foot and gender, age and dominance, the arch height and stiffness of the participants have been measured, indicating no difference between the genders neither any correlation between the age and arch angles, in parallel with the present study. Yet, a different study conducted on the USA population has been designed to present basic data on the angular and linear variables of the foot in heathy individuals, and to show the difference between genders, finding no statistically significant difference between the genders but angular values higher than the present study (33). A similar result has also been reported in another study which has examined the angular measurements of the foot in Saudi Arabia in terms of age and gender (34). The lower angular values found in the present study may be due to the comparison of different populations and smaller sample sizes used in those studies. Finally, unlike the present study, a report (35-37) aiming to evaluate arch angles and the differences of the foot morphometry resulting from age, gender, and side by using foot radiographs of adolescents and adults, has shown significant differences between the genders, and higher arch angles. This is obviously due to the fact that the adolescent group has not been included in the present study.

Study limitations

Since the present study was designed retrospectively, important points such as the arch of the foot or the alignment of the posterior part of the foot could not be intervened in the X-ray images. This may affect the measurement of foot angles and is considered as a limitation of the study.

Conclusion

As a conclusion, the findings of the present study contribute to calcaneal and arch angle data in literature in terms of healthy Turkish population. They may be useful reference values serving a guide in the treatment and follow-up processes of calcaneus and talus fractures and in the determination of foot arch deformities

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