DOI: 10.37990/medr.1419133 Med Records 2024;6(2):239-48

MEDICAL RECORDS-International Medical Journal

Research Article

Distance Parameter Values of Calcaneus and their Performance for Gender Estimation

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Abstract

Aim: The calcaneus has a significant role in the foot due to its location. It is used together with the pelvis and skull bones in gender determination. In this study, it was aimed to determine the morphometric characteristics of the calcaneus and determine the suitability of these measurement locations for gender estimation.

Material and Method: In the study, seven measurements were taken bilaterally from 1,080 lateral foot radiographs of 540 individuals aged 20-65 years. For foot bone height (FBL), the distance between the anterior end of the distal phalanx of the most distal toe and the most posterior end of the foot was taken, while for maximum calcaneal length (maxCaL), the distance between the anterior end of the calcaneus and the posterior end of the calcaneus was taken. SPSS 21 program was used for statistical analyses and the ratio of gender prediction performances was examined by Receiver operating characteristic (ROC) analysis.

Results: All length measurements were higher in males than females ($p<0.05$), and foot bone height (FBL) ($p=0.035$) and maximum calcaneus height (maxCaH) ($p=0.007$) were higher on the right side than on the left side. The study also found a weak negative correlation between age and the right-sided medial calcaneus length parameter (rmedCaL) and strong correlations between certain measurements. Foot bone length (FBL) was found to have the highest accuracy in predicting gender (AUC=0.913).

Conclusion: The findings provide useful information for forensic cases, provide reference data for diagnosis and treatment processes in the clinic, and provide data for the development of machine learning software that can be used in medical and forensic cases.

Keywords: Calcaneus, forensic science, gender prediction, radiology, receiver operating characteristic analysis

INTRODUCTION

The feet carry and transfer the weight of the body to the ground throughout life and have anatomical features that do not require any auxiliary organs to fulfill their function (1). The calcaneus, one of the parts of the foot in contact with the ground, is the largest, longest, and most robust of the seven tarsal bones in the foot and is a roughly box-shaped bone that forms the heel at the back of the foot. It has complex contours and joint surfaces (2,3).

Due to its shape and position, the calcaneus plays a major role in transmitting force between the body and the ground. It plays a critical role in weight bearing. Due to its complexity and multiple joints connecting the ankle and hindfoot, disruption of the calcaneal anatomy can alter the biomechanics of the foot and lower extremities (4). In some pathologic conditions, changes in the morphometric characteristics of the calcaneus may be observed . In such cases, normal morphometric values of the calcaneus may guide the diagnosis and treatment processes (5).

Due to natural disasters, tragic accidents, terrorist attacks, and homicides, victims and their bodies can become unrecognizable. Identification of the body is particularly difficult in cases where the body has been decomposed, mutilated, or burned (6). One of the important fields of anthropology, and forensic anthropology in particular, is the identification of individuals. In the identification process, the age, race, and gender of the person are important. Therefore, knowing the gender of the person is quite important in terms of reducing the result set in the identification process (7,8).

Although the identification by DNA analysis is highly accurate, it is not practical to use this method in complex cases with a large number of cases due to its cost and time-consuming nature (8,9). Although the pelvis and skull bones used to estimate gender from bone have a high accuracy rate, other bones can be used in case of deterioration and fragmentation (10). One of these bones, the calcaneus, is often evaluated in forensic anthropology.

CITATION

Ceranoglu FG, Yilmaz MT, Akin Saygin D, Kadiyoran C. Distance Parameter Values of Calcaneus and their Performance for Gender Estimation. Med Records. 2024;6(2):239-48. DOI:1037990/medr.1419133

Received: 19.01.2024 **Accepted:** 12.02.2024 **Published:** 08.05.2024

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The calcaneus can withstand high tensile forces due to its shape and the density of its trabeculae. It is a bone that is more protected against external factors since it is constantly in shoes and socks in daily life (11,12).

The objective of this study was to measure the length parameters of the calcaneus from lateral radiographs of the foot in a Central Anatolian population and to determine the effectiveness of these values for gender prediction.

MATERIAL AND METHOD

The study was conducted with a retrospective design with the approval of Necmettin Erbakan University Drug and Non-Medical Device Research Ethics Committee dated 04.02.2022 and numbered 2022/3632. Bilateral comparative foot radiography images (RI) of 8,001 people who applied to the Department of Radiology between 2018 and 2021 were scanned in the PACS (Picture Archiving and Communication System) archive system. The number of participants for this study was determined by G*Power (3.9.1) analysis based on the Agoada 2018 study (13). Images were randomly selected from PACS by two investigators according to the criteria. RI images of healthy individuals without any pathology in the foot region were included in the study. Patients with fractures, trauma or bone pathology in the tarsal, metatarsal bones and phalanxes, structural defects, previous surgical intervention, aged 20 years or younger, and RI defects were excluded from the study. A total of 540 people between the ages of 20 and 65, 137 (25.4%) men and 403 (74.6%) women, who met these criteria were included in the study. The individuals included in the study (20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60-65 years) were divided into age groups (Table 1). Seven distance measurements were made on the lateral RI of the foot (Figure 1). Measurements were taken three times by the same person at certain date intervals and the average values were used.

Table 1. Classification of the study population into five different groups according to age

		N	%
Sex	Male	137	25.4
	Female	403	74.6
Age groups	20-29	45	8.3
	30-39	126	23.3
	40-49	157	29.1
	50-59	177	32.8
	60-65	35	6.5

N: number of individuals

Definitions of Measurements

Foot bone height (FBH): The vertical distance between the line passing between the calcaneus and the caput os metatarsale-I and the highest point of the talus was measured (14) (Figure 1a).

Foot bone length (FBL): The distance between the anterior end of the phalanx distalis of the most distal finger (1st or 2nd finger) and the most posterior end point of the foot was measured (15) (Figure 1b).

Maximum calcaneus length (maxCaL): The distance between the anterior extreme point of the calcaneus and the posterior extreme point was measured (16) (Figure 1c).

Medial calcaneus length (medCaL): The distance between the point where the anterior border of the lateral surface of the calcaneus begins to curve upward and the most posterior point of the tuber calcanei was measured (13) (Figure 1d).

Minimum calcaneus height (minCaH): The distance between the deepest point behind the facies articularis talaris posterior of the calcaneus and the highest point of the lower border of the lateral surface in front of the tuber calcanei was measured (13) (Figure 1e).

Calcaneus anterior facet height (CaAFH): On the anterior face of the calcaneus, the minimum distance between the upper and lower borders of the articular surface for cuboid on calcaneum was measured (16) (Figure 1f).

Maximum calcaneus height (maxCaH): The perpendicular distance between the line extending distally from the plantar aspect of the tuber calcanei parallel to the long axis of the calcaneus and the highest point of the anterior talar articular posterior surface was measured (13) (Figure 1g).

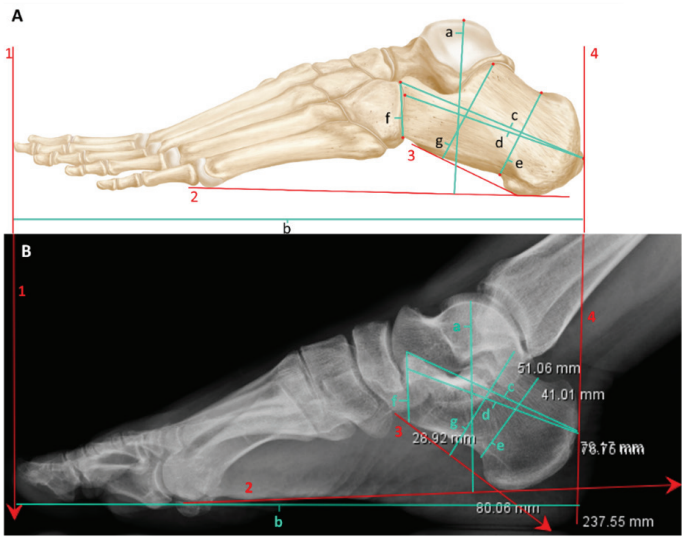

Figure 1. Measurements in the study (**1A:** Schematic view, **1B:** PACS image, 1: line through the most anterior point of the foot, 2: contact surface, 3: parallel drawn on the lower surface of the calcaneus, 4: line through the most posterior point of the foot, **1a:** foot bone length, **1b:** foot bone height, **1c:** maximum calcaneus length, **1d:** medial calcaneus length, **1e:** minimum calcaneus height, **1f:** calcaneus anterior facet height, **1g:** maximum calcaneus height)

Statistical Analysis

Statistical analysis of the study was performed with the IBM SPSS Statistics 21.0 (SPSS, V21; IBM Corp) program. The conformity of the data to normal distribution was analyzed with Kolmogorov–Smirnov test. The relationship between genders and ages was evaluated by the Chi-square analysis. Independent t-test was used to separate

and evaluate the measurements according to gender. The One-Way ANOVA-Tukey test was used for the evaluation between age groups. All measurements were analyzed with a dependent t-test between the right and left sides. Receiver operating characteristic (ROC) analysis was also performed to evaluate the suitability of gender prediction from the measured parameters. Analysis results were presented as Mean±SD for quantitative data and percentage (frequency) values for categorical data. The level of significance was taken as p<0.05 in statistical analysis.

RESULTS

The minimum (min.), maximum (max.), mean, and standard deviation (SD) values of the right and left side and gender measurement data obtained in the study are given in Tables 2,3. Comparing the right and left sides of our measurement data, FBH (p=0.035) and maxCaH (p=0.007) values were found to be statistically significantly higher on the right side (Table 3).

All of the distance measurements made on the right and left sides were statistically significantly greater in men (p<0.05) (Table 3).

Table 2. Minimum, maximum and mean values for all parameters

	Right			Left			p
	Min.	Max.	Mean±SD	Min.	Max.	Mean±SD	
FBH	54.63	98.8	83.29±6.43	62.97	99.82	82.96±6.27	**0.035***
FBL	129.56	313.45	242.04±18.63	202.38	360.63	242.87±18.08	0.105
maxCaL	27.92	108.25	83.13±6.96	71.17	109.42	83.22±5.96	0.566
medCaL	35.14	100.5	76.86±6.16	43.26	100.77	76.79±5.98	0.633
minCaH	26.39	78.3	39.57±4.27	27.73	68.71	39.43±4.06	0.279
CaAFH	18.69	37.75	25.73±2.7	17.23	45.49	25.76±3.01	0.798
maxCaH	24.76	61.34	46.71±3.93	35.19	59.94	46.43±3.75	**0.007***

Min.: minimum value, Max.: maximum value, SD: standard deviation value, FBH: foot bone height, FBL: foot bone length, maxCaL: maximum calcaneus length, medCaL: medial calcaneus length, minCaH: minimum calcaneus height, CaAFH: calcaneus anterior facet height, maxCaH: maximum calcaneus height, *0.05 significance level

Table 3. Comparison of the measurements according to gender

		Male (N=137)			Female (N=403)			
		Min.	Max.	Mean±SD	Min.	Max.	Mean±SD	p
	Age	20	65	42.29±11.48	20	65	43.81±10.46	0.174
Right	**FBH**	64.24	98.88	89.07±5.97	54.63	97.42	81.33±5.31	**<0.001***
	FBL	167.39	313.45	261.27±16.89	129.56	299.55	235.5±14.15	**<0.001***
	maxCaL	77.25	108.25	89.94±5.58	27.92	98.85	80.81±5.76	**<0.001***
	medCaL	71.88	100.5	83.26±5.29	35.14	90.32	74.69±4.77	**<0.001***
	minCaH	33.92	53.32	42.89±3.57	26.39	78.3	38.44±3.88	**<0.001***
	CaAFH	21.26	34.82	27.47±2.76	18.69	37.75	25.14±2.40	**<0.001***
	maxCaH	42.03	61.34	50.58±3.61	24.76	57.07	45.4±3.07	**<0.001***
Left	**FBH**	73.54	99.82	89.03±5.93	62.97	94.58	80.89±4.89	**<0.001***
	FBL	225.18	315.2	261.81±15.13	202.38	360.63	236.43±14.03	**<0.001***
	maxCaL	74.73	109.42	89.7±5.6	71.17	98.68	81.02±4.22	**<0.001***
	medCaL	72.8	100.77	83.02±5.05	43.26	90.36	74.66±4.64	**<0.001***
	minCaH	35.57	68.71	43.21±4.2	27.73	47.2	38.15±3.1	**<0.001***
	CaAFH	19.38	34.15	27.53±2.74	17.23	45.49	25.16±2.86	**<0.001***
	maxCaH	35.19	59.94	50.02±3.72	36.37	56.16	45.22±2.89	**<0.001***

N: number of individuals, Min: minimum value, Max: maximum value, SD: standard deviation value, FBH: foot bone height, FBL: foot bone length, maxCaL: maximum calcaneus length, medCaL: medial calcaneus length, minCaH: minimum calcaneus height, CaAFH: calcaneus anterior facet height, maxCaH: maximum calcaneus height, *0.05 significance level

Examining the relationship between the length measurements of the calcaneus between age groups, it was seen that the parameter right calcaneus anterior facet height (rCaAFH) had a significant difference between age groups (p=0.026). Nevertheless, none of the parameters, including rCaAFH, showed a regular increase or decrease with age.

Examining the correlation between the data on the right side, it was seen that all length measurements had a strong positive correlation among themselves (p<0.05) (Table 4). When the correlation between the data on the left side was examined, a positive correlation was observed between all length measurements as on the right side (p<0.05). While the correlation between left foot bone height (lFBH) and left foot bone length (lFBL) was weaker (p<0.05, r=0.562), the correlation between the remaining data was found to be strong (Table 4).

Table 4. Correlation of the data of the parties within themselves

		AGE	rFBH	rFBL	rmaxCaL	rmedCaL	rminCaH	rCaAFH	rmaxCaH			
rmaxCaH	r	.041	.651**	.603**	.579**	.558**	.573**	.392**	1			
	p	.343	.000	.000	.000	.000	.000	.000		1	r	AGE
rCaAFH	r	.059	.367**	.427**	.418**	.441**	.365**	1			p	
	p	.171	.000	.000	.000	.000	.000		1	.005	r	lFBH
rminCaH	r	.059	.541**	.494**	.465**	.500**	1			.902	p	
	p	.172	.000	.000	.000	.000		1	.578**	-.076	r	lFBL
rmedCaL	r	-.060	.565**	.727**	.739**	1			.000	.079	p	
	p	.162	.000	.000	.000		1	.755**	.701**	-.063	r	lmaxCaL
rmaxCaL	r	-.094*	.572**	.670**	1			.000	.000	.142	p	
	p	.029	.000	.000		1	.840**	.728**	.582**	.058	r	lmedCaL
rFBH	r	-.079	.496**	1			.000	.000	.000	-.082	p	
	p	.067	.000		1	.529**	.595**	.587**	.639**	.022	r	lminCaH
rFBL	r	.018	1			.000	.000	.000	.000	.610	p	
	p	.679		1	.409**	.406**	.469**	.404**	.377**	.012	r	lCaAFH
AGE	r	1			.000	.000	.000	.000	.000	.781	p	
	p		1	.419**	.675**	.583**	.655**	.599**	.724**	.074	r	lmaxCaH
				.000	.000	.000	.000	.000	.000	.088	p	
			lmaxCaH	lCaAFH	lminCaH	lmedCaL	lmaxCaL	lFBL	lFBH	AGE		

*. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed), r: right, l: left, FBH: foot bone height, FBL: foot bone length, maxCaL: maximum calcaneus length, medCaL: medial calcaneus length, minCaH: minimum calcaneus height, CaAFH: calcaneus anterior facet height, maxCaH: maximum calcaneus height

In the study, the results of the ROC analysis for the usability of the parameters in gender prediction are presented in tables and graphs (Table 5, Figure 2). Analyzing the data on the right side, the highest accuracy rate was found in right foot bone height (rFBH) (0.913) and rmedCaL (0.910) values. Among the length data, right calcaneus anterior facet height (rCaAFH) (0.737) had the lowest rate of gender prediction accuracy. When the results of the parameters on the left side for gender estimation were analyzed, it was seen that the values on the left side had a higher accuracy rate in the minCaH and CaAFH parameters, while the data on the right side had a higher accuracy rate in the FBH, FBL, maxCaL, medCaL, maxCaH parameters. Based on the foot model obtained by analyzing all parameters, the parameters on the left side give a reliable rate of 87.5% and the parameters on the right side give a reliable rate of 85.7%. When only the calcaneus data are evaluated, the left side gives a reliable result of 85.2% and the right side 84.9%. Thus, in both models, the left-hand side parameters were found to have a higher accuracy rate.

Table 5. ROC analysis results

		AUC (95%)	Min-Max	Cut off value	p
Right	FBH	0.841	0.800-0.881	F<84.59<M	**0.021***
	FBL	0.913	0.884-0.942	F<247.48<M	**<0.001***
	maxCaL	0.904	0.874-0.933	F<83.34<M	**<0.001***
	medCaL	0.91	0.883-0.938	F<78.81<M	**<0.001***
	minCaH	0.831	0.791-0.87	F<40.53<M	**0.020***
	CaAFH	0.737	0.686-0.788	F<26.11<M	**0.026***
	maxCaH	0.867	0.832-0.902	F<47.68<M	**0.018***
Left	FBH	0.853	0.815-0.892	F<84.50<M	**0.020***
	FBL	0.913	0.886-0.94	F<247.63<M	**0.014***
	maxCaL	0.897	0.865-0.929	F<84.7<M	**0.016***
	medCaL	0.905	0.877-0.933	F<78.36<M	**0.014***
	minCaH	0.852	0.816-0.889	F<40.37<M	**0.019***
	CaAFH	0.755	0.706-0.803	F<26.13<M	**0.025***
	maxCaH	0.852	0.814-0.891	F<47.32<M	**0.020***

AUC: area under the ROC curve, Min: minimum value, Max: maximum value, FBH: foot bone height, FBL: foot bone length, maxCaL: maximum calcaneus length, medCaL: medial calcaneus length, minCaH: minimum calcaneus height, CaAFH: calcaneus anterior facet height, maxCaH: maximum calcaneus height, F: female, M: male, p: significance level

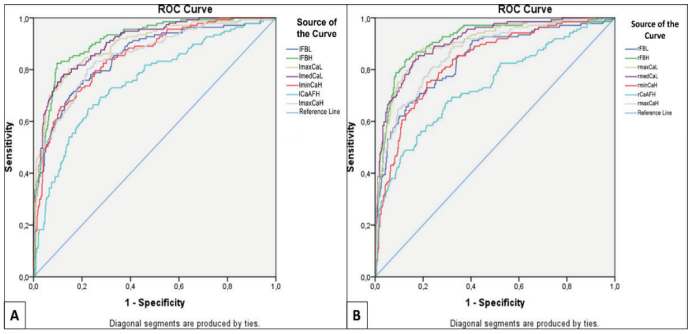

Figure 2. ROC analysis graph for gender prediction (A: Left side, B: Right side)

DISCUSSION

One of the three points of the foot in contact with the ground is the calcaneus. There are studies in the literature on morphometric measurements of both the foot and calcaneus on bones, cadavers, and living specimens (2,4,13,17-21). Evaluation of RI is necessary prior to calcaneus surgical treatment. Furthermore, knowledge of calcaneus morphometry before surgery provides useful information to prevent surgical complications.

Radiological approaches allow the examination of the relevant region without any intervention to the individual during the diagnosis of diseases. The data obtained as a result of radiological measurements of the foot and calcaneus can determine the degree of disease and the programming of treatment in cases involving this area.

Some measurements of the calcaneus are utilized both in clinical practice and in various forensic cases or archaeological excavations to estimate gender from bone (22,23). Distance measurements of the foot and calcaneus were performed within the scope of the study. Considering the biomechanical importance of the calcaneus in the foot, we aimed to determine its relationship with foot bone length and foot bone height. In the literature, there are few studies on RI regarding our measurement parameters in the Turkish population (15,23,24) In the study conducted by Schepers et al. (2007), examining the changes caused by calcaneus fractures in foot measurements in the foot RI of 33 individuals belonging to the Dutch population, the FBH value was 81 mm on the intact side, while this value was 77 mm on the side where the fracture was present, and a statistically significant difference was found between these values. In a study conducted in a German population, the FBH value was 84 mm (25). Altuntas (2021) measured the FBH data on the foot RI of 90 male and 90 female individuals as 84.48±6.12 mm on the right side and 84.5±6 mm on the left side. Altuntas (2021) found a statistical significance between the right and left sides of men in his study (p=0.022). However, he reported that there was no statistical significance between the two sides in women (23).

In the present study, no significant difference was found between right and left foot lengths (p=0.105). This conclusion supports the results of the study by Zeybek et al. (2008) on cadavers in which they aimed to estimate gender from foot anthropometric characteristics and Torun and Cay's (2018) study in which they examined the relationship between arcus longitudinalis medialis and foot length bilaterally in 106 patients (19,24). Torun and Cay (2018) reported that the foot dome flattened as the FBL increased. In the study, comparing the FBL values between genders, the lengths of the right and left sides were found to be significantly higher in men (p<0.001) (24). This result is consistent with the result obtained by Gwani et al. (2017) who measured foot lengths in two different ways with and without including metatarsal bones (26). Altuntas (2021) reported that the foot lengths of males were significantly higher than females in his study (23). We think that the fact that our measurements in the Turkish population have higher values than the studies of Sanli et al. (2005) and Dogruyol and Cimen (2021) is due to the age difference of the study populations (Table 6). Hill et al. (2017) evaluated the FBL value in their study with the 3D modeling method (27). We think that the differences in this study, which has higher FBL values than the current study, may be due to differences in methodology rather than racial differences in the study population.

There are two measurements of the length of the calcaneus in the study. In the literature, maxCaL is the most evaluated of these lengths, which is generally used in studies to estimate gender. In the study, it was determined that there was no statistically significant difference between the right and left sides of maxCaL data (p>0.05). Statistically significant differences were detected in both right and left maxCaL data in males and females (p<0.001) (Table 7).

Riepert et al. (1995) found no significant differences between males and females in the sex prediction of calcaneus length in lateral foot RI of 800 individuals from a Central European population (p<0.001) (16). Cekdemir et al. (2021) found statistically significant differences between the two sides in their study performed on CT images aiming to predict gender from the calcaneus (p<0.001) (28). These results are consistent with the findings of the present study. In addition, there are studies in the literature showing that there are no statistically significant differences between maxCaL lengths on the right and left sides as a result of research on dry bones (2,20). We think that the higher values of the results obtained in the present study compared to studies on cadavers in different populations are due to the different populations. Furthermore, López-Capdevila et al. (2020) measured the maxCaL value as 91 mm before surgical intervention applied to calcaneus fractures and 85.25 mm after surgery (29) (Table 7). They found significant differences between preoperative and postoperative outcomes (p<0.025).

We think that the medCaL data obtained in the study is lower than the data obtained by Agoada (2018) due to the difference in sample size and the characteristics of the populations (Table 7) (13).

Table 6. FBL value in other studies in the literature

Authors	Method	Population	N	Age range	Mean±SD			
Sanlı et al. (2005) (17)	Human	Türkiye	155	17-23	249.10±18.55			
Sen and Ghosh (2008) (18)	Human	India	350	18-50	222.6±1			
Zeybek et al. (2008) (19)	Human	Türkiye	249	18-44	Right		Left	
					Male	Female	Male	Female
					256.01±11.17	230.46±9.03	255.79±11.17	230.79±9.07
Gwani et al. (2017) (26)	RI	Nigeria	32	20-35	Male		Female	
					257.2±11.5		236±10.4	
Hill et al. (2017) (27)	3D Modeling	UK	62	-	Male		Female	
					Right	Left	Right	Left
					268.25±11.52	268.50±12.13	240.22±9.62	240.07±9.76
Torun and Cay (2018) (24)	RI	Türkiye	106	18-80	Male		Female	
					264.1±16.5		237.5±12.1	
Altuntas (2021) (23)	RI	Türkiye	180	20-64	Right		Left	
					261.13±17.28		261.08±17.2	
Dogruyol and Cimen (2021) (15)	RI	Türkiye	662	18-86	Right		Left	
					258.9±22.5		258.1±22.4	
Present study	RI	Türkiye	540	20-65	Right		Left	
					242.04±18.63		242.87±18.08	
					Male	Female	Male	Female
					261.27±16.89	235.5±14.15	261.81±15.13	236.43±14.03

FBL: foot bone length, N: number of individuals, RI: radiography images, 3D: three-dimensional, SD: standard deviation

Table 7. maxCaL and medCAL values in studies in the literature

maxCAL								
Authors	Method	Population	N	Age range	Mean±SD			
Riepert et al. (1995) (16)	RI	Central Europe	800	20-79	Male		Female	
					89.8±4.7		82±4.6	
Kim et al. (38)	Cadaver	South Korea	42	54-91	74.32±3			
Agoada (2018) (13)	RI and Cadaver	USA	54	35-89	RI		Cadaver	
					86.75±6.72		83.87±6.56	
Amuti et al. (2020) (2)	Cadaver	Kenya	64	18-65	Right		Left	
					68.95±9.85		68.26±10.46	
Schmutz et al. (2020) (4)	3D CT	Thailand and Japan	41	44-90	Right		Left	
					76.31±5.15		76.43±5.26	
Cekdemir et al. (2021) (8)	CT	Türkiye	489	-	Male		Female	
					85.65±5.16		76.74±4.21	
Present study	RI	Türkiye	540	20-65	Right		Left	
					83.12±6.96		83.22±5.96	
					Male	Female	Male	Female
					89.94±5.58	80.81±5.76	89.7±5.6	81.02±4.22
medCAL								
Authors	Method	Population	N	Age range	Mean±SD			
Agoada (2018) (13)	RI and Cadaver	USA	54	35-89	RI		Cadaver	
					83.32±6.74		82.15±6.74	
Altuntas (2021) (23)	RI	Türkiye	180	20-64	Right		Left	
					81.06±6.45		81.02±6.4	
					Male	Female	Male	Female
					85.4±4.9	76.8±4.7	85.3±4.9	76.8±4.7
Present study	RI	Türkiye	540	20-65	Right		Left	
					76.86±6.16		76.79±5.98	
					Male	Female	Male	Female
					83.26±5.29	74.69±4.77	83.02±5.05	74.66±4.64

maxCaL: maximum calcaneus length, medCaL: medial calcaneus length, N: number of individuals, RI: radiographic images, 3D: three-dimensional, CT: computed tomography, SD: standard deviation

There are two different measurements that determine the height of the calcaneus in the study. In the literature, no study has been found in which minCAH and maxCAH measurements were taken the same in the Turkish population. Additionally, in our study, maxCAH and minCAH data were found to have similar accuracy rates in gender prediction. It has been revealed that minCAH measurements can be preferred in bones where maxCAH measurements cannot be taken (Table 5). We think that the differences between the results of Zakaria et al. (2010) and Riepert et al. (1996), whereas the results of the present study and Agoada (2018) are close to each other, are due to the racial characteristics of the populations in the studies (13,16,30) (Table 8).

One of the lengths indicating calcaneus height is maxCaH. In the literature, this value was compared between the sides with (47 mm) and without (50 mm) calcaneus fracture and it was shown that maxCaH decreased on the fractured side with statistically significant differences (p=0.001) (14). Arslan et al. (2014) measured maxCaH as 47.68±2.8 mm in men and 43.16±2.71 mm in women in their study and reported a statistically significant difference between the two sides (p<0.001). This result is consistent with the result obtained in the current study (p<0.001) (31) (Table 8).

The last length measurement of the calcaneus evaluated in the study was CaAFH. The data obtained by Amuti et al. (2020) have lower values than the data in the present study (2). Cekdemir et al. reported statistically significant differences between the genders in this length in their study in which they aimed to predict gender from the calcaneus (p<0.001) (8). These data are consistent with the results of the present study (p<0.001) (Table 8).

Table 8. minCaH, maxCaH and CaAFH values in other studies in the literature

			minCaH			
Authors	**Method**	**Population**	**N**	**Age range**	**Mean±SD**	
Riepert et al. (1995) (16)	RI	Central Europe	800	20-79	**Male**	**Female**
					42.3±3.1	37.8±2.9
Zakaria et al. (2010) (30)	RI	Egypt	204	20-70	**Male**	**Female**
					40.29±3.1	34.59±3.2
Agoada (2018) (13)	RI and Cadaver	USA	54	35-89	**RI**	**Cadaver**
					38.98±3.82	39.24±3.65
Present study	RI	Türkiye	540	20-65	**Right**	**Left**
					39.57±4.27	39.43±4.06
			maxCaH			
					Mean±SD	**Authors**
Riepert et al. (1995) (16)	RI	Central Europe	800	20-79	**Male**	**Female**
					51.8±4.0	46.7±3.6
Schepers et al. (2007) (14)	RI	Holland	33	18-65	50	
Zakaria et al. (2010) (30)	RI	Egypt	204	20-70	**Male**	**Female**
					47.94±3.5	41.41±3.5
Arslan et al. (2014) (31)	RI	Türkiye	69	18-79	**Male**	**Female**
					47.68±2.8	43.16±2.71
Kim et al. (2014) (38)	Cadaver	South Korea	42	54-91	42.5±3.0	
Agoada (2018) (13)	RI and Cadaver	USA	54	35-89	**RI**	**Cadaver**
					50.50±5.68	49.75±4.31
Present study	RI	Türkiye	540	20-65	**Right**	**Left**
					46.71±3.93	46.43±3.75
			CaAFH			
Agoada (2018) (13)	RI and Cadaver	USA	54	35-89	**RI**	**Cadaver**
					23.08±2.21	25.07±2.12
Amuti et al. (2020) (2)	Cadaver	Kenya	64	18-65	**Right**	**Left**
					18.83±4.71	17.91±3.93
Cekdemir et al. (2021) (28)	CT	Türkiye	489	-	**Male**	**Female**
					28.83±2.13	25.45±1.99
Present study	RI	Türkiye	540	20-65	**Right**	**Left**
					25.73±2.7	25.76±3.01

minCaH: minimum calcaneus height, maxCaH: maximum calcaneus height, CaAFH: calcaneus anterior facet height, N: number of individuals, RI: radiographic images, CT: computed tomography, SD: standard deviation

Gender estimation from bones is gaining importance in various forensic cases or major disasters affecting masses (12). Gender estimation from skeletal remains is an important issue in both forensics and bioarchaeology (32). In the present study, right and left calcaneus measurement parameters were subjected to ROC analysis to determine their accuracy in gender prediction. As a result of the analysis, FBL was the parameter with the highest accuracy rate on both the right (0.913) and left (0.913) sides. In the Turkish population, it was reported that the FBL parameter on cadavers (19) and the FBL parameter on RI (23) provided highly accurate results for gender prediction. Fun et al. (2011) reported that the accuracy rate of predicting gender from foot length was 85.7-86.7% in their study in which they stated that predicting gender from foot length has a high accuracy rate (33). Another study reported that FBL is a strong parameter in predicting gender (34). In another study conducted on a northern Australian population, which aimed to predict gender from foot and footprint measurements, it was reported that FBL was 90.5% successful in predicting gender (35). In a study conducted on a Nigerian population that examined the ability to predict gender from foot measurements, height, and body mass index, FBL was found to be an important parameter for gender prediction (36).

In the present study, the accuracy of maxCaL was 0.904 on the right side and 0.897 on the left side. DiMichele and Spradley (2012) reported the accuracy of this parameter in predicting gender as 0.800 (37).

In the study, minCaH had an accuracy of 0.831 on the right side and 0.852 on the left side; CaAFH had an accuracy of 0.737 on the right side and 0.755 on the left side. In the study by Kim et al. (2013) in which these parameters were also evaluated, the accuracy value of maxCaL was 0.902, minCaH value was 0.871 and CaAFH was 0.780 as well (38). In another study, the accuracy of maxCaL was reported to be 83.5%, while the accuracy of CaAFH was 78.7% (39). In a different study, it was reported that maxCaL length was successful by 82.3% in predicting gender. In the same study, the value of minCaH length was reported as 81.2% and CaAFH as 78.5% (10). Ekizoglu et al. (2017) reported that maxCaL was quite different between genders in their study based on computed tomography images (40). Gualdi-Rosso (2007) reported that talus lengths were more successful in predicting gender than calcaneus lengths (22). However, he stated that length and width measurements of the calcaneus were more accurate than height measurements. In another study performed on computed tomography images in the Turkish population, Cekdemir et al. (2021) reported the accuracy of maxCaL as 0.911 and CaAFH as 0.878 (8).

The limitations of our study are that it is a retrospective study and that the individuals participating in the study do not know their body mass index, so the relationship between weight, height and body mass index and our measurement data could not be revealed.

CONCLUSION

The conclusion is very detailed and long written. It will be sufficient to emphasize the result of the study, its difference from other studies and its contribution to the literature in one paragraph.

The calcaneus plays an important role in body biomechanics. One of the most important features that enables it to fulfill this role is that it is one of the strongest bones in the body. Due to its robust structure, the calcaneus can maintain its morphometric properties even under the ground or in natural disasters. In addition to revealing morphometric differences between races, it provides information about people and communities that lived many years ago in forensic medicine, archaeology, and anthropology for gender determination. For these reasons, the morphometric measurements of the calcaneus and the accuracy of these measurements in gender determination were presented in the present study. These data are important for many disciplines such as forensics, archaeology, and anthropology. In this study, we aimed to contribute to the literature with various morphometric measurements of the calcaneus. The study was carried out on 1,080 calcanei belonging to individuals aged 20-65 years.All the values of length were higher in men than in women. Among the parameters in the study, FBL and maxCaL showed the highest accuracy in gender prediction. Besides, the right-side parameters in the study have a higher accuracy rate in gender determination than the left side.

In future studies, the inclusion of individuals under the age of 20 years and over the age of 65 years in studies covering larger populations will allow more comprehensive data on the calcaneus to be obtained. These data can be used for the development of machine learning and artificial intelligence methods in future studies.

It is believed that the results obtained in the study will be helpful in forensic and clinical applications. Knowing the average values of the measured parameters in the Turkish population will allow for more accurate results. Contributory results are presented for situations where gender prediction is required.

Financial disclosures: *The authors declared that this study has received no financial support.*

Conflict of interest: *The authors have no conflicts of interest to declare.*

Ethical approval: *The study was conducted with a retrospective design with the approval of Necmettin Erbakan University Drug and Non-Medical Device Research Ethics Committee dated 04.02.2022 and numbered 2022/3632.*

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