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Discriminant Function Sexing of the Calcaneus of the South African Whites*

ABSTRACT: The skull and some postcranial elements, such as the humerus, femur, and tibia, have been used in their intact states for sex determination in forensic and archaeological cases. But, in practice, these bones are often recovered in fragmented states, which render them unsuitable for use in sex determination. The calcaneus is a compact bone that is able to withstand high tensile forces. Some of its parameters have been used for sex determination in American whites and blacks (1) and Italians (2). This bone has not been used for sex determination in the South African white population. Therefore, the aim of this study was to assess the degree of sexual dimorphism of the calcaneus of the South African white population sample, derive discriminant function score equations for use in sex determination, and determine the level of accuracy of its sex-determining ability. Nine parameters were measured on each pair of 53 male and 60 female calcanei of known South African white skeletons, obtained by a random sampling technique from the Raymond A. Dart Collection of Human Skeletons, School of Anatomical Sciences, University of the Witwatersrand, Johannesburg. Basic statistic and discriminant function analysis was performed on the acquired data. The basic statistics showed that all measured parameters were sexually dimorphic. Discriminant function score equations were generated for use in sex determination. The average accuracy of sex classification ranged from 73 to 86% for the univariate method, 81 to 91% for the stepwise method, and 82 to 92% for the direct method. It is concluded that the calcaneus is useful for sex determination in the South African white population.

KEYWORDS: forensic science, discriminant function, sexing, calcaneus, South African whites

Personal identification from skeletal remains is of major interest to forensic anthropologists. Sex, which is one of the demographic factors necessary for human identification, can be determined by visual observation of certain (nonmetrical) features of bone and by measurements of other (metrical) parameters that display sexual dimorphism. The metrical method is, however, the preferred method because of its objectivity and repeatability (2). The skull (3–7) and many bones of the postcranial skeleton such as the femur (8–12), tibia (13,14), and humerus (15) have been used for sex determination in different population groups. But the calcaneus has not been sufficiently assessed for use in human identification compared to the long bones of the human skeleton. Steele (1) used the calcaneus and the talus for sex determination among American whites and blacks. He used five measurements from each bone and combinations of measurements from both bones to obtain discriminant function scores, which were used for sex determination in these population groups. The degree of accuracy of sex determination from these bones by the different combinations of variables used in his study ranged from 79 to 89%. Riepert et al. (16) reported an average accuracy of sex identification of 84% from radiographs of the calcaneus of central Europeans. Introna et al. (2) used eight measurements from the calcaneus of a southern Italian population for sex determination by means of the discriminant function analysis and achieved an accuracy of 69 to 85%. All of these studies have proved the usefulness of calcaneus in sex determination.

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It is well established that osteometric standards obtained for skeletal identification differ between population groups (14,15,17–20). The results of the studies of the calcaneus in American whites and blacks, the Italians, and central Europeans may, therefore, not be applicable to the South African whites, who are an admixture of migrants from the Netherlands, United Kingdom, France, Germany, and other European nations (14).

Therefore, the aim of this study was to subject certain measurements of a sample of the calcaneus of the South African whites to discriminant function analysis and thereby to obtain discriminant function score equations that may be used for sex determination in this population group. Since the calcaneus is a compact bone that is relatively well preserved, a situation that is believed to be due to the wearing of footgear, the establishment of reliable sexing parameters of the bone may provide the needed help to forensic anthropologists and archaeologists when other bones are not available for use.

Materials and Methods

Two sets of samples were used. The first sample (Sample 1) consisted of 53 white male and 60 white female calcanei, within the age range of 22 to 75 years, randomly selected from the Raymond A. Dart Collection of Human Skeletons, School of Anatomical Sciences, University of the Witwatersrand, Johannesburg. This sample was used in the derivation of discriminant function equations for sex determination. The second sample (Sample 2) consisted of 40 calcanei distributed equally by sex obtained from the Pretoria Bone Collection of the Department of Anatomy of the University of Pretoria and the Raymond A. Dart Collection of Human Skeletons. The skeletal elements in Sample 2 obtained from the Raymond A. Dart Collection did not include those that were used in the derivation of discriminant function equations. Sample 2 being an independent sample served to test the accuracy of discriminant function equations that were derived using Sample 1. All calcanei showing any obvious bone pathologies such as excessive osteophytic lippings or loss of cortical tissue were excluded.

The nine parameters that were measured on each calcaneus were the maximum length (MAXL/MCAL), the load arm length (LAL), the dorsal articular facet length (DAFL), the body height (BH), the maximum height (MAXH), the cuboidal facet height (CFH), the middle breadth (MIDB), the dorsal articular facet breadth (DAFB), and the minimum breadth (MINB). A preliminary comparison of the measurements taken from paired calcanei showed no statistically significant side differences ($P < 0.05$). Therefore, the left calcanei were used in this study. However, the right calcanei were used whenever the left calcaneus of the randomly selected pair was not available or morphologically unsuitable for measurement. The definitions of these parameters were those of Steele (1) and Martin and Knussman (21) except in the case of MINB, BH, and MAXH, in which the measurements could not be precisely reproduced. Appropriate modifications were made to the measuring techniques of the three parameters, which were redefined as follows:

Minimum breadth: This is the distance between the medial and the lateral surfaces of the superior part of the body of the calcaneus.

Body Height: This is the distance between the superior and the inferior surfaces of the body of the calcaneus taken in the coronal plane, midpoint between the most posterior point of the dorsal articular facet and the most anterior point of the calcaneal tuberosity.

Maximum Height: This is the distance between the most superior and the most inferior points of the calcaneal tuberosity.

All of the nine measurements listed above were tested for repeatability using the concordance correlation coefficients of reproducibility (22). The values of these coefficients, being in the range of 0.915 to 0.985, were within the internationally accepted standards (23). The mean values of the nine parameters were compared between the sexes in order to determine whether statistically significant differences existed using the Student's t-test. The variables were classified into three categories according to the dimension, which were:

a. Breadth measurements (MINB, MIDB and DAFB).
b. Length measurements (MAXL, LAL, and DAFL).
c. Height measurements (BH, MAXH, and CFH).

The ungrouped and grouped variables were subjected to stepwise, univariate, and direct discriminant function analyses using the Statistical Product and Service Solution (SPSS) software program.

Results

Assessment of Sexual Dimorphism

The mean values of all nine male parameters were significantly greater ($P < 0.001$) than those of the females (Table 1), indicating the presence of significant sexual dimorphism in all measured variables of the calcaneus.

Stepwise Discriminant Function Score Equation

All nine measured parameters were entered into the stepwise discriminant function analysis. Out of these, the DAFB, MAXL, and MIDB were selected. Table 2*a* shows the unstandardized coefficients, constants, and sectioning points that were used to formulate the discriminant function score equation

$$y = (\mathrm{DAFB} \times 0.314) + (\mathrm{MAXL} \times 0.081) + (\mathrm{MIDB} \times 0.159) + (-19.932)$$

where y = discriminant function score.

DAFB, MAXL, and MIDB are the corresponding measured values of these parameters. Substituting for DAFB, MAXL, and MIDB in this equation will give the value of y, which is then compared with the value of the sectioning point (−0.042). Since the mean values of these parameters are greater in males than in females, y greater than the sectioning point will indicate a male calcaneus. On the contrary, y less than the value of the sectioning point will indicate a female calcaneus. The tested accuracy of sex determination of the calcaneal sample by stepwise discriminant function analysis was 90.6%.

Table 2*a* also shows that two variables were selected out of three from each of the dimensional categories of variables. The corresponding discriminant function score equations are shown in Table 2*b*.

Direct Discriminant Function Score Equations

Table 3*a* shows the unstandardized discriminant function coefficients, constants, and sectioning points for combinations of variables of the calcaneus that were entered directly into, and used for, the discriminant function analyses. The corresponding discriminant function score equations are shown in Table 3*b*. The tested accuracy of sex determination by these combinations of variables

TABLE 1—*Descriptive statistics of measured variables.*

	Male			Females				
Variables	*N*	Mean	SD	*N*	Mean	SD	*F*-Statistic	*P* Value
DAFB	53	24.02	2.01	60	20.21	1.58	126.88	0.000
MAXL	52	84.78	4.73	54	75.87	4.07	108.33	0.000
MIDB	53	41.96	2.07	59	37.94	2.13	102.13	0.000
DAFL	53	31.18	2.09	60	27.49	1.86	98.63	0.000
LAL	53	48.19	3.41	54	43.32	2.94	62.67	0.000
MINB	53	22.34	2.09	58	19.43	2.22	50.31	0.000
MAXH	53	47.72	3.55	59	43.39	3.33	44.34	0.000
BH	53	39.44	2.76	60	36.03	2.79	42.46	0.000
CFH	47	22.98	2.16	48	20.22	2.02	41.40	0.000

DAFB = dorsal articular facet breadth, MAXL = maximum length, MIDB = middle breadth, DAFL = dorsal articular facet length, LAL = load arm length, MINB = minimum length, MAXH = maximum height, BH = body height, CFH = cuboidal facet height

TABLE 2*a*—*Stepwise discriminant function analysis for South African whites.*

Functions	Unstandardized Coefficient	Standardized Coefficient	Wilk's Lambda	Structure Point	Group Centroids	Sectioning Point	Accuracy %
All 9 variables							
DAFB	0.314	0.578	0.467	0.848	M = 1.204	−0.042	90.6
MAXL	0.081	0.356	0.408	0.749	F = −1.288		
MIDB	0.159	0.339	0.387	0.715			
Constant	−19.932						
Breadth variables							
DAFB	0.366	0.664	0.527	0.860	M = 1.283	0.065	91.1
MIDB	0.260	0.547	0.467	0.785	F = −1.153		
Constant	−18.421						
Length variables							
MAXL	0.163	0.721	0.579	0.937	M = 1.080	0.010	88.7
DAFL	0.180	0.411	0.494	0.790	F = −1.060		
Constant	−18.343						
Height variables							
CFH	0.341	0.717	0.739	0.782	M = 0.849	0.009	80.9
BH	0.223	0.627	0.694	0.701	F = −0.831		
Constant	−15.765						

M = male, F = female.

TABLE 2*b*—*Discriminant function score equations for stepwise analysis.*

Equations	Sectioning Points
From all 9 variables	
y = (DAFB × 0.314) + (MAXL × 0.081) + (MIDB × 0.159) + (−19.932)	−0.042
From breadth variables	
y = (DAFB × 0.366) + (MIDB × 0.260) + (−18.421)	0.065
From length variables	
y = (MAXL × 0.163) + (DAFL × 0.180) + (−18.343)	0.010
From height variables	
y = (CFH × 0.341) + (BH × 0.223) + (−15.765)	0.009

TABLE 3*a*—*Direct discriminant function analysis for South African whites.*

Groups	Functions	Unstandardized Coefficient	Standardized Coefficient	Wilk's Lambda	Structure Point	Group Centroid	Sectioning Point	Accuracy %
1	DAFB	0.295	0.544	0.359	0.799	M = 1.278	−0.045	92.1
	MAXL	0.088	0.388		0.705	F = −1.367		
	MIDB	0.163	0.347		0.674			
	DAFL	0.038	0.087		0.590			
	LAL	−0.036	−0.109		0.561			
	CFH	0.103	0.215		0.524			
	MINB	0.075	0.159		0.513			
	MAXH	−0.008	−0.027		0.454			
	BH	−0.093	−0.266		0.427			
	Constant	−19.628						
2	DAFB	0.352	0.640	0.399	0.871	M = 1.260	0.044	89.1
	MIDB	0.228	0.477		0.773	F = −1.172		
	MINB	0.063	0.135		0.548			
	Constant	−18.133						
3	MAXL	0.154	0.681	0.461	0.935	M = 1.082	0.010	86.7
	DAFL	0.170	0.388		0.788	F = −1.062		
	LAL	0.025	0.080		0.708			
	Constant	−18.478						
4	CFH	0.313	0.657	0.572	0.767	M = 0.865	0.001	81.7
	BH	0.151	0.425		0.688	F = −0.846		
	MAXH	0.083	0.278		0.733			
	Constant	−16.208						

TABLE 3*b*—*Multivariate discriminant function score equations.*

Groups	Equations	Sectioning Point
1	y = (DAFB × 0.295) + (MAXL × 0.088) + (MIDB × 0.163) + (DAFL × 0.038) + (LAL × [−0.036]) + (CFH × 0.103) + (MINB × 0.075) + (MAXH × [−0.008]) + (BH × [−0.266]) + (−19.628)	−0.045
2	y = (DAFB × 0.352) + (MIDB × 0.228) + (MINB × 0.063) + (−18.133)	0.044
3	y = (MAXL × 0.154) + (DAFL × 0.170) + (LAL × 0.025) + (−18.478)	0.010
4	y = (CFH × 0.313) + (BH × 0.151) + (MAXH × 0.083) + (−16.208)	0.001

TABLE 4*a*—*Univariate discriminant function analysis.*

Variable	Unstandardized Coefficient	Constant	Group Centroids	Sectioning Point	Accuracy (%)
DAFB	0.552	−12.152	M = 1.121 F = −0.991	0.065	85.8
MAXL	0.227	−18.208	M = 1.029 F = −0.991	0.019	84.9
MIDB	0.476	−18.964	M = 1.007 F = −0.905	0.051	83.9
DAFL	0.448	−13.080	M = 0.878 F = −0.775	0.052	81.4
MINB	0.463	−9.634	M = 0.705 F = −0.644	0.031	74.8
CFH	0.479	−10.345	M = 0.675 F = −0.661	0.007	74.7
BH	0.360	−13.558	M = 0.653 F = −0.577	0.038	73.5
MAXH	0.291	−13.223	M = 0.664 F = −0.596	0.034	73.2
LAL	0.314	−14.382	M = 0.781 F = −0.767	0.007	72.9

TABLE 4*b*—*Univariate discriminant function score equations.*

Equations	Sectioning Point
y = (DAFB) × (0.552) + (−12.150)	0.065
y = (MAXL) × (0.227) + (−18.210)	0.019
y = (MIDB) × (0.476) + (−18.960)	0.051
y = (DAFL) × (0.448) + (−13.080)	0.052
y = (MINB) × (0.463) + (−9.634)	0.031
y = (CFH) × (0.479) + (−10.350)	0.007
y = (BH) × (0.360) + (−13.566)	0.038
y = (MAXH) × (0.291) + (−13.220)	0.034
y = (LAL) × (0.314) + (−14.380)	0.007

y = discriminant function score; listed in descending order of accuracy of sex determination.

ranged from 86.7 to 92.1%, with the best combination being one that included all nine variables.

Univariate Discriminant Function Score Equations

The unstandardized discriminant function coefficients, constants, and sectioning points for individual measured variables of the calcaneus that were separately entered into and treated by the discriminant function analyses are shown in Table 4*a*. The DAFB, MAXL, and MIDB are the three most accurate of the parameters in determining the sex of the calcanei, with accuracy levels of 85.8, 84.8, and 83.9%, respectively. The corresponding discriminant function score equations are shown in Table 4*b*.

Validity of Discriminant Function Equations

The best equation from each of the analyses, i.e., univariate, stepwise, and direct, was tested for validity using an independent sample (Sample 2). This sample represented adults of known sex. The sectioning point for each of the equations was used to classify the sample. Eighty-five percent of the sample was correctly classified using the equation for DAFB (Table 4*b*). The equation from stepwise analysis of all variables (Table 2*b*) correctly sexed 88% of the sample, while that from direct analysis (Table 3*b*) produced an accuracy of 84% in correct classification.

Discussion

Reproducibility of Bone Measurements

It is of utmost importance in skeletal biology and anthropology that specific parameters are sufficiently well defined so that every scientist who is using the parameters is able to understand the definition and reproduce the measurement. Testing and re-testing of measurements were done in this study for that purpose. Statistically acceptable coefficients of reproducibility could not be obtained in the cases of the minimum breadth, middle breadth, and maximum height of the calcaneus when Steele's (1) and Martin and Knussmann's (21) definitions were used on our samples because of the variability of the levels of measurement along the vertical and horizontal planes. Steele (1), for example, defined the minimum breadth as the projected line of minimum horizontal width through the body of the calcaneus. This definition does not state precisely where along the vertical plane of the body of the calcaneus this measurement should be taken. In our sample, the position of the minimum breadth was inconsistent with respect to the superior, middle, and inferior aspects of the body of the calcaneus. For the sake of consistency of measurement, the minimum breadth was measured close to the superior surface of the bone.

The body height of the calcaneus as defined by Steele (1) is the greatest projected height of the calcaneus measured from the most superior point of the posterior facet of the calcaneus to the most inferior point of the calcaneal tuberosity. This measurement, which appears to be the same as the maximum height (MAXH) of the calcaneus used in this study, lies on an oblique plane. Measurements in the vertical plane are easier to reproduce than those in the oblique plane, hence the modifications in our study. The modified definitions produced acceptable coefficients of reproducibility.

Sexual Dimorphism of the Calcaneus

Each of the nine variables measured on the calcaneus of the South African whites showed statistically significant sex differences between males and females, indicating that the calcaneus is sexually dimorphic in this population group. Therefore, the discriminant function score equations that were derived from each of them may be used for sex determination. This is in contrast to Steele's (1) conclusion that the overlap of the ranges between sexes is so great that single measurements are of little practical value for sex determination. Our finding in the South African whites, however, agrees with that in the Southern Italian population (2).

Although the accuracies of sex determination by individual variables in this study (73 to 86%) are slightly higher than those of the Southern Italian population (2), which were 69 to 84%, both studies demonstrated higher accuracies when various combinations of variables were used. Individual variables will be useful only when fragments of the bone are recovered. The accuracies obtained from the use of combinations of variables in this study (88 to 92%) are higher than those (76 to 85%) observed in the southern Italian population (2). Similar comparison could not be made with the American whites (1), because the result of accuracy in the study was presented for only one variable of the calcaneus.

The breadth and length measurement of the calcaneus generally contribute more to sex determination than the height measurements as shown by the relative values of their structure coefficients when all nine variables were analyzed together (Table 2*a*). These measurements also show higher degrees of accuracy of sex determination than the height measurements.

The equations derived for American whites (1) were tested on two independent samples, and the result showed a range of accuracy of between 80 and 85% in correct classification. The result of the test of the validity of equations from this study (84 to 88%) compared well with those obtained by Steele (1).

The skeletal remains used in the derivation of these equations represent individuals who lived between the late 20th century and late 21st century. Therefore, the question of the applicability of these equations on the present South African white population arises. This was observed by Steele (1) when he questioned the applicability of his equations obtained from the 70-year-old Terry Skeletal Collection on the present American whites. He concluded that until there are newer collections from which discriminant function equations could be derived, his equations should prove effective in sex differentiation.

However, when the validity of the equations derived from the present study were tested on the 16-year-old Pretoria Bone Collection, the results obtained were satisfactory, thereby confirming the applicability of these equations to the present South African white population.

Conclusion

All the nine variables measured on the calcanei of the South African whites are individually sexually dimorphic, and their individual and combined discriminant function score equations can be used for sex determination. High accuracies obtained from various combinations of these variables confirm the usefulness of the calcaneus for sex determination in this population group.

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