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TECHNICAL NOTE

Mubarak Ariyo Bidmos,[1] *M.Sc. and Samuel A. Asala,*[1] *Ph.D.*

Sexual Dimorphism of the Calcaneus of South African Blacks

ABSTRACT: Forensic anthropology is a rapidly growing field in South Africa and skeletal biologists are often called upon by the police to assist in personal identification from skeletal remains, which are recovered in suspected cases of homicide and suicide and in mass disaster. Measurements of the calcaneus have been shown to be sexually dimorphic in South African whites. Since the validity of discriminant function equations in sex determination is population specific, the aim of the present study was to derive similar equations for the calcanei of the South African blacks. The bones that were used in this study were obtained from the Raymond A. Dart Collection of Human Skeletons, School of Anatomical Sciences, University of the Witwatersrand, Johannesburg. One hundred and sixteen (116) intact and non-pathological calcanei, consisting of 58 males and 58 females and belonging to individuals whose age at death ranged between 22 and 75 years, were selected by the simple random sampling technique. The measured variables included the maximum length, the load arm length, the dorsal articular facet length, the body height, the maximum height, the cuboidal facet height, the middle breadth, the dorsal articular facet breadth and the maximum breadth. Discriminant function analyses were done using the Statistical Product and Service Solutions (SPSS) program. All measured parameters of the calcaneus showed significant sexual differences. Length measurements were found to be the most sexually dimorphic. Combinations of variables provided better estimate of sex (79%–86%) than individual variables (64%–79%).

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

Forensic anthropology is a new but rapidly growing field in South Africa. The political situation in the country during and immediately after the apartheid era resulted in large-scale violent activities that resulted in increased number of missing and unidentified persons. The increased number of illegal immigrants further worsened the situation (1). Skeletal biologists are often called upon by the police to assist in personal identification from skeletal remains, which are recovered in suspected cases of homicide and suicide and in mass disaster such as fire accidents and motor vehicular accidents. Sex is the first demographic factor that is determined because it reduces the number of possible matches by 50% (2).

Previous studies have shown that the skull (3–5) and postcranial elements (6–8) can be used for sex determination in forensic and archaeological cases. While some authors prefer the use of morphological trait in sex determination (2,9) because it is not size dependent, others are in favor of the use of metrical methods because of their objectivity and reproducibility (4,10). Discriminant function analysis is a metrical method that is widely used. It involves the generation of function equations that are similar to regression equations. From these equations, discriminant function scores can be obtained, which when compared with the sectioning point (11,12), can assist in sex allocation. Numerous studies have shown that discriminant function equations are population-specific and are therefore not applicable to populations other than those from which they are derived (4,8,10,11,13–19). Therefore, there is a need to generate discriminant function equations for sex determination for as many bones of the skeleton as possible in different South African population groups.

The calcaneus is the largest of the foot bones and is often recovered intact in forensic and archaeological cases perhaps because of the use of protective shoes in these categories of cases. The variation in the number of articular facets present on its superior surface has been shown to suggest sex and population differences but the accuracy of sex assignment is low (20). However, no reason has been given for the population differences that have been observed in this non-metric trait. Measurements of the calcaneus have been shown to be sexually dimorphic in American whites and blacks (15), Central Europeans (21) and Italians (10). In a recent preliminary study (23), the usefulness of calcaneal measurements in sex determination in South African whites was shown.

Since the validity of discriminant function equations in sex determination is population specific, the aim of the present study was to derive similar equations for South African blacks, which form the largest of the four population groups in South Africa, and to test the validity of the derived equations.

Materials and Methods

The skeletal remains that were used in this study were obtained from the Raymond A Dart Collection of Human Skeletons housed in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg. In this Collection, different tribes such as the Zulu, Sotho, Tswana, and Xhosa, constitute the South African black population. For the purpose of this study, these tribes were treated

[1] School of Anatomical Sciences, Faculty of Health Sciences, University of the Witwatersrand, 7 York Road, Parktown 2193, Johannesburg.

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as a single homogenous group because previous works showed no significant differences in most of the metrical and non-metrical characteristics of their skull (3) and postcranial elements (24).

One hundred and sixteen intact and nonpathological calcanei, consisting of 58 males and 58 females and belonging to individuals whose age at death ranged between 22 and 75 years, were selected by the simple random sampling technique. Their years of birth ranged between 1907 and 1970. Nine parameters were measured on the left calcanei only because preliminary comparison of measurements taken from paired calcanei showed no significant side differences ($P > 0.05$). These measurements included the maximum length (MAXL), 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 maximum breadth (MAXB). All measurements followed Martin and Knussman's (22) definitions except in the case of BH, MAXH and MAXB in which the measurements could not be precisely reproduced and appropriate modifications were made. BH and MAXH had been defined previously (23) while MAXB is redefined as the maximum distance between the medial and the lateral surfaces of the body of the calcaneus.

Repeating all nine measurements on 10 calcanei using the concordance correlation coefficients of reproducibility (25) assessed the reliability of the measuring technique. The result of the repeatability showed that the measuring technique used in the study was satisfactory. The data were analyzed using the Statistical Product and Service Solutions (SPSS) program. For each of the measurements, descriptive statistics including mean and standard deviation were obtained. After using the Student's t test to establish that a significant difference existed between the male and female mean values for each of the measurements, stepwise and direct discriminant function analyses (12) were performed on each of the three groups as described previously (23). Univariate analysis was also performed on each of the variables in order to obtain demarking points (average of male and female mean values) that could be used for fragmentary bones in which all parameters are not measurable. The validity of the discriminant function score equations generated were assessed using the "leave-one-out" classification procedure (11,12).

TABLE 1—*Descriptive statistics of measured variables.*

	Male			Females				
Variables	*N*	Mean	SD	*N*	Mean	SD	F-statistic	*P* value
MAXL	58	79.82	3.77	58	73.68	4.83	58.23	0.000
LAL	58	44.15	2.58	58	41.04	2.86	37.85	0.000
MAXB	58	27.58	2.47	58	25.56	2.52	19.10	0.000
BH	58	36.31	2.75	58	33.83	2.86	22.71	0.000
MAXH	58	43.11	3.45	58	40.05	3.20	24.52	0.000
MIDB	58	42.54	2.66	58	39.20	2.76	44.17	0.000
DAFL	58	30.32	1.94	58	27.17	2.16	68.52	0.000
DAFB	58	22.85	1.70	58	20.63	1.90	43.89	0.000
CFH	58	23.97	1.89	58	20.97	1.83	74.68	0.000

MAXL = maximum length, LAL = Load arm length, MAXB = Maximum breadth, BH = Body height, MAXH = Maximum height MIDB = Middle breath, DAFL = Dorsal articular facet length, DAFB = Dorsal articular facet breadth, CFH = Cuboidal facet height.

TABLE 2—*Demarking points (in mm) for sex differentiation using individual variables.*

Variables	Demarking Points	Accuracy %
DAFL	females < 28.8 < males	79.3
DAFB	females < 21.7 < males	77.6
CFH	females < 22.7 < males	77.6
MAXL	females < 76.8 < males	75.8
LAL	females < 42.6 < males	75.0
MIDB	females < 40.9 < males	75.0
BH	females < 35.1 < males	69.0
MAXH	females < 41.6 < males	65.5
MAXB	females < 26.6 < males	63.8

Results

Assessment of Sexual Dimorphism

Males presented with significantly greater ($P < 0.001$) mean values for all measurements than females (Table 1) indicating the presence of significant sexual dimorphism in all measurements of the calcaneus. The average of the male and female mean values gives the demarking point (Table 2), which is a rapid way of determining sex from single variables. A measured value higher than the demarking point classifies an individual as male and a lower value suggests female. The percentage average accuracy in correct sex classification for each of the variables is also presented (Table 2). DAFL, DAFB and CFH are the three most sexually dimorphic variables with accuracies of 79.3, 77.6, and 77.6% respectively.

Stepwise Discriminant Function Analysis

Of the nine variables entered into the analysis, the best three were selected (Function 1, Table 3). Two variables were selected from each of the length (Function 2, Table 3), breadth (Function 3, Table 3) and height (Function 4, Table 3) dimensional groups. The functions are arranged in descending order of accuracy with length measurements having the highest accuracy (80.2%) amongst the three groups.

From Table 3, discriminant function score equation can be formulated for each of the functions using the unstandardized coefficients and constants. For example the discriminant function score equation for function 1 will be:

$$y = (\text{DAFL} \times 0.269) + (\text{DAFB} \times 0.184) + (\text{CFH} \times 0.272) + (-17.826)$$

where y = discriminant function score and DAFL, DAFB and CFH represent the magnitudes of the variables in millimeters. If the y is greater than the sectioning point (0.000) the bone is classified male and vice versa. The average accuracy (mean of male and female accuracies) of correct sex classification using this function is 85.3% (Function 1, Table 3).

Direct Discriminant Function Analysis

From Table 4, direct analysis of all variables provided the highest accuracy of correct sex classification (86.2%). The other combinations are arranged in descending order of accuracy. Discriminant function equations can be derived for each of these combinations in a similar way as described above for stepwise analysis.

Validity of Discriminant Function Equations

The "leave-one-out" classification method was used to assess the validity of these equations. Percentages of cases correctly classified according to sex and cross-validated percentages using step-

TABLE 3—*Stepwise discriminant function analysis for South African blacks.*

Functions	Unstandardized Coefficient	Standardized Coefficient	Wilk's Lambda	Structure Point	Group Centroids	Sectioning Point	Accuracy %
1 All 9 variables							
DAFL	0.269	0.551	0.560	0.743	M = 1.034	0.000	85.3
DAFB	0.184	0.332	0.504	0.595	F = −1.034		
CFH	0.272	0.507	0.538	0.776			
Constant	−17.826						
2 Lenght variables							
MAXL	0.118	0.571	0.625	0.825	M = 0.859	0.000	80.2
DAFL	0.315	0.647	0.662	0.895	F = −0.859		
Constant	−18.115						
3 Breadth variables							
DAFB	0.340	0.615	0.721	0.809	M = 0.760	0.000	79.3
MIDB	0.228	0.619	0.722	0.812	F = −0.760		
Constant	−16.732						
4 Height variables							
CFH	0.461	0.860	0.823	0.908	M = 0.884	0.000	79.3
MAXH	0.127	0.423	0.604	0.520	F = −0.884		
Constant	−15.636						

Example: Function 2, discriminant function equation = (0.118 × MAXL) + (0.315 × DAFL) − 18.115. A discrimnant function score greater than 0.000 indicates male and less than 0.000 indicates female.

TABLE 4—*Direct discriminant function analysis for South African blacks.*

Groups	Functions	Unstandardized Coefficient	Standardized Coefficient	Wilk's Lambda	Structure Point	Group Centroid	Sectioning Point	Accuracy %
1	MAXH	0.018	0.060	0.428		M = 1.146	0.000	86.2
	BH	0.038	0.108			F = −1.146		
	CFH	0.253	0.472					
	MAXL	0.090	0.389					
	LAL	−0.206	−0.562					
	MAXB	−0.200	−0.500					
	MIDB	0.061	0.165					
	DAFL	0.365	0.749					
	DAFB	0.237	0.428					
	Constant	−18.685						
2	MAXL	0.146	0.634	0.568	0.819	M = 0.885	0.000	80.2
	LAL	−0.071	−0.193		0.660	F = −0.885		
	DAFL	0.334	0.685		0.888			
	Constant	−17.805						
3	CFH	0.451	0.842	0.551	0.897	M = 0.894	0.000	79.3
	BH	0.073	0.205		0.495	F = −0.894		
	MAXH	0.084	0.279		0.514			
	Constant	−16.180						
4	MIDB	0.222	0.601	0.630	0.812	M = 0.760	0.000	79.3
	DAFB	0.339	0.612		0.809	F = −0.760		
	MAXB	0.013	0.033		0.534			
	Constant	−16.772						

wise and direct discriminant function equations are presented in Table 5. While some remained unchanged, the difference between the original and cross-validated cases for the other functions ranged between 1 and 4%, which confirms their validity.

Discussion

All the nine variables displayed significant sex differences between the male and female mean measurements, thereby showing sexual dimorphism of the calcaneus of South African blacks. This agrees with previous studies in Italians (10) and South African whites (23). However, the average accuracy obtained from the present study (64%–79%) using demarking points for individual variables is lower than that (73%–86%) for South African whites (23) and that (69%–84%) obtained for the Southern Italian population (10) using univariate discriminant function analysis.

The average accuracies obtained from stepwise analysis of the dimensional groups ranged between 79% and 80%. The average accuracies remained the same when all variables were used in the direct analyses of each dimensional group. The reason for this might be due to the fact that the contribution of each of LAL, MAXB and BH in association with the variables selected in stepwise analyses is insignificant. Therefore, the inclusion of LAL, MAXB and BH will not affect the overall classification. When the variables selected in stepwise analysis are measurable on the calcaneus, they should therefore be used in sex assignment.

A combination of the three most sex discriminating variables from univariate analysis (Table 2) were selected in the stepwise analysis of all nine variables with an average accuracy of 85%. This finding is in agreement with previous observation made on the study of the calcaneus of South African whites (23) but contradicts earlier observation by Introna et al. (10,19). In the direct analysis of

TABLE 5—*Percentage of cases correctly classified and cross-validated.*

Functions	Variables		Total No.	Male		Females		Average Accuracy (%)
				%	No.	%	No.	
Stepwise								
1	DAFL, DAFB, CFH	O	116	86.2	50/58	84.5	49/58	85.3
		C	116	86.2	50/58	84.5	49/58	85.3
2	MAXL, DAFL	O	116	82.8	48/58	77.6	45/58	80.2
		C	116	79.3	46/58	77.6	45/58	78.4
3	DAFB, MIDB	O	116	81.0	47/58	77.6	45/58	79.3
		C	116	81.0	47/58	75.9	44/58	78.4
4	CFH, MAXH	O	116	79.3	46/58	79.3	46/58	79.3
		C	116	79.3	46/58	79.3	46/58	79.3
Direct								
5	MAXH, BH, CFH, MAXL, LAL	O	116	89.7	52/58	82.8	48/58	86.2
	MAXB, MIDB, DAFL, DAFB	C	116	86.2	50/58	77.6	45/58	81.9
6	MAXL, LAL, DAFL	O	116	81.0	47/58	79.3	46/58	80.2
		C	116	79.3	46/58	77.6	45/58	78.4
7	CFH, BH, MAXH	O	116	77.6	45/58	81.0	47/58	79.3
		C	116	75.9	44/58	77.6	45/58	76.7
8	MIDB, DAFB, MAXB	O	116	81.0	47/58	77.6	45/58	79.3
		C	116	81.0	47/58	77.6	45/58	79.3

O = Original group cases correctly classified, C = Cross validated group cases correctly classified.

all variables, the average accuracy (86%) was slightly higher than that obtained from the stepwise analysis.

The average accuracies obtained from both stepwise and direct analyses (79%–86%) compare favourably with those (76%–85%) obtained for Southern Italian population (10) but are slightly lower than those (88%–92%) obtained for South African whites (23). When these combinations are measurable on an intact calcaneus, they should be used for sex determination, as they will provide a better assignment of sex than the use of individual variables.

In contrast to the observation made in the study of the calcaneus of South African whites (23) that breadth measurements were the most sexually dimorphic of the three dimensional groups, length measurements were found to be the most sexually dimorphic in the present study (Function 2, Table 3 and Function 2, Table 4). These contrasting findings support an earlier observation (13) that showed the existence of population differences in sexual dimorphism between dimensional groups.

Conclusion

This study has shown that the calcaneus of South African blacks is sexually dimorphic. The level of accuracy obtained from the use of individual variables is not sufficient enough to make them useful in forensic cases. Since combinations of variables provide higher level of accuracy, they should therefore be used, as they will provide better estimation of sex than individual variables. The equations derived in the present study should be used with caution in cases when only the calcaneus is available for sex determination.

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Additional information and reprint requests:
Mubarak A. Bidmos, MBBS, M.Sc.
School of Anatomical Sciences
Faculty of Health Sciences
University of the Witwatersrand
7 York Road, Parktown 2193
Johannesburg, South Africa