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TECHNICAL NOTE

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Further Evidence to Show Population Specificity of Discriminant Function Equations for Sex Determination Using the Talus of South African Blacks

ABSTRACT: Several studies have shown that osteometric differences exist between different population groups. Thus, discriminant function equations derived for the determination of sex from skeletal elements are population specific. In a previous study, the authors derived such equations from nine measurements of the talus of South African whites with high levels of average accuracies. The validity of some of the equations was tested on data collected from a South African black sample that consisted of 120 tali, equally distributed by sex, derived from the Raymond A. Dart Collection of Human Skeletons. The average accuracies dropped significantly. This necessitated the derivation of new equations for the South African black population and the average accuracies obtained ranged between 80% and 89%. The validity of the equations derived from the present study was tested using the leave-one-out classification and two independent samples (1 and 2). The applicability of the equations with very high classification rate from the present study was tested on Independent sample 1 of 10 white tali with poor results. The result of the validity of these equations on an Independent sample 2 of 10 black tali revealed acceptably high average accuracies in correct classification thereby supporting earlier observations on population specificity of discriminant function equations.

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

The talus is a foot bone that is compact and unlike long bones is normally found intact during the recovery of human skeletons for personal identification (1). Sex determination is important in skeletal analysis as it reduces the search for missing persons by half (2), especially in forensic cases. The determination of sex is also important as it sets the stage for other demographic factors to be determined. However, it can be a very difficult exercise in the absence of a complete skeleton (3). Specific complex morphological features that display sexual dimorphism on some bones have been used for this purpose (2–8). The accuracy in correct sex classification using these bones is reduced if they are recovered in fragmentary states.

Thus, researchers have attempted and used metric variables from intact and fragmentary skeletal materials (9–29) in the derivation of discriminant function equations. In South Africa, discriminant function equations have been derived for the purpose of sex determination in personal identification from different bones of the human skeleton. These include the skull and mandible (30–31), humerus (32), femur and tibia (33,34) and calcaneus (35).

In a recent study on the talus (36), the authors showed the usefulness of measurements taken on the talus of South African whites in sex determination. Because it has been well documented that discriminant function equations are population specific (1,13,24,26–27,31–32,35–37), it is therefore the aim of this paper to investigate the sexing potential of the talus of South African blacks, test the validity of the equations derived from this study on independent samples and test the validity of equations derived from the previous study on the present data.

Materials and Methods

The source of all human skeletal remains used in the study was the Raymond A. Dart Collection of Human Skeletons, which is housed in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg. Only tali not showing any obvious gross pathologies were selected for this study.

A total of 120 (60 male, 60 female) tali of South African blacks were used for the derivation of discriminant function equations. The validity of these functions was tested using two independent samples. Sample 1 consisted of 10 tali (six males, four females) of South African blacks that were not used in the derivation of the functions. Sample 2 consisted of 10 tali (five males, five females) of South African whites. The age at death of these individuals ranged from 18 to 70 years. The left talus was measured in each case from a selection of randomly selected individuals using a table of random numbers. Nine measurements were taken on each talus, which included Talar length (TL), Talar width (TW), Talar height (TH), Length of the trochlea (TrL), Breadth of the trochlea (TrB), Head-neck length (HNL), Height of the head (HH), Length of the

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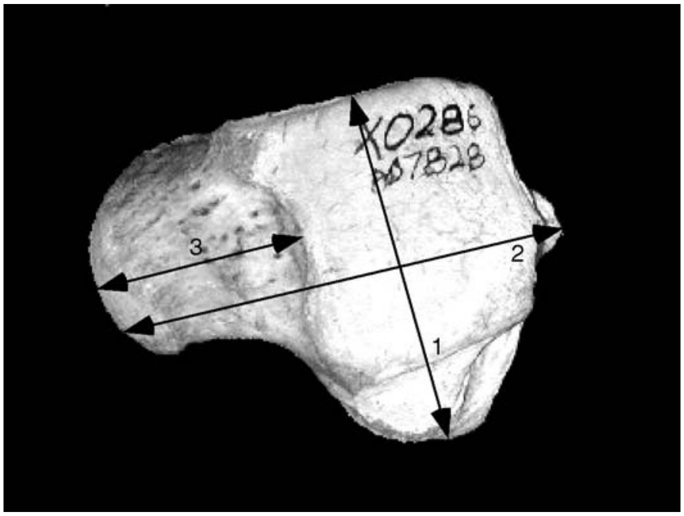

FIG. 1—*Superior view of Left Talus showing the measurements of Talar Width (1), Talar Length (2) and Head-Neck Length (3).*

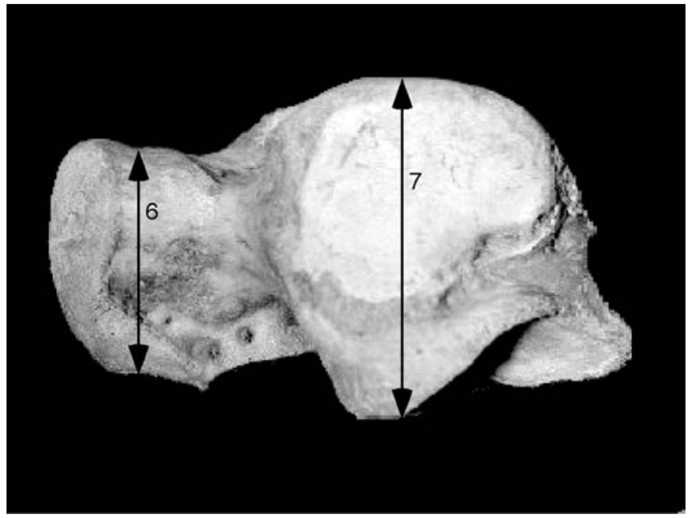

FIG. 3—*Medial view of Left Talus illustrating the following: Head Height (6) and Talar Height (7).*

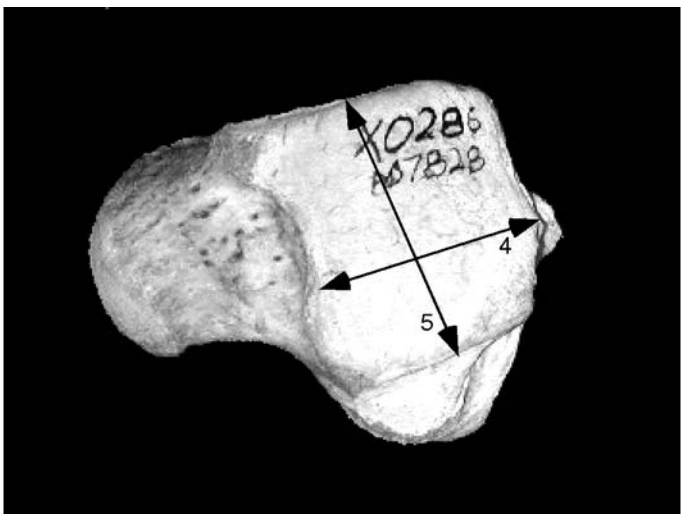

FIG. 2—*Superior view of Left Talus illustrating Trochlear Length (4) and Trochlear Breadth (5).*

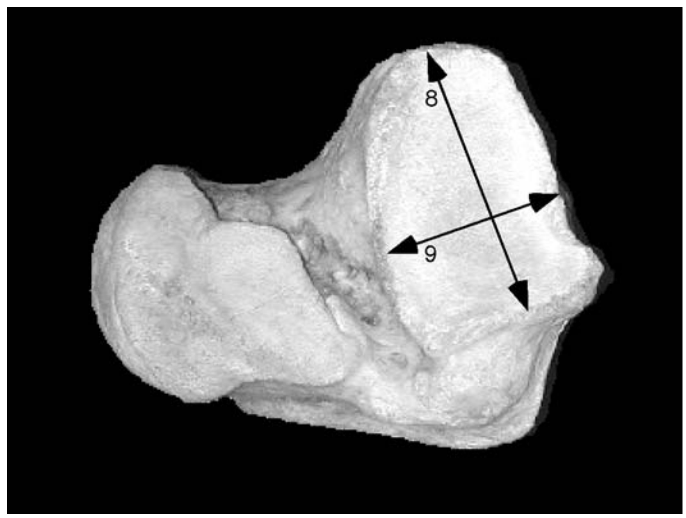

FIG. 4—*Inferior view of Left Talus illustrating the following: Length of Posterior Articular Surface and Breadth of Posterior Articular Surface (9).*

posterior articular surface (LPAS) and Breadth of the posterior articular surface (BPAS). These measurements (Figs. 1–4) were adapted from Martin and Knussman (38).

All measurements were taken using a digital vernier calliper except for TH, HNL, and HH, which were taken with the use of a manual calliper. A repeatability test was done to ensure the reproducibility of the techniques and measurements used in the study. The normal descriptive statistics were obtained for each measurement. Thereafter, the data collected were then subjected to discriminant function analyses using the Statistical Product and Service Solutions (Version 8; SPSS Inc., Chicago IL) package.

The validity of the functions was tested using: (i) a "leave-one-out" classification system (36) and (ii) the two independent samples derived from the Raymond A. Dart Collection of Human Skeletons. The three best equations from the stepwise, univariate, and direct analyses were tested using the data collected from these two independent samples. The average accuracy of correct sex classification for each of the functions was obtained and compared with the original percentage average accuracy.

Results

The mean values of all nine male variables were significantly greater ($P < 0.001$) than corresponding female mean values (Table 1). This indicates the presence of significant sexual dimorphism in all measured variables of the talus. A rapid way of determining sex is by the use of demarking points. This is defined as the average of the male and female mean measurement for each variable (Table 2). The HH is the most useful individual variable based on the average accuracies of correct sex classification (Table 2). The other variables are arranged in descending order of average accuracy. Since males presented with higher mean values for all variables, a measured value higher than the demarking point indicates male and vice versa.

TABLE 1—*Descriptive statistics of the talus for South African blacks.*

	Male			Female				
Variable	*N*	Mean	SD	*N*	Mean	SD	**F*-statistic	*P* value
TL	60	51.68	2.62	60	47.07	2.70	90.07	0.000
TW	60	41.47	2.62	60	37.63	2.32	72.50	0.000
TH	60	31.05	1.84	60	27.98	1.90	80.68	0.000
TrL	60	32.54	2.70	60	28.80	2.06	72.73	0.000
TrB	60	30.59	1.76	60	27.91	1.45	83.80	0.000
HNL	60	20.85	2.38	60	19.56	2.21	9.52	0.002
HH	60	25.33	1.77	60	21.84	2.00	102.82	0.000
LPAS	60	34.07	1.85	60	30.63	1.86	103.31	0.000
BPAS	60	22.06	1.51	60	19.83	1.39	70.65	0.000

* All significant at $p < 0.05$, N = Sample size, Measurements in millimeters.

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

Measurements	Demarking Points	Average Accuracy %
HH	females < 23.57 < males	85.8
TrL	females < 30.67 < males	85.0
TrB	females < 29.25 < males	85.0
LPAS	females < 32.35 < males	82.5
TL	females < 49.37 < males	80.8
TH	females < 29.52 < males	80.8
BPAS	females < 20.95 < males	80.0

Stepwise Analyses

When all nine measured variables were entered into the stepwise discriminant function analysis, three variables were selected (Function 1, Table 3). The average accuracy of correct sex classification obtained from this combination of variables is 86.7%. Stepwise analysis of all length (Function 2, Table 3) and breadth (Function 3, Table 3) measurements yielded average accuracies of 85.0% and 84.2% respectively. Discriminant function equations can be obtained for each of these functions from the unstandardised coefficients and constants provided in Table 3.

Direct Analyses

In direct analyses, the highest average accuracy (89.2%) was obtained from a combination of the best three sexually dimorphic individual variables (Function 1, Table 4). Functions 2 to 6 were obtained from direct analysis of: (a) all nine variables, (b) all length, (c) both height, (d) all talar, and (e) both posterior articular facet variables respectively. These are listed in descending order of average accuracies (Table 4).

Validity of Equations

"Leave-one-out" Classification—Validity of functions was tested using the "leave-one-out" classification method. Average accuracies of correct classification obtained for each function were compared with those obtained from the cross validation process (Tables 3 and 4). The validity of these functions is confirmed by the fact that most percentages remained unchanged while the difference in percentages between the original and cross-validated cases for the other functions ranged between 0.9% and 4.2%.

Test on Independent Sample 1—This sample consisted of tali of South African blacks that were not included in the original sample used in the derivation of the functions in this study. The accuracy of the functions after testing on this sample ranged between 70% and 90% (Table 5).

Test on Independent Sample 2—South African white tali were used for testing the validity of the functions derived in this study. Low levels of average accuracies were obtained which ranged from 40% to 80% (Table 5). In most cases, females were misclassified as males.

Discussion

Previously, the authors observed that only two variables of the talus of South African whites (36) presented with acceptably high average accuracies (80–82%). In fact, the head height, which was the least sexually dimorphic variable in the whites (36), presented with the highest average accuracy in the present study. With the exception of talar width (TW) and head neck length (HNL), all the variables produced acceptably high average accuracies (80–86%) in correct sex classification in the present study. Therefore, most individual variables of the talus of South African blacks are sexually dimorphic and are useful in the determination of sex. This observation reveals possible population differences in the expression of sexual dimorphism by variables of the talus of South Africans.

TABLE 3—*Stepwise discriminant function analyses.*

Functions	Variables	Unstandardized Coefficient	Standardized Coefficient	Wilk's Lambda	Structure Point	Centroids	Sectioning Point	Average Accuracy (%) O	Average Accuracy (%) C
1	TH	0.207	0.388	0.395	0.668	M = 1.228	0.000	86.7	86.7
	HH	0.295	0.557		0.754	F = −1.228			
	LPAS	0.229	0.425		0.756				
	Constant	−20.487							
2	TL	0.131	0.350	0.460	0.807	M = 1.073	0.000	85.0	83.3
	TrL	0.141	0.34		0.725	F = −1.073			
	LPAS	0.294	0.545		0.864				
	Constant	−20.341							
3	BPAS	0.228	0.332	0.514	0.796	M = 0.964	0.000	84.2	84.2
	TrB	0.298	0.479		0.867	F = −0.964			
	TW	0.160	0.397		0.807				
	Constant	−19.852							

Example: Function 1, discriminant function equation = (0.207 × TH) + (0.295 × HH) + (0.229 × LPAS) −20.487. A discrimnant function score greater than 0.000 indicates male and less than 0.000 indicates female.

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

TABLE 4—*Direct discriminant function analyses.*

Functions	Variables	Unstandardized Coefficient	Standardized Coefficient	Wilk's Lambda	Structure Point	Centroids	Sectioning Point	Average Accuracy (%) O	C
1	HH	0.297	0.561	0.423	0.799	M = 1.158	0.000	89.2	88.3
	TrB	0.249	0.401		0.722	F = −1.158			
	TrL	0.163	0.39		0.672				
	Constant	−19.288							
2	TL	−0.039	−0.104	0.377	0.679	M = 1.276	0.000	88.3	86.7
	TrL	0.084	0.202		0.61	F = −1.276			
	LPAS	0.156	0.289		0.727				
	HNL	−0.039	−0.089		0.221				
	TW	0.049	0.122		0.609				
	TH	0.166	0.310		0.643				
	TrB	0.058	0.094		0.655				
	HH	0.266	0.502		0.726				
	BPAS	0.066	0.095		0.602				
	Constant	−21.104							
3	TL	0.140	0.372	0.460	0.807	M = 1.074	0.000	86.7	82.5
	TrL	0.138	0.332		0.725	F = −1.074			
	LPAS	0.292	0.541		0.864				
	HNL	−0.013	−0.029		0.262				
	Constant	−20.307							
4	TH	0.317	0.593	0.431	0.813	M = 1.139	0.000	86.7	85.8
	HH	0.374	0.706		0.720	F = −1.139			
	Constant	−18.170							
5	TL	0.158	0.420	0.505	0.882	M = 0.983	0.000	84.2	83.3
	TH	0.204	0.382		0.835	F = −0.983			
	TW	0.159	0.393		0.791				
	Constant	−20.103							
6	LPAS	0.390	0.723	0.487	0.911	M = 1.019	0.000	84.2	82.5
	BPAS	0.312	0.454		0.753	F = −1.019			
	Constant	−19.513							

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

TABLE 5—*Validity of functions on independent samples.*

Functions	Original Accuracy	Cross Validation: Independent Sample 1	Independent Sample 2
Stepwise			
Function 1	86.7	80.0	50.0
Function 2	85.0	80.0	60.0
Function 3	84.2	90.0	80.0
Univariate			
Function 1	85.8	70.0	50.0
Function 2	85.0	80.0	70.0
Function 3	85.0	80.0	40.0
Direct			
Function 1	89.2	80.0	50.0
Function 2	88.3	70.0	50.0
Function 3	86.7	80.0	60.0

In the stepwise analysis, three variables were selected from the nine variables entered with an average accuracy of 87%. These variables (TH, HH and LPAS) with the exception of TH, did not fall into the top three best discriminating variables (see Table 1). This is not surprising since it is well documented that a combination of the best discriminating variables does not always give the best multivariate (stepwise) function (24,36,37).

Two of the best three variables selected in stepwise analysis of all variables (Function 1, Table 3) were height measurements (TH and HH). When talar height (TH) and head height (HH) were both used in the direct analysis (Function 4, Table 4), the percentage average accuracy (86.7%) in sex classification remained the same as with the stepwise analysis of all variables that selected a length measurement in addition to talar height and head height. Individually, head height and talar height, presented with high average accuracies of 86% and 81% respectively. This shows that height variables of the talus contribute greatly to separation of sexes in South African blacks. In contrast, length measurements of the talus were found to be the best indicators of sex in South African whites (36). Table 6 shows the combined descriptive statistics of talar measurements for South Africans. A statistically significant difference exists between means for blacks and whites for most variables except TW and LPAS (for males) and BPAS (for females). Generally the average accuracies in correct sex classification obtained from the present study compares well with previous studies on South African skeletal samples (Table 7).

Some studies (26,32) have shown the existence of population differences in osteometric dimensions thus leading to the derivation of population specific discriminant function equations (1,13,24,26–27,31–32,35–37). Population specificity of these equations can be reliably assessed in this study because the previous study on the talus of South African whites (36) and the present study followed the same methodology in terms of number and definition of measurements, and reliability of the measuring technique.

The average accuracies obtained when some of the equations derived in the present study were used on an independent sample derived from the same population (Independent sample 1) were closer to the original average accuracies (Table 5). However, the accuracies decreased significantly when these functions were tested on an independent sample (Independent sample 2) obtained from another population group (South African whites) (Table 5).

TABLE 6—*Comparison of means of talal measurements for South African blacks and whites.*

		Male					Female			
Variable	N	Black	White	*F-statistic	P value	N	Black	White	*F-statistic	P value
TL	60	51.68	55.61	57.80	0.000	60	47.06	51.11	71.85	0.000
TW	60	41.47	42.25	3.16	0.078	60	37.63	39.02	9.19	0.003
TH	60	31.05	33.44	44.54	0.000	60	27.98	30.73	56.00	0.000
TrL	60	32.53	35.54	41.55	0.000	60	28.80	32.34	63.76	0.000
TrB	60	30.59	32.53	40.48	0.000	60	27.91	29.96	45.90	0.000
HNL	60	20.85	23.89	46.51	0.000	60	19.56	21.43	25.81	0.000
HH	60	25.30	28.45	61.23	0.000	60	21.84	27.37	199.69	0.000
LPAS	60	34.07	34.70	2.61	0.109	60	30.63	31.56	6.79	0.010
BPAS	60	22.06	23.00	7.76	0.006	60	19.83	20.40	3.79	0.054

* All significant at $p < 0.05$, N = Sample size.

TABLE 7—*Range of average accuracies in correct sex classification from studies in South Africa*

Bones	Authors	Average Accuracies %
Viscerocranium of blacks	Kierser and Groeneveld 1986	78–91
Cranium and mandible of whites	Steyn and Iscan 1998	80–86
Humerus of blacks	Steyn and Iscan 1999	82–93
Humerus of whites	Steyn and Iscan 1999	80–93
Proximal tibia	Kierser et al. 1992	85–92
Femur and tibia of whites	Steyn and Iscan 1997	86–91
Calcaneus of whites	Bidmos and Asala 2003	73–92
Talus of whites	Bidmos and Dayal 2003	80–88
Present study	Bidmos and Dayal	80–89

Conclusion

Different combinations of measurements of the talus have been shown to yield acceptably high average accuracies, which makes them useful in the determination of sex in forensic cases. When all the nine variables are not measurable on the talus, most individual variables can be used for sex determination as evident from the low misclassification rate obtained in the univariate analysis. The height variables provide the highest separation of the sexes. This study also supports previous observations that discriminant function equations are population specific, further confirming that osteometric differences exist between different population groups.

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