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TECHNICAL NOTE

ANTHROPOLOGY

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Sex Determination from the Talus of Koreans by Discriminant Function Analysis*

ABSTRACT: The aims of this study were to investigate the sex discriminating potential of the talus in Koreans and compare this with other analyses in different populations. Statistical analyses were performed using data from nine measurements acquired from 140 tali (70 men, 70 women). The talus of Koreans is dimorphic between sexes in all measurements ($p < 0.01$). Discriminant function equations were generated by univariate, multivariate, and stepwise methods with a range of accuracy from 67.1 to 87.1%. Stepwise equations of other populations did not discriminate the sex of the Korean sample as accurately as each equation's own accuracies. The variables with high accuracy in this study are useful for sex determination of Koreans on the basis of confirmation of population specificity.

KEYWORDS: forensic science, sex determination, talus, Korean, validation test, population specificity

The determination of sex is an early important step in the analysis of skeletal remains because it makes the sequential analysis of the biological profile of human remains more sex specific. Size and architectural differences of bones between males and females can be used to differentiate the sexes. There are two investigative methods for detecting sexual differences: morphologic (nonmetric) and metric methods. The morphologic method, mainly using the skull and the pelvis, determines the sex of unknown skeletal remains in a descriptive manner using observations of the morphologic characteristics of these bones. Although this method centered on observation consumes less time than taking a measurement, accurate results depend on the observer's experience and subjectivity, whereas metric methods assess sexual differences based on measurements and statistical results rather than one's expertise in the field, and can objectively validate results. Moreover, this method can detect dimorphism in skeletal elements that have ambiguous morphologic differences between either sex. Metric analysis is gaining favor within the discipline as more forensic anthropologists report their results in court and are asked to provide statistical weight to their opinion (1).

Data from the forensic anthropologists report 90–100% accuracy in assessing morphologic traits for sex determination when using the entire skeleton (2,3). However, incomplete or fragmentary bones are more often excavated, and it can be difficult to conduct an analysis for sex determination. Therefore, analytical methods considering fragmentation need to be devised. Many researchers have attempted to investigate metric variables from intact and fragmentary skeletal remains, and report statistical results providing more reliable and quantifiable estimation (4–22).

The talus, one of the tarsal bones, is a useful bone for human identification that is better preserved during the recovery of human skeletons compared with long bones, and is readily distinguished, even in a fragmentary state, because of its characteristic morphology. Besides the merits of the talus in excavations, several statistical studies of the talus suggest that a discriminant function equation using this bone's metric data is able to identify sex with high accuracy. However, the functions derived from metric studies are reported to be specific for the studied population and cannot be extrapolated to other population groups (7,10,11,13,16,18,22).

Therefore, the aim of this study was to investigate the sex-discriminating potential of the metric data from the talus in Koreans, an East Asian population, and to verify the specificity of the discriminant function equations to different population groups by comparing the results with other analyses of different populations.

Materials and Methods

The specimens used in this study were 140 left tali (70 men, 70 women) randomly selected from the skeletal collection housed in Yonsei University and The Catholic University of Korea. The skeletons are collected from the cadavers that are donated by the Koreans for medical dissection courses. The age at death ranged from 21 to 94 years. Bones with a pathologic condition or deformity were excluded from this study.

Each talus was investigated using nine measurements, as described by Steele (22) and Bidmos and Dayal (13). Figure 1 shows these measurements. All metric values were acquired by one observer with a digital vernier caliper by placing each talus on an

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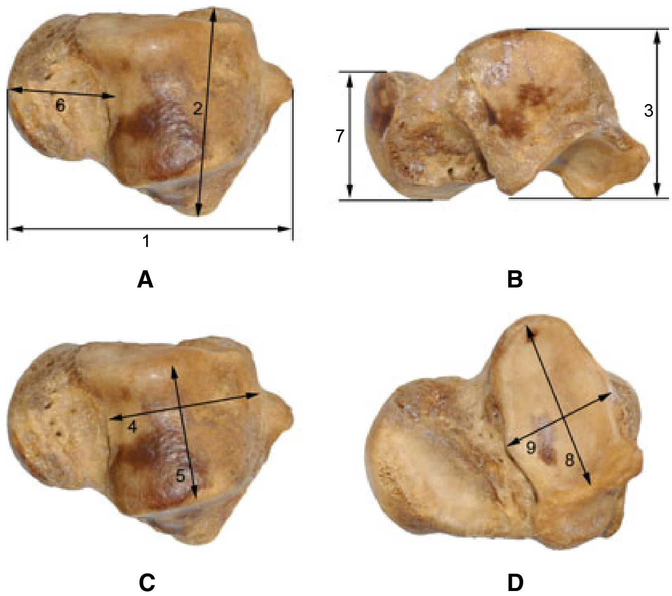

FIG. 1—*The measurements of the talus. Talar length (TL, 1), talar width (TW, 2), talar height (TH, 3), trochlear length (TrL, 4), trochlear breadth (TrB, 5), head–neck length (HNL, 6), head height (HH, 7), length of the posterior articular surface (LPAS, 8), breadth of the posterior articular surface (BPAS, 9). A, C: Superior view, B: lateral view, D: inferior view.*

osteometric board-like device to set the horizontal and the vertical plane. To evaluate the reproducibility of the measuring technique, the intraclass correlation coefficients were calculated from the result of a triplicate examination of 40 tali (20 men, 20 women) by the same observer. The test for inter-observer reliability was excluded on account of the measuring process involving a single observer.

All statistical analysis was performed using SPSS (version 17.0; SPSS, Chicago, IL). The normal descriptive statistics were obtained for each measurement. The mean differences between sexes were evaluated using Student's *t*-test at a level of significance of $p < 0.01$. To investigate sexual dimorphism from the characteristics of talar shape, eight indexes produced from the combination of length, width, and height components were analyzed using Student's *t*-test at a level of significance of $p < 0.01$. The discriminant functions were derived from the data using one variable, two variables, and multiple variables that were selected directly, or using the stepwise method. Sectioning points were zero because of the same sample size in each sex group.

The metric data acquired from the Korean sample in this study were applied to the functions derived from other studies to verify the population specificity of the discriminant function analysis. The functions with highest accuracy derived by the stepwise method in each study were used for white and black Americans (22), white South Africans (13), black South Africans (11), Northern Italians (7), and prehistoric Polynesians (16). If other studies provided the function using the same variables selected using the stepwise method in this study, these functions were used to ascertain the accuracy of sex discrimination for Koreans.

Results

All intraclass correlation coefficients for the reproducibility of the measuring technique in this study ranged from 0.90 to 0.98 (Table 1). These values showed that the data in this study were reliable.

The talus of Koreans is dimorphic between male and female at a level of significance of $p < 0.01$ (Table 2). While the mean value for size of the male talus is greater than that for females, eight indexes produced from a combination of length, width, and height components, representing the shape of talus, indicate no differences between sex at a level of significance of $p < 0.01$.

Only the variables showing sexual dimorphism at a level of significance of $p < 0.01$ were selected for the discriminant function analysis. The discriminant function equations were generated by univariate, bivariate, and multiple variables that were selected directly or using the stepwise method.

In the equations obtained from one variable, the equation using the length of posterior articular surface had the highest accuracy for sex classification at 82.9% and the range of accuracy for each equation was from 67.1% to 82.9% (Table 3). A univariate function provided a demarcation point from which it was possible to classify sex easily from a simple numeric value.

TABLE 1—*The intraclass correlation coefficients of repeated measurements of the talus.*

Measurements	Intraclass Correlation Coefficients	Maximum Difference Between the Repeat Measurements (mm)	Average Difference Between the Repeat Measurements (mm)
TL	0.98	0.97	0.55
TW	0.95	1.00	0.48
TH	0.95	0.98	0.53
TrL	0.97	1.00	0.49
TrB	0.94	1.00	0.55
HNL	0.96	0.97	0.54
HH	0.95	1.00	0.47
LPAS	0.97	0.98	0.44
BPAS	0.90	0.96	0.49

TL, talar length; TW, talar width; TH, talar height; TrL, trochlear length; TrB, trochlear breadth; HNL, head–neck length; HH, head height; LPAS, length of the posterior articular surface; BPAS, breadth of the posterior articular surface.

TABLE 2—*Descriptive statistics of nine measurements and eight index of the talus of Koreans.*

	Male (n = 70)		Female (n = 70)			
	Mean	*SD*	Mean	*SD*	*t*-Value	*p*-Value
Measurements (mm)						
TL	55.78	3.42	52.07	2.99	−6.83	<0.001
TW	41.87	2.47	39.10	2.46	−6.64	<0.001
TH	32.69	1.78	30.89	2.26	−5.24	<0.001
TrL	33.30	2.11	30.79	1.40	−8.28	<0.001
TrB	28.31	2.09	26.45	1.84	−5.59	<0.001
HNL	20.99	2.13	19.28	1.64	−5.32	<0.001
HH	26.74	2.35	25.30	1.94	−3.96	<0.001
LPAS	32.21	2.54	28.70	1.70	−7.81	<0.001
BPAS	21.42	1.45	19.72	1.08	−9.61	<0.001
Index						
TW/TL	75.14	3.20	75.14	3.35	−0.01	0.99
TH/TL	58.70	2.89	59.31	2.48	1.34	0.18
TrL/TL	59.77	3.12	59.23	2.63	−1.12	0.26
HNL/TL	37.66	3.40	37.06	2.92	−1.13	0.26
TH/TW	78.14	2.73	79.03	3.82	1.59	0.12
TrB/TW	67.64	3.65	67.70	3.51	0.10	0.92
HH/TH	81.80	5.70	82.07	5.75	0.28	0.78
BPAS/LPAS	66.70	4.78	68.88	4.46	2.79	0.01

TL, talar length; TW, talar width; TH, talar height; TrL, trochlear length; TrB, trochlear breadth; HNL, head–neck length; HH, head height; LPAS, length of the posterior articular surface; BPAS, breadth of the posterior articular surface.

TABLE 3—*Accuracies and demarcation points resulted from univariate discriminant function analysis.*

Variables	Average Accuracy (%)	Leave-One-Out Accuracy (%)	Demarcation Points (mm)
TL	75.0	74.3	F < 54.0 < M
TW	75.0	75.0	F < 40.5 < M
TH	73.6	73.6	F < 31.8 < M
TrL	78.6	77.9	F < 32.0 < M
TrB	70.0	70.0	F < 27.4 < M
HNL	69.3	69.3	F < 20.1 < M
HH	67.1	67.1	F < 26.0 < M
LPAS	82.9	82.9	F < 30.5 < M
BPAS	73.6	73.6	F < 20.6 < M

TL, talar length; TW, talar width; TH, talar height; TrL, trochlear length; TrB, trochlear breadth; HNL, head–neck length; HH, head height; LPAS, length of the posterior articular surface; BPAS, breadth of the posterior articular surface.

The range of accuracy of the equations using two variables was 69.3–84.3%, and the equation derived from trochlear length, head–neck length, length or breadth of the posterior articular surface classified sex with the highest accuracy of 84.3%. The functions with accuracies >80.0% included talar width and height, trochlear length and breadth, head–neck length, and the length and breadth of the posterior articular surface. In particular, the functions including the length of the posterior articular surface that presented the highest accuracy in univariate analysis had the best potential for correctly classifying sex with accuracy >80.0%. Details of the functions with accuracies >80% are presented in Table 4.

The analysis using a stepwise method selected the best two variables out of the nine measurements: the length and breadth of the posterior articular surface (Function 7, Table 4). The accuracy of the equation using the stepwise method was 82.1%. The reason why the stepwise analysis selected the length and breadth

TABLE 4—*Bivariate discriminant function analysis with accuracies >80.0% and multivariate discriminant function analysis using the variables selected directly.*

Functions	Variables	Unstandardized Coefficient	Wilks' Lambda	Centroids		Average Accuracy (%)	Leave-One-Out Accuracy (%)
				Male	Female		
Bivariate discriminant function equations							
1	HNL	0.270	0.597	0.816	−0.816	84.3	84.3
	TrL	0.466					
	Constant	−20.365					
2	BPAS	0.417	0.611	0.793	−0.793	84.3	84.3
	TrL	0.351					
	Constant	−19.819					
3	HNL	0.140	0.583	0.839	−0.839	84.3	84.3
	LPAS	0.410					
	Constant	−15.295					
4	LPAS	0.326	0.567	0.867	−0.867	84.3	83.6
	TrL	0.234					
	Constant	−17.446					
5	TH	−0.019	0.599	0.812	−0.812	82.9	82.1
	LPAS	0.472					
	Constant	−13.783					
6	TrB	0.051	0.597	0.815	−0.815	82.9	81.4
	LPAS	0.437					
	Constant	−14.703					
7	BPAS	0.320	0.565	0.871	−0.871	82.1	82.1
	LPAS	0.342					
	Constant	−16.993					
8	TW	0.025	0.599	0.813	−0.813	82.1	81.4
	LPAS	0.443					
	Constant	−14.498					
Multivariate discriminant function equations							
1	TH	−0.121	0.559	0.882	−0.882	86.4	85.0
	TrL	0.285					
	LPAS	0.361					
	Constant	−16.275					
2	TL	0.202	0.723	0.615	−0.615	72.9	72.1
	TW	0.242					
	TH	−0.105					
	Constant	−17.370					
3	TL	−0.068	0.504	0.985	−0.985	87.9	87.1
	TW	−0.030					
	TH	−0.131					
	TrL	0.350					
	TrB	−0.018					
	HNL	0.242					
	HH	−0.048					
	LPAS	0.256					
	BPAS	0.268					
	Constant	−18.582					

TL, talar length; TW, talar width; TH, talar height; TrL, trochlear length; TrB, trochlear breadth; HNL, head–neck length; HH, head height; LPAS, length of the posterior articular surface; BPAS, breadth of the posterior articular surface.

TABLE 5—*Verification of the population specificity using data from Korean sample in equations derived from different populations.*

Populations	Authors	Variables of Functions	Original Accuracy (%)	Cross-Validation of Korean Sample			
				Male (%)	Female (%)	Average (%)	Difference (%)
Black and white Americans	Steele (22)	TL-TW	83.0	81.4	65.7	73.6	−9.4
White South Africans	Bidmos and Dayal (13)	TL-HNL-LPAS	87.5	30.0	100.0	65.0	−22.5
		LPAS-BPAS	81.7	37.1	100.0	68.6	−13.1
Black South Africans	Bidmos and Dayal (11)	TH-HH-LPAS	86.7	90.0	54.3	72.1	−14.6
		LPAS-BPAS	84.2	48.6	100.0	74.3	−9.9
Northern Italians	Gualdi-Russo (7)	TL-TH	91.5	88.6	54.3	71.4	−20.1
Prehistoric Polynesians	Murphy (16)	TL-TrL	91.3	91.4	41.4	66.4	−24.9

TL, talar length; TW, talar width; TH, talar height; TrL, trochlear length; TrB, trochlear breadth; HNL, head–neck length; HH, head height; LPAS, length of the posterior articular surface; BPAS, breadth of the posterior articular surface.

of the posterior articular surface instead of variables of the equations with the highest accuracies in bivariate analysis might be that Wilks' lambda in the length and breadth of the posterior articular surface was lowest in a total combination of the variables, and so the function derived from the length and breadth of the posterior articular surface had a better potential for discrimination of sex.

Three functions were generated by direct selection of the variables (Table 4). Function 1 obtained from three variables (talar height, trochlear length, length of posterior articular surface) had the highest accuracy of 86.4%. Function 2, including the variables of talar dimension (talar length, width, and height), classified sex with an accuracy of 72.9%. Function 3, using all measurements, had the highest accuracy of 87.9% in this study.

To verify the population specificity of discriminant function equation, the metric data of the Korean sample was entered into the functions from the analyses of other population groups: black and white Americans (22), white South Africans (13), black South Africans (11), Northern Italians (7), and prehistoric Polynesians (16). The sex-discriminating rates of these functions for Koreans were not generally as accurate as the original accuracies of the functions and ranged from 65.0% to 74.3% (Table 5).

Discussion

The talus is a bone that is frequently excavated in archaeological or forensic fields because of its durability (22), and might be useful in the identification of unknown skeletal remains if the characteristics of the bone for biological profiling are known. The statistical analyses provide more replicable results and are more reliable and quantifiable estimations than visual estimates (23). This study focused on the estimation of sex using discriminating statistics of the talus. Descriptive statistics showed that the size of the talus in Koreans is dimorphic between the sexes at a level of significance of $p < 0.01$, whereas the shape of the talus is similar for each sex because of a lack of difference at the same level of significance. This difference might be the result of a different pattern of walking or physical labor between sexes. Univariate

TABLE 6—*Comparison of talar measurements with different populations.*

	Authors	Present Study			Steele (22)						Bidmos and Dayal (13)			Bidmos and Dayal (11)			Gualdi-Russo (7)			Murphy (16)		
	Population	Koreans			White Americans			Black Americans			White South Africans			Black South Africans			Northern Italians			Prehistoric Polynesians		
Sex	Measurements (mm)	*n*	Mean	*SD*	*n*	Mean	*SD*	*n*	Mean	*SD*	*n*	Mean	*SD*	*n*	Mean	*SD*	*n*	Mean	*SD*	*n*	Mean	*SD*
Male	TL	70	55.78	3.42	28	55.3	3.2	33	55.2†	3.6	60	55.6	3.0	60	51.7*†	2.6	56	56.1	2.9	23	53.2*	2.6
	TW	70	41.87	2.47	28	43.0	2.9	33	43.0*†	2.7	60	42.3	2.1	60	41.5†	2.6	56	43.4*	2.2	24	44.2*	3.0
	TH	70	32.69	1.78	28	32.7	2.7	33	32.3†	1.9	60	33.4*	2.1	60	31.1*†	1.8	56	32.6	1.7	23	29.1*	1.3
	TrL	70	33.30	2.11	28	36.0*	3.2	33	35.8*†	3.6	60	35.5*	2.4	60	32.5*†	2.7	–	–	–	24	32.8	2.0
	TrB	70	28.31	2.09	28	32.1*	2.1	33	32.3*†	1.8	60	32.5*	1.6	60	30.6*†	1.8	–	–	–	24	32.9*	1.3
	HNL	70	20.99	2.13	–	–	–	–	–	–	60	23.9*	2.5	60	20.9	2.4	–	–	–	–	–	–
	HH	70	26.74	2.35	–	–	–	–	–	–	60	28.5*	2.5	60	25.3*	1.8	–	–	–	–	–	–
	LPAS	70	32.21	2.54	–	–	–	–	–	–	60	34.7*	2.1	60	34.1*	1.5	–	–	–	–	–	–
	BPAS	70	21.42	1.45	–	–	–	–	–	–	60	23.0*	2.4	60	22.1*	1.9	–	–	–	–	–	–
Female	TL	70	52.07	2.99	29	49.7*†	2.4	30	49.2*†	2.7	60	51.1†	2.5	60	47.1*†	2.7	51	49.3*	2.1	24	48.0*	2.1
	TW	70	39.10	2.46	29	38.8	1.8	30	38.4	2.0	60	39.0	2.7	60	37.6*	2.3	46	38.5	2.0	27	39.5	2.0
	TH	70	30.89	2.26	29	29.8*†	1.7	30	29.3*†	1.9	60	30.7†	2.1	60	28.0*†	1.9	50	29.2*	1.2	26	26.2*	2.8
	TrL	70	30.79	1.40	29	33.9*†	2.2	30	31.9*†	2.8	60	32.3*†	2.8	60	28.8*†	2.1	–	–	–	24	30.0*	1.8
	TrB	70	26.45	1.84	29	29.5*	1.4	30	28.1*	2.2	60	30.0*	1.8	60	27.9*	1.5	–	–	–	27	29.5*	1.6
	HNL	70	19.28	1.64	–	–	–	–	–	–	60	21.4*	1.8	60	19.6	2.2	–	–	–	–	–	–
	HH	70	25.30	1.94	–	–	–	–	–	–	60	27.4*	2.3	60	21.8*	2.0	–	–	–	–	–	–
	LPAS	70	28.70	1.70	–	–	–	–	–	–	60	31.6*	1.8	60	30.6*	1.4	–	–	–	–	–	–
	BPAS	70	19.72	1.08	–	–	–	–	–	–	60	20.4*	2.0	60	19.8	1.9	–	–	–	–	–	–

*Significant difference to Korean tali.

†Significant difference between American and South African, all significance at a level of $p < 0.05$.

TL, talar length; TW, talar width; TH, talar height; TrL, trochlear length; TrB, trochlear breadth; HNL, head–neck length; HH, head height; LPAS, length of the posterior articular surface; BPAS, breadth of the posterior articular surface.

analyses using all indexes provided only low accuracies for the sex determination ranging from 46.4% to 62.9%. Only measurements excluding the indexes were used as variables for the discriminant analyses.

Equations using one or multiple variables among nine measurements in this study provided sex determination with a range of accuracy from 66.0% to 87.0%. Univariate analyses were less accurate than bivariate analyses, which is in agreement with a report that single measurements are of little practical value for the sex determination because of the large overlap of the ranges between sexes (22). It was of interest that the discriminating accuracy was increased in bivariate analyses using the length of the posterior articular surface and showed the highest accuracy in univariate analyses. Moreover, the stepwise method suggested a function using the length and breadth of the posterior articular surface has high discriminatory power. Although a function using all measurements classify sex correctly with the highest accuracy in this study, the functions derived from bivariate analyses are more suitable for excavated tali that are frequently incomplete in archaeological or forensic contexts. Therefore, measurements using the multivariate functions should be applied in the laboratory to increase discriminatory power after a screening test at the field using demarking points derived from univariate functions.

The talar dimensions of Koreans were compared with other populations using *t*-tests based on the descriptive statistical information for each population studied by Steele (22), Bidmos and Dayal (11,13), Gualdi-Russo (7), and Murphy (16) (Table 6). The talar size of Koreans of both sexes is relatively similar to white and black populations except for black South Africans, who had smaller dimensions than Koreans. The trochlear size of Korean males and females is distinctively smaller than comparative populations. The talar head is shorter than in white South Africans, but larger than in black South Africans. The posterior articular surface has a smaller or similar size to white and black South Africans. Prehistoric Polynesians had smaller-sized tali but a larger trochlear breadth than modern Koreans. In a comparison between Americans and South Africans, no differences were found between white American and white South African males, while black American males have a larger talus than black South African males. The talus of white American females is smaller than those of black American females, whose tali are larger than those of black South African females. Although it has been reported that the talar measurement generally showed minimal racial variation (22), comparative analysis on the talus of several populations in this study supports recent reports of the existence of a distinctive difference in talar morphology, according to population. For this reason, the variables included in the discriminant function equations with accuracies over 80.0% or selected by the stepwise method are various in each population.

The results of stepwise functions suggested by individual researchers for Koreans were not generally as accurate as their own accuracies and indicate the population specificity of discriminant function equations. Therefore, it is important that the discriminant function analyses for the sex determination should be preceded by analyses of each population to correctly estimate the sex of skeletons of unknown sex.

It is difficult to select variables for discriminant function equations with high accuracy in common because of the specificity of the variables to each population. Interestingly, the length and breadth of the posterior articular surface were suggested as variables with high predictability for white and black South Africans (11,13). The posterior articular surface was considered more suitable than other talar dimensions for accurate sex estimation in this study. What this study is suggesting is that the size of the posterior articular surface might have wide applicability for each population as a common variable for sex discrimination using the talus.

The atlas (24), 12th thoracic vertebra (25), hyoid bone (26), sternum (27), pelvic bone (28), mandible (29,30), and teeth (31) have been analyzed in metric studies for the sex determination of Koreans. The accuracy of the discriminant function equation derived from these studies ranges from 60.0% to 90.0%. This study provides equations using different combinations of measurements with accuracies >80.0% that have practical usefulness in the determination of the sex of Korean skeletal remains. It has been shown that the variables with a high predictability power in this study are specific for the sex determination of Koreans on the basis of confirmation of population specificity. We conclude that the talus of Koreans is useful for the sex determination of skeletal remains in either a complete or fragmentary state.

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