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Sex determination from the talus and calcaneus measurements

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Abstract

Several studies have demonstrated that discriminant function equations used to determine the sex of a skeleton are population-specific. The purpose of the present research was to develop discriminant function equations for sex determination on the basis of 18 variables on the right and left talus and calcaneus in a modern northern Italian sample. The sample consisted of 118 skeletons (62 males and 56 females) from the Frassetto Collection (University of Bologna). The ages of the individuals ranged from 19 to 70 years. The results indicated that metric traits of the talus (in particular) and calcaneus are good indicators of sexual dimorphism. The percentage of correct classification was high (87.9–95.7%).

In view of the differences among current Italian populations, we tested the validity of the discriminant function equations in an independent sample of individuals of different origin (northern and southern Italy). The accuracy of classification was high only for the northern Italians. Most southern Italian males were misclassified as females, confirming the population-specificity of discriminant function equations.

Keywords: Forensic anthropology; Discriminant functions; Talus; Calcaneus; North-Italians

1. Introduction

Many skeletal traits have been investigated in studies of sex identification of adult skeletons. Interest in the degrees and patterns of variation of these skeletal traits between males and females is related to the analysis of bio-diversity in past and present human populations (physical anthropology) and to more practical purposes in forensic science (forensic anthropology), in which sex-specific tests of identity (estimation of age and stature) are fundamental for personal identification [1,2].

The main bones used in sex identification are the pelvis and skull [3–12], although some researchers have analysed traits of other bones of the skeleton – especially appendicular skeleton – in order to sex human remains [13–23].

Sex estimation is the starting point in the forensic identification of skeletal remains. However, such remains are often fragmentary and there is a need to evaluate the contribution of any bone to sex estimation. Owing to the high incidence of recovery of intact foot bones, several studies have focused on sex determination using the talus and calcaneus [24–29]. However, discriminant function equations used in sex estimation have been shown to be population-specific [26,28,30].

Discriminant function equations based on the calcaneus have been derived for southern Italians [25]. Nevertheless, the evident population-specificity in Italy, previously demonstrated for cranial characters [12], makes it necessary to obtain discriminant function equations for sex determination in subjects from northern Italy.

Recent studies have demonstrated sexual dimorphism of talar and calcaneal measurements. Therefore, the purpose of the present study was to develop discriminant function equations to determine sex in northern Italians based on the talus and calcaneus, and to test the validity of the equations in an independent sample.

2. Materials and methods

The specimens used in this study represent a modern northern Italian population from the Emilia-Romagna region. The osteometric measurements were taken from 118 adult skeletons (62 males and 56 females) from the Frassetto skeletal collection housed in the Museum of Evolution, Department of Experimental Evolutionary Biology, University of Bologna. The skeletons came mainly from the Bologna cemetery and represent individuals who died at the beginning of the 20th century. The age at death (from 19 to 70 years old), sex and provenience of these individuals were well documented by the cemetery

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archives. All measurements were taken on bones from the right and left side, whenever possible. For cross-validation, an independent sample of sixteen individuals – not used to derive the discriminant function equations – was chosen at random from the same Frassetto skeletal collection: a first group of eight individuals (four males and four females) from different areas of northern Italy; a second group of eight individuals (four males and four females) from different areas of southern Italy. The sex and age at death (first group: from 23 to 69 years old; second group: from 19 to 69 years old) of these individuals were also known.

Pathological or damaged specimens were excluded.

Talar and calcaneal dimensions were measured with a sliding caliper according to standard measuring techniques [6,31] and approximated to the nearest 0.1 mm. The three main spatial dimensions of the talus and calcaneus were chosen because they are representative of the bones and very easy to measure. The talar measurements were length, width and height, while the calcaneal measurements were maximum length, medial breadth (breadth across the sustentaculum) and height of the body.

The asymmetry index was calculated for all the talar and calcaneal characters, as

$$\frac{|R - L|}{\mathrm{Min}(R, L)} \times 100$$

where R and L are respectively, the measurements taken on the right and left bones of the same individual, and Min(R, L) is the minimum value between the measurements taken on both sides [32].

Thus, for each individual, we considered nine variables for the talus (length on the right, LeR_T, and on the left, LeL_T; Asymmetry I. of lengths, LeI_T; width on the right, WiR_T, and on the left, WiL_T; Asymmetry I. of widths, WiI_T; height on the right, HeR_T, and on the left, HeL_T; Asymmetry I. of heights, HeI_T) and nine variables for the calcaneus (maximum length on the right, LeR_C, and on the left, LeL_C; Asymmetry I. of lengths, LeI_C; medial breadth on the right, BrR_C, and on the left, BrL_C; Asymmetry I. of breadths, BrI_C; height on the right, HeR_C, and on the left, HeL_C; Asymmetry I. of heights, HeI_C).

Student's *t*-test was applied to the male and female data for each variable; $p < 0.05$ was considered statistically significant.

Stepwise discriminant function analyses were performed using Statistica for Windows, version 5 (StatSoft Italia srl, Vigonza, Padua, Italy). Analyses were carried out on both sides and separately on each side to obtain functions that could be used to sex unknown individuals from the same territory in the case of fragmentary skeletons. To validate the resulting classification functions, we computed the posterior probabilities of the new cases by Mahalanobis distance.

3. Results

Table 1 gives the mean values of the talar and calcaneal measurements and indices for the northern Italian sample and the statistical probability from the *t* tests. In all cases, the male values are always greater than the female ones. The asymmetry indices do not show significant sex differences, with the exception of the asymmetry index of talar height. These results confirm for the foot bones the known tendency to low asymmetry in the human lower limb [33]. Moreover there is no evidence of any tendency of talus and calcaneus to a greater size and robusticity of the left side, which is the dominant pattern of the long bones of the lower limb [34–36].

The results of the stepwise discriminant function analysis for talus and calcaneus are given in Table 2. For the talus, two variables were selected for each side and seven for both sides. The best two variables were selected for the left calcaneus, three for the right calcaneus and four for the left and right calcanei. For both talus and calcaneus, four variables were selected for the left sides, three (two from the talus) for the right sides and six (five from the talus) for both sides. Table 2 also reports the group centroids for discriminant function scores for males and females and the sectioning point (mean value of the two centroids in case of samples of different sizes).

The standardized and unstandardized coefficients are provided in Table 3 using the best talar variables selected: length (highest coefficient) and height on the left, length (highest coefficient) and width on the right; of the seven variables selected on both sides, the left and right heights show the highest standardized coefficients. For the calcaneus the

Table 1
Means, standard deviations and statistical comparison for the talus and for the calcaneus of northern Italians

Bones	Males		Females		Males vs. females, *P*
	N	Mean ± SD	*N*	Mean ± SD	
Talus					
Right length (mm)	60	56.1 ± 2.9	50	49.2 ± 2.3	<0.001
Left length (mm)	56	56.1 ± 2.9	51	49.3 ± 2.1	<0.001
Index asym. length	55	0.9 ± 1.1	46	0.7 ± 1.0	0.304
Right width (mm)	60	43.3 ± 2.2	47	38.3 ± 2.2	<0.001
Left width (mm)	56	43.4 ± 2.2	46	38.5 ± 2.0	<0.001
Index asym. width	55	1.7 ± 2.9	39	1.5 ± 1.8	0.700
Right height (mm)	60	32.3 ± 1.8	48	29.0 ± 1.4	<0.001
Left height (mm)	56	32.6 ± 1.7	50	29.2 ± 1.2	<0.001
Index asym. height	55	0.7 ± 1.6	44	1.8 ± 1.8	<0.001
Calcaneus					
Right maximum length (mm)	60	81.5 ± 4.4	50	73.1 ± 3.4	<0.001
Left maximum length (mm)	61	81.6 ± 4.4	50	73.5 ± 3.2	<0.001
Index asym. length	60	1.0 ± 1.1	47	1.1 ± 1.1	0.737
Right medial breadth (mm)	60	43.7 ± 2.4	49	38.3 ± 2.0	<0.001
Left medial breadth (mm)	60	43.7 ± 2.3	49	38.2 ± 2.0	<0.001
Index asym. breadth	59	1.6 ± 2.2	45	1.4 ± 1.8	0.549
Right height (mm)	60	43.1 ± 2.8	49	38.2 ± 2.4	<0.001
Left height (mm)	60	43.0 ± 2.9	50	38.3 ± 2.6	<0.001
Index asym. height	59	1.4 ± 1.3	48	1.6 ± 2.0	0.567

Table 2
Stepwise discriminant function analysis for northern Italians

Functions	Eigenvalue	Wilks' λ	Canonical correlation	χ^2	d.f.	P	Group centroid	Sectioning point	Correct males (%)	Correct females (%)	Correct classification (%)
Talus											
Left											
LeL_T							$M = -1.204$				
HeL_T	1.841	0.352	0.805	102.318	2	<0.001	$F = 1.498$	0.294	87.5	96.0	91.5
Right											
LeR_T							$M = -1.160$				
WiR_T	1.789	0.359	0.801	105.658	2	<0.001	$F = 1.513$	0.353	86.7	95.7	90.7
Left and right											
LeL_T											
WiR_T											
WiI_T											
LeI_T											
HeL_T											
HeR_T							$M = 1.233$				
HeI_T	2.248	0.308	0.832	103.073	7	<0.001	$F = -1.784$	−0.551	94.5	97.4	95.7
Calcaneus											
Left											
BrL_C							$M = -1.149$				
LeL_C	1.764	0.362	0.799	102.673	2	<0.001	$F = 1.506$	0.357	91.7	89.4	90.7
Right											
BrR_C											
LeR_C							$M = 1.159$				
HeR_C	1.748	0.364	0.798	104.607	3	<0.001	$F = -1.480$	−0.321	85.0	91.5	87.9
Left and right											
BrL_C											
LeR_C											
HeR_C							$M = -1.138$				
BrI_C	1.871	0.348	0.807	100.201	4	<0.001	$F = 1.610$	0.472	89.8	88.4	89.2
Talus + calcaneus											
Left											
LeL_T											
BrL_C											
HeL_T							$M = -1.146$				
LeL_C	1.961	0.338	0.814	94.424	4	<0.001	$F = 1.673$	0.527	89.1	100.0	93.9
Right											
LeR_T											
WiR_T							$M = -1.124$				
LeR_C	1.855	0.350	0.806	101.252	3	<0.001	$F = 1.618$	0.494	89.8	95.3	92.2
Left and right											
LeL_T											
WiR_T											
WiI_T											
LeI_T											
HeR_C							$M = 1.112$				
HeI_T	2.167	0.316	0.827	91.078	6	<0.001	$F = -1.902$	−0.789	88.9	97.1	92.1

standardized and unstandardized coefficients are provided in Table 4 from the best variables selected: medial breadth (highest coefficient) and maximum length on the left, all three variables on the right; of the nine variables on both sides, the best four are left medial breadth (highest coefficient), right length and height and the asymmetry index of medial breadth. Table 5 reports the standardized and unstandardized coefficients from the combined analysis of talus and calcaneus using two talar (highest coefficient for length) and two calcaneal parameters on the left; two talar (highest coefficient for length) and one calcaneal parameters on the right; five talar (highest coefficient for left length) and one calcaneal parameters on both sides.

Unstandardized coefficients and constants (Tables 3–5) were used to calculate discriminant function equations for each of the functions. A score greater or smaller than the sectioning point indicates a different sex (according to the centroid values). For example, if in the stepwise procedure we select the function of

Table 3
Standardized and unstandardized discriminant function coefficients when the talar variables selected in the stepwise analysis are used

Functions	Standardized coefficient	Unstandardized coefficient
Left		
LeL_T	−0.727	−0.2764
HeL_T	−0.361	−0.2350
Constant		21.962
Right		
LeR_T	−0.714	−0.2642
WiR_T	−0.371	−0.1699
Constant		21.000
Left and right		
LeL_T	0.556	0.2078
WiR_T	0.505	0.2337
WiI_T	−0.256	−0.0101
LeI_T	−0.289	−0.0270
HeL_T	1.106	0.7001
HeR_T	−1.033	−0.6186
HeI_T	−0.196	−0.0118
Constant		−22.861

the left talus (Table 3), which provides a high percentage of correct classification, the equation is:

$$y = +21.962 + (-0.2764 \times \text{LeL\_T}) + (-0.2350 \times \text{HeL\_T}).$$

In this case, a y-value greater than the sectioning point of 0.294 (Table 2) indicates a female, while a smaller value indicates a male.

The percentage of correctly classified individuals in the Italian sample is quite high, with greater accuracy in females than in males. The accuracies of sex determination based on the talar measurements are higher than those obtained from the calcaneal measurements.

The cross-validation of stepwise function equations in an independent sample of individuals of different origin is reported in Table 6. The posterior probability of correct classification is high for individuals from the northern Italy. Instead, there are low probabilities of correct classification or misclassification for the males from the southern Italy.

Table 4
Standardized and unstandardized discriminant function coefficients when the calcaneal variables selected in the stepwise analysis are used

Functions	Standardized coefficient	Unstandardized coefficient
Left		
BrL_C	−0.702	−0.3198
LeL_C	−0.428	−0.1100
Constant		21.816
Right		
BrR_C	0.609	0.2725
LeR_C	0.310	0.0774
HeR_C	0.255	0.0999
Constant		−21.367
Left and right		
BrL_C	−0.626	−0.2827
LeR_C	−0.299	−0.0761
HeR_C	−0.264	−0.1057
BrI_C	−0.141	−0.0083
Constant		22.114

Table 5
Standardized and unstandardized discriminant function coefficients when the talar and calcaneal variables selected in the stepwise analysis are used

Functions	Standardized coefficient	Unstandardized coefficient
Left		
LeL_T	−0.384	−0.1463
BrL_C	−0.283	−0.1236
HeL_T	−0.271	−0.1738
LeL_C	−0.254	−0.0651
Constant		23.446
Right		
LeR_T	−0.533	−0.1933
WiR_T	−0.372	−0.1704
LeR_C	−0.238	−0.0581
Constant		21.839
Left and right		
LeL_T	0.580	0.2182
WiR_T	0.368	0.1757
WiI_T	−0.317	−0.0169
LeI_T	−0.214	−0.0197
HeR_C	0.240	0.0972
HeI_T	−0.142	−0.0093
Constant		−22.524

4. Discussion

The use of discriminant function equations to sex unidentified skeletal remains is now a frequent practice. This paper provides indications that the talus (in particular) and calcaneus are important bones for sex diagnosis and they could be effectively used as alternatives in forensic cases.

The average accuracies obtained in our stepwise analyses (87.9–95.7%) are higher than those (76.2–85%) reported in the literature [25] for a southern Italian sample, based on eight traits measured on the right calcaneus. However, the lowest accuracy in our study was also obtained when only variables on the right calcaneus were used (87.9%). Indeed, the standardized coefficients indicated a greater contribution to the functions from the talar variables than from the calcaneal variables when both bones were used.

The standardized coefficients generated in this study are consistent with previous observations [26] showing that the length and breadth of the calcaneus contribute more to sex determination than calcaneal height. We found the same pattern for the talus, since talar length provided better sex separation than other variables.

The predictive validity of the resulting classification functions was assessed by posterior classification probabilities in new cases of different origins (northern and southern Italy). The classification functions proved to be a useful diagnostic tool to identify the sex of the northern Italian individuals, but were less suitable or inadequate to sex the southern Italians. On average, the different classification functions failed to successfully predict the sex in 56.3% of the southern Italian males.

Table 6
Validity of discriminant functions on an independent sample of individuals of different origin

Functions	Original accuracy (males) (%)	Original accuracy (females) (%)	Original accuracy (total) (%)'	Cross-validation on North-Italian males (%)	Cross-validation on North-Italian females (%)	Cross-validation on North-Italian sample (tot) (%)	Cross-validation on South-Italian males (%)	Cross-validation on South-Italian females (%)	Cross-validation on South-Italian sample (tot) (%)
Talus									
Left, stepwise	87.5	96.0	91.5	87.8	91.9	89.9	64.0	96.0	80.0
Right, stepwise	86.7	95.7	90.7	89.0	85.0	87.0	50.4	99.1	74.7
Left and right, stepwise	94.5	97.4	95.7	81.9	93.5	87.7	48.2	96.2	72.2
Calcaneus									
Left, stepwise	91.7	89.4	90.7	65.9	99.4	82.6	31.2	98.3	64.7
Right, stepwise	85.0	91.5	87.9	80.9	97.0	89.1	50.8	97.5	74.1
Left and right, stepwise	89.8	88.4	89.2	51.8	99.5	75.6	30.0	98.9	64.4
Talus + calcaneus									
Left, stepwise	89.1	100.0	93.9	50.6	98.8	75.2	34.3	98.2	66.2
Right, stepwise	89.8	95.3	92.2	86.6	85.0	85.8	52.3	95.7	74.0
Left and right, stepwise	88.9	97.1	92.1	84.8	99.3	92.1	31.9	98.0	64.9

This is not surprising if we consider the current composition of Italian populations, with a prevailing presence of Alpine and Adriatic ethnic types in the northern Italy and of the Mediterranean type in south-central Italy. This complex population pattern is reflected in the morphological biodiversity among groups, from dermatoglyphics to morphometric skeletal traits [12,37–40]. Discriminant function analysis on metrical traits is size dependent: the generally smaller size of Mediterranean individuals may be responsible for the misclassifications of males on the basis of talar and calcaneal dimensions and for the contemporaneous increased probabilities of females to be classified into the female sex.

On the basis of Mediterranean specimens analysed to evaluate the applicability of discriminant functions, it is worth noting that unreliable results may be achieved in some cases. The functions developed by using northern Italian skeletons may not always be appropriate for the classification of individuals from southern Italy.

In forensic cases, human skeletal remains are frequently incomplete. Therefore, the diagnosis of sex must be made with different techniques applicable to various parts of the skeleton. In view of the population-specificity of discriminant functions, our study provides new equations for accurate sex determination in subjects from northern Italy using measurements of the talus and calcaneus.

In conclusion, our results permit forensic diagnoses of sex using bones alternative to those traditionally used in sex determination; the results also underline the importance of population variability in skeletal biology.

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