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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