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Sex determination from calcaneus by discriminant function analysis

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ABSTRACT

Using the skeleton remains for developing profile of an individual is reliable in the field of forensic science and anthropology. It provides information about age, sex, stature and ancestry of individual. Calcaneus bone is a dense tarsal bone and recovered intact. The aim of this study is to determine the sex of an individual from calcaneus bone.

In the present study we have used total 59 calcaneus (42 male and 17 female) of known age and sex. Total 11 variables were measured from each calcaneus. All variables showed statistically significant difference between male and female. Discriminant function analysis was done for sex determination. Univariate, direct and stepwise discriminant function analysis was performed which showed accuracies of 86.4%, 98.3% and 91.5% respectively. Comparison of the equation with other study showed that the equations developed in this study is population specific and should be limited to use in West Indian population.

Keywords: Anthropology, Calcaneus, discriminant function analysis.

INTRODUCTION

Creating a biological profile of an individual from the skeletonized remains is area of interest for anthropologist1. These biological remains contain information about age, sex and ancestry of individual (physical anthropology) 2, 3. The use of this information to solve the cases like mass disaster and murder etc. is known as forensic anthropology 4, 5. Forensic anthropologist use skeletal abnormality to determine the cause of death, past trauma, medical procedure and disease like bone cancer etc.

Sex estimation is the basic step in biological identification process of skeletal remains as it decreases the possibility by 50%. It is the basis to identify the age, stature and population affinity of individual1, 2, 3, 6. Determination of sex from skeleton remains is based on three kind of process: molecular, morphological or non- metrical and use of measurements or metrical. Molecular process is best and accurate method to identify the individual but it fails when applied to ancient samples7.

Morphological method is simple and quicker but it needs an experienced observer8. Pelvis and skull contains many morphological features like weight, muscle impressions, subpubic angle, ischiopubic ramus etc. and are the most commonly used bones for identification of individual with accuracies close to 99%8-13. The mandible14 and long bones of limb1 having unique morphological features also provide information about individual1. These bones are often found fragmented or incomplete. Hence it is necessary to use denser bones that are recovered intact like patella, calcaneus and talus etc15. These bones (patella, bones of foot etc.)do not have distinct morphological features. Therefore metrical method is necessary to determine the sex16.

In metric method scientist use anthropological measurements and put it into statistical analysis like student t- test, ANOVA test, discriminant function analysis and derive a formula which is used to determine sex and age of individual17. These formulas are population specific18-20. Metrical method is more scientific and can be repeated to validate the results1.

Discriminant function analysis has been in use science 195721. In discriminant function analysis, measurement of a bone which is suitable for determination of sex is used and discriminant function equation is derived in the form of y= mx+ c, where m is the unstandardized coefficient, x is the magnitude of the variable in millimeters or centimeters and c is constant15.

When the equation is derived using single variable it is termed as univariate discriminant function analysis and when combination of measurements are used, it is then referred as multivariate discriminant function analysis which further classified into direct and stepwise discriminant function analysis. Calcaneus is the largest weight bearing compact bone of foot and shows large difference between male and female1. Calcaneus bone is easy to recover and have ability to withstand the majority of post-mortem alteration22.

The aim of this study is to determine the sex of individual from calcaneus bone by using discriminant function analysis.

Materials and methods:

In this study total 59 calcaneus (42 male and 17 female) were used. Calcaneus was extracted from cadavers ranging from the age of 15 years to 93 years. Calcaneus with fracture or any abnormalities were excluded from the study.

Inclusion criteria:

1. The individuals used in this study were adults that had accompanying records on age, sex, and ancestry.

   Exclusion Criteria:

2. Individuals with missing demographic information were excluded.
3. Calcanei that showed damage or exhibited pathological conditions such as severe osteoarthritis or lipping that hindered accurate measurements were excluded in this study.

11 measurements were taken from each calcaneus in three dimensional groups' length, breadth and height. Measurements of calcaneus were taken by using digital Vernier calliper. The measurements of calcaneus were as follows-

1. Maximum length (MAXL) - Distance between most anterior point of calcaneus and most posterior point of calcaneal tuberosity (fig. a).
2. Load arm length (LAL) - Distance between anterior point of calcaneus and posterior point on the posterior articular facet (Fig. c).
3. Dorsal articular facet length (DAFL) – Distance between most anterior and posterior point of posterior articular facet (fig. b).
4. Middle breadth (MAXB) – Distance from medial point of sustentaculum tali to lateral point on posterior articular facet (fig. d).
5. Minimum breadth (MINB) – Distance between the medial and lateral surface of the body of calcaneus (fig. f).
6. Dorsal articular facet breadth (DAFB) – Distance between most lateral and medial point of posterior articular facet (fig. e).
7. Maximum height (MAXH) – Distance between superior and inferior point of calcaneal tuberosity.
8. Cuboidal facet height (CFH) – Distance between superior and inferior point of cuboidal articular facet (fig. g).
9. Body height (BH) – Body height was taken at three levels which were label as BHa, BHb and BHc.
10. BHa – Distance between superior point of posterior articular facet and inferior point of body of calcaneus (fig. h).
11. BHb – Midpoint of posterior articular facet and calcaneal tuberosity and inferiorly most anterior point of calcaneal tuberosity (fig.i).
12. BHc – Distance between posterior point of posterior articular facet and inferiorly anterior end of calcaneal tuberosity.

All these parameters were entered in Microsoft excel sheet. The discriminant function analysis was done by using statistical product and service solution (SPSS) software program.

Results:

Mean, standard deviation of all the measurements showed in table no.1. These parameters were found to

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be higher and statistically significant ($p < 0.05$) in male compared with females (Table no. 1).

Table no. 1 Descriptive statistics of calcaneum

Dimension	Variable	Male (n= 42)		Female (n=17)		Pooled (n=59)		P value
		Mean	sd	Mean	sd	Mean	sd	
Length	MAXL	82.07	5.18	73.43	2.75	79.58	6.06	<0.0001
	LAL	49.06	3.66	44.34	1.06	47.69	3.85	<0.0001
	DAFL	27.38	2.39	24.50	2.37	26.55	2.71	0.0002
Breadth	MAXB	42.05	3.15	37.78	3.28	40.82	3.72	<0.0001
	MINB	26.96	4.46	23.32	2.69	25.91	4.34	0.0004
	DAFB	29.39	3.66	25.36	2.88	28.23	3.89	<0.0001
Height	CFH	25.75	4.54	22.45	2.25	24.80	4.27	0.0005
	MAXH	45.63	4.25	40.03	4.14	44.02	4.90	<0.0001
	BHa	49.33	3.94	42.32	3.38	47.31	4.94	<0.0001
	BHb	42.82	3.00	37.17	3.67	41.19	4.09	<0.0001
	BHc	38.39	2.67	34.46	3.30	37.26	3.36	0.0002

Discriminant function analysis- Calcaneal measurements were entered into SPSS software to produce sectioning point and discriminant function equation using different methods.

Univariate discriminant function analysis- This analysis was done using each variant. Maximum length (MAXL) and height (BHa and BHb) produce high average accuracies 83.1%, 83.1% and 86.4% respectively (Table no. 2).

Discriminant function score (y) for each parameter were obtained using discriminant function equation. Unstandardized coefficient use to produce equation that is as follows

$Y = 0.312 \times BHb\ (mm) - 12.860$

If the discriminant function score (y) is greater than 0.00001, the bone will be classified as male and if the score (y) is less than or equal to 0.00001, bone will be classified as female.

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Table no. 2 Univariate discriminant function analysis

Variable	Unstandardized coefficient	constant	Eigen value	Canonical correlation	Wilk's Lambda	Centroid	Sectioning point	Accuracy
MAXL	.216	-17.178	.739	.652	.575	M= .538 F= -1.328	.00034	83.1%
LAL	.310	-14.809	.456	.560	.687	M= .422 F= -1.043	-.00011	78%
DAFL	.419	-11.113	.308	.485	.764	M= .347 F= -.858	-.00020	72.9%
MAXB	.314	-12.800	.382	.526	.724	M= .386 F= -0.954	-.00010	76.3%
MINB	.247	-6.411	.172	.383	.854	M= .259 F= -0.640	-.00003	71.2%
DAFB	.289	-8.160	.288	.473	.777	M= .335 F= -0.828	-.00010	72.9%
CFH	.248	-6.158	.143	.353	.875	M= .236 F= -0.583	.00001	72.9%
MAXH	.237	-10.435	.375	.522	.727	M= .383 F= -0.946	.00006	78.0%
Bha	.264	-12.485	.728	.649	.579	M= .534 F= -1.318	.00037	83.1%
BHb	.312	-12.860	.660	.631	.602	M= .508 F= -1.255	.00001	86.4%
BHc	.349	-13.010	.402	.535	.713	M= .396 F= -0.979	-.00019	76.3%

Direct discriminant function analysis- All the 11 measurements were entered into discriminant function analysis. Direct discriminant function analysis tends to obtain high average accuracy for correct classification of individual with 98.3% (Table. No.3). Discriminant function score is

Y= .139x MAXL+ (-.167) X LAL +.173X DAFL+ (-.020)X MAXB+ (-.030)X MINB

+.032X DAFB+.070 X CFH+ (-.091)X MAXH+.136X BHa+ .065X BHb+ .208X BHc- 21.592

If the discriminant function score (y) is greater than -0.00027, the bone will be classified as male and if the score (y) is less than or equal to -0.00027, bone will be classified as female.

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Table no. 3 direct discriminant function analysis

Variable	Standardized coefficient	Unstandardized Coefficient	Eigen Value	Canonical Correlation	Wilk's lambda	Sectioning point	Accuracy
MAXL	.644	.139	1.557	.780	.391	-.00027	98.3%
LAL	-.538	-.167					
DAFL	.413	.173					
MAXB	-.064	-.020					
MINB	-.120	-.030					
DAFB	.111	.032					
CFH	.283	.070					
MAXH	-.382	-.091					
Bha	.514	.136					
BHb	.207	.065					
BHc	.595	.208					
Constant		-21.592					

Stepwise direct discriminant function analysis-

Stepwise direct discriminant function analysis selects the group of variate which shows high average accuracy. Maximum length (MAXL) and breadth (BHa, BHc) produce accuracy 91.5% (Table no. 4). Discriminant function score will be

Y= 0.095x MAXL + 0.147 x BHa+ 0.138x BHc

Sectioning score for this analysis obtain .00020 which means if the score obtained is more than .00020 than bone will be classified as male and if score obtained is less than or equal to .00020 than bone will be classified as female.

Table no. 4 Stepwise discriminant function analysis

Variable	Standardized coefficient	Unstandardized coefficient	Eigen Value	Canonical coefficient	Wilk's lambda	Sectioning Point	Accuracy
MAXL	.441	.095	1.217	.741	.575	.00020	91.5%
BHa	.556	.147			.489		
BHc	.395	.138			.451		
Constant		-19.646					

Discussion:

Tarsal and metatarsal bones are often preserved well because of wearing socks and shoes. The present study demonstrates that the calcaneus bone is reliable for estimation of sex of an individual in western Indian population. In this study we used 11 different parameters of calcaneus. All parameters showed

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statistically significant difference between sexes and were higher in male then female, which is similar to the study done in Gujrat23. In the present study the direct discriminant analysis shows higher accuracy with 98.3% while in Gujarati it was 94.25% (close to the present study). In Koreans24 it was stated to be 89.4% which is less than this study. In South African whites1 it was 92.1% and in Japanese7 it was 88-90%.

According to Bidmos and Asala1, Gualdi- Russo2 and Kim et al24, length of the calcaneus showed highest accuracy and height shows lowest accuracy whereas in the present study height of the calcaneus contribute more to discriminate sex of an individual.

DiMichele et al25, Thomas Dwight26, Bidmos et al1 and Wilbur27 reported that the measurement of calcaneus which include articular facet shows highest accuracy for determining sex of the individual. Because articular surface of bone respond to musculature stresses, stress markers may change the length and breadth measurements of the bone.

According to DiMichele et al25 (in Modern American) load arm width (similar to middle breadth of the present study) and load arm length shows most accurate sexual dimorphism. Bidmos et al l stated that dorsal articular facet breadth and middle breadth proved most accurate in South African whites. According to Sumati et al23, in Gujarati population, dorsal articular facet length and middle breadth were selected for best sex determination.

In this study, stepwise discriminant analysis, selected for three parameters (MAXL, BHa and BHc) showed higher accuracy of 91.5%. This indicates that by using these three

Diameters (MAXL, BHa and BHc) one can predict the sex of the individual. This shows that the sex determinant varies in different population group.

Conclusion:

This study concluded that the calcaneus bone has the ability to determine the sex of the individual when partial skeleton is recovered. The reliable measurement for sex determination was height of calcaneus. Highest accuracy (98.3%) for sex determination was found with direct discriminant function analysis.

Comparison with other studies showed that the discriminant function equations are population specific and the equations derived from the present study may be used in West Indian population.

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