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SEX DETERMINATION FROM ADULT HUMAN TIBIA BY STEPWISE DISCRIMINANT FUNCTION ANALYSIS

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ABSTRACT

Background: Determination of biological sex is one of the most important determinations to be made from human remains and is an essential first step in the development of the biological profile in forensics, anthropology and bioarchaeology. The aim of this study was to determine whether sexing of unknown adult human tibia bones can be done by applying values of morphometric parameters and formulae generated by present study on adult human tibia bones of known sex and to find out the best parameters for sex determination.

Methods: Various metric measurements were recorded using osteo metric board, measuring tape, non elastic thread, sliding calipers and vernier calipers on adult human Tibia bones.

Results: Sex was correctly estimated by using direct stepwise discriminant analysis for the tibia 95.6% of males and 89.5 % of females with a total accuracy of 93.5%.

Conclusions: Present study exhibited better classification accuracy for multiple variables than those of single variables. In the tibia, the most discriminating variable in stepwise analysis are Mid shaft circumference and Circumference of upper end.

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INTRODUCTION

Sex determination of the human skeleton has been studied in forensic and physical anthropology.¹ Since the beginning of the field of physical anthropology, osteologists and anatomists have studied human remains in order to provide new and more accurate ways of building the biological profile.

When unidentified skeletal remains are found in natural mass disasters like earth quakes, tsunamis, landslides, floods etc., and in man-made disasters such as terrorist attacks, bomb blasts, mass murders and in cases when the body is highly decomposed or dismembered to deliberately conceal the identity of the individual, a biological profile is created by a forensic anthropologist to help estimate the sex, ancestry, age, and stature of the individual. Of all of these, sex is one of the most important aspects, as it is a key element in the process of identification.

While DNA analysis has proven successful in identifying unknown victims and perpetrators of crime, it is of little value when there are no family members to positively identify or claim the deceased.^{2,3,4} In India, forensic pathologists frequently encounter situations in which standard avenues for identification, e.g., fingerprints, DNA and ante mortem dental

records, are of little or no value. In these situations, Forensic personnel frequently consult the Anatomists to give their expert opinion for medico legal purposes, regarding the personal identity with respect to sex, age, stature, race and also probable cause of death. Examination of such skeletal remains forms the basis of their opinion.^{5,6}

In the present scenario, forensic anthropologists are involved in discovering new methods of identification from skeletal remains, cadavers as well as living beings. The reason to work on new populations is that the earlier acquired standards of age and sex determination have lost their values due to secular changes in the modern populations.^{7,8} Therefore, there is always a need to apply and test the methods to newer populations for making population standards for achieving precision and accuracy.

Therefore, it was suggested that osteometric studies should be considered "population specific", which implies that sexual dimorphism varies between populations to such an extent that osteometric standards developed from one group cannot be reliably used on another population.⁹

Very few studies are available in India on determination of sex from human Tibia bones, so present study made a sincere effort to enhance the accuracy of sex determination from adult human Tibia bones using various parameters by applying

stepwise Discriminant function analysis on population of Marathwada region of Maharashtra.

METHODS

The bones used in this study was obtained from Govt. Medical College, Aurangabad, Maharashtra. For the study, fully ossified dry bones, free of damage or deformity were used. Total of 275 bones were selected for the study out of which 180 were of males and 95 were of females. All the measurements were measured in millimeters. Present study was done on dry human bones, so ethical issues were not arised.

1. Length (L): distance between the most superior point of upper end (intercondylar eminence) and most inferior point of lower end (tip of medial malleolus) is measured with the help of Osteometric board.
2. Circumference of upper end (CUE): a point is fixed at the margin of condyle and marked. By running non elastic thread from that point around the margin and condyles again back to fixed point. Thread is measured on scale.
3. Circumference of lower end (CLE): a point is fixed at the level of plane of lower end and marked. By running non elastic thread from that point around the margin again back to fixed point. Thread is measured on scale.
4. Mid shaft circumference (CMS): circumference is measured with non elastic thread around mid shaft of tibia and thread length is measured on scale.
5. Antero-posterior diameter of upper end (APD-UE): maximum diameter of upper end between its anterior and posterior aspect is measured with vernier calipers.
6. Antero-posterior diameter of lower end (APD-LE): maximum diameter of lower end between its anterior and posterior aspect is measured with vernier calipers.
7. Transverse diameter of upper end (TD-UE): maximum transverse diameter across the condyles is measured with vernier calipers.
8. Transverse diameter of lower end (TD-LE): maximum distance between the two projection points on the medial malleolus and lateral surface of the distal articular region is measured with vernier calipers.

RESULTS

An analysis of variance test (ANOVA) provided descriptive statistics including the means, standard deviations and F-ratios of all the variables in both sex groups (Table 1).

Table 1 Means, Standard deviations, Univariate F-ratio and demarking points for the Tibia

Variable Descriptions	Males (n =180)			Females (n = 95)			F- ratio	t- test	p value
	Mean	SD	SE	Mean	SD	SE			
TIBIA									
L	376.83	18.80	1.40	343.87	19.16	1.96	188.53	13.73	.000
CUE	195.73	13.31	0.99	170.65	10.78	1.10	249.88	15.80	.000
CLE	131.41	8.02	0.59	117.04	8.57	0.87	190.34	13.79	.000
CMS	75.74	4.44	0.33	64.10	4.16	0.42	444.54	21.08	.000
APD-UE	46.61	3.24	0.24	40.83	3.14	0.32	201.90	14.20	.000
APD-LE	33.64	2.60	0.19	29.14	2.16	0.22	206.66	14.37	.000
TD-UE	70.51	5.52	0.41	62.27	4.44	0.45	157.62	12.55	.000
TD-LE	41.33	3.26	0.24	36.66	2.79	0.28	140.39	11.84	.000

The greatest differences in mean values appeared to be in Mid shaft circumference (males: 75.74 mm, females: 64.10 mm.), Circumference of upper end (males 195.73 mm, females: 170.65 mm.) A statistically significant difference (p < 0.001)

was found between males and females for the osteometric variables of tibia.

Stepwise discriminant analysis of Tibia

A Stepwise discriminant function was performed to determine the most significant variables contributing to the discrimination of gender.

Stepwise analysis was run on 8 measurements from the tibia. The stepwise discriminant function procedure was performed using Wilk’s Lambda with F = 3.84 to enter and F = 2.71 to remove.

Function 1 Analysis of Tibia (Stepwise) (Table 2, 3 & 4)

Table 2 Variable wise calculation of discriminant functions of Tibia (Stepwise analysis)

Function	Variable	unstandardized co efficient	standard coefficient	structured coefficient	Wilks Lambda	eigen value	canonical correlation
1 All variables	CMS	0.179	0.778	0.932	0.348	1.875	0.808
	CUE	0.032	0.394	0.699			

Table 3 Discriminant function equation for determining sex of Tibia (Stepwise analysis)

Function	Variable	Constant	Discriminant equation	Group centroid		Sectioning point
				Male	Female	
1All variables	CMS	-18.705	B = -18.705 + 0.179* CMS + 0.032* CUE	0.991	-1.878	-0.000109
	CUE					

Table 4 Percentage of predicted group membership and cross validation for the Tibia (Stepwise analysis)

Function	Variable	% of bones Correctly classified					
		Male (n =180)		Female (n =95)		Total (n=275)	
		original	Cross validated	original	Cross validated	original	Cross validated
1	CMS	172	172	85	85	257	257
All variables	CUE	95.6	95.6	89.5	89.5	93.5	93.5

When all 8 variables were entered for the tibia (Function 1), selected variables included: Mid shaft circumference and Circumference of upper end showed largest metric discrimination between the sexes.

Discriminant function score formula for Function 1 analysis of Tibia is

$$D= -18.705 + 0.179* CMS + 0.032* CUE$$

The classification accuracy of the Tibia for the discriminant function formulae are presented in Table 4.

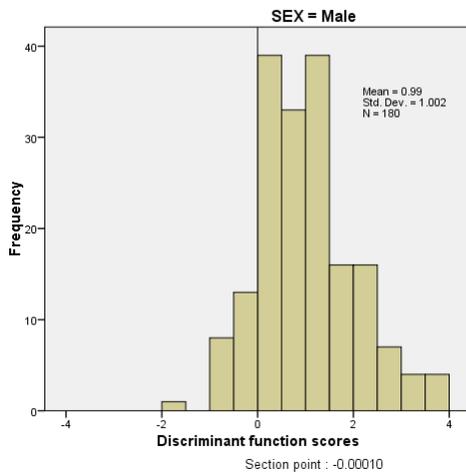
For the Tibia, Function 1 analysis (Table 4) showed that 172 males out of 180 cases were correctly classified with 8 individuals misclassified as females, thus resulting in 95.6 % accuracy. 85 females out of 95 cases were correctly classified with 10 individuals misclassified as males, thus resulting in 89.5% accuracy. Total 257 out of 275 cases were correctly classified with total accuracy of 93.5 %. Cross validation showed similar result of original analysis.

Table 5 Comparison of Tibia metric analysis for sex determination between previous studies and our study

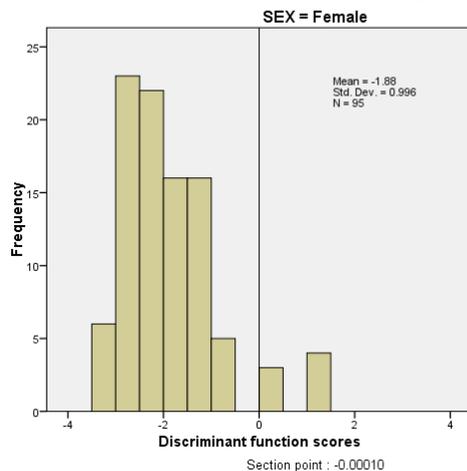
Study	Country	Year	Method	Overall accuracy	Accuracy in males	Accuracy in females
Iscan <i>et al.</i> ¹²	Whites blacks	1984	CML , CNF MDNF TDNF	87.3	-	-
			CML , CNF MDNF TDNF	90.0	-	-
Holland ¹³	Hamann Todd collection	1991	CML, MPEB, MDEB	86-95	-	-
Iscan M.Y <i>et al.</i> ¹⁵	Japan	1994	CML, MPEB, MDEB APDMAS,TDMAS, APDLAS, TDLAS	-	96	79
M. Steyn <i>et al.</i> ¹⁰	South Africa	1997	CML, MPEB, MDEB APDMAS, TDMAS, APDLAS TDLAS	86 -91	-	-
kirici <i>et al.</i> ¹⁶	turkey	1999	CML, MPEB, MDEB	87-89	-	-
Gonzalez <i>et al.</i> ¹⁷	Canary Islands	2000	CML, MPEB, MDEB	-	94.9	98.3
Kazuhiro Sakaue ¹¹	Japanese	2004	Proximal epiphyseal Breadth	94	-	-
Rashmi Srivastava <i>et al.</i> ¹⁸	India	2010	Proximal breadth+ Distal breadth+ Minimum girth of shaft	84.5	87.5	77.8
Mario Slaus <i>et al.</i> ¹⁴	Croatia	2013	CML, MPEB, MDEB, MDNF, TDNF, CNF	90.0	92.7	90.1
Present study	India	2013	CMS, CUE	93.5	95.6	89.5

CML = Length of the tibia
 MPEB= Maximum epiphyseal breadth of the proximal tibia
 MDEB= Maximum epiphyseal breadth of the distal tibia
 MDNF =Maximum diameter of the tibia at the nutrient foramen
 TDNF =Transverse diameter of the tibia at the nutrient foramen
 CNF= Circumference of the tibia at the nutrient foramen
 APDMAS= Anteroposterior diameter of medial articular surface,
 TDMAS=Transverse diameter of medial articular surface,
 APDLAS= Anteroposterior diameter of lateral articular surface,
 TDLAS=Transverse diameter of lateral articular surface)
 CUE=Circumference of upper end
 CMS=Mid shaft circumference

Canonical Discriminant Function Tibia (Stepwise analysis)



Canonical Discriminant Function Tibia (Stepwise analysis)



Graph 1 Discriminant scores of Tibia by sex using multivariate equation
 $B = -18.705 + 0.179 * CMS + 0.032 * CUE$

CONCLUSIONS

Steyn and Iscan investigating a South African Caucasian population of known sex found that the distal epiphyseal breadth was the most effective for sex discrimination followed by the proximal breadth, the antero-posterior diameter, the circumference and the transverse diameter.¹⁰ The results obtained by other workers including Sakaue,¹¹ using contemporary documented Japanese material, Iscan *et al.*¹² looking at 20th century Chinese, Japanese and Thai samples of known sex, Holland¹³ documented specimens from the Hamann–Todd Collection, Slaus and Tomicic¹⁴ investigated tibia from mediaeval Croatian sites with the sex based on pelvic and cranial morphology.

Işcan MY *et al.* (1994)¹⁵ studied in population of contemporary Japan. Average prediction accuracy ranged from 80% from minimum shaft circumference to 89% with proximal epiphyseal breadth. Classification accuracy was higher in males (96%) than in females (79%).

Kirici Y and Ozan H. (1999)¹⁶ studied in population of Turkish cadavers. Results indicated that classification accuracy ranged from 89% in the right and 87% in the left for biarticular breadth. E. Gonzalez-Reimers *et al.* (2000)¹⁷ studied in the pre Hispanic population of the Canary Islands. The functions obtained showed high average accuracies, ranging from 94.9 to 98.3%, with female accuracies of 100%. Rashmi Srivastava *et al.* (2009)¹⁸ studied in Indian population of Varanasi region. The average predictive accuracy is 82.8 % (87.5 % for males and 72.2% for females).

Present study shows similar results when compared to previous research and also exhibited better classification accuracy for multiple variables than those of single variables.

In summary, the measurements of the tibia appear to be high discriminators of sex in present sample analyzed by stepwise discriminant analysis.

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Declarations

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Conflict of interest: None

Ethical approval: Study involved only dry human skeletal material, so ethical approval is not required.

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