International Journal of Research in Medical Sciences
Reddy BB et al. Int J Res Med Sci. 2017 Sep;5(9):3891-3897
www.msjonline.org
pISSN 2320-6071 | eISSN 2320-6012

DOI: http://dx.doi.org/10.18203/2320-6012.ijrms20173702

Original Research Article

Sex determination from adult human humerus by discriminant function analysis

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Received: 31 July 2017
Accepted: 04 August 2017

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ABSTRACT

Background: Sex determination of unidentified skeletal remains from crime scenes or excavation sites is an important component in the development of the biological profile in forensics, anthropology and bioarchaeology. The purpose of this research is to determine whether sexing of unknown adult human humerus bones can be done by applying values of morphometric parameters and formulae generated by present study on adult human humerus 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 humerus bones.
Results: Sex was correctly estimated by using stepwise discriminant function analysis, for the clavicle 100% of males and 95% of females, with a total accuracy of 98.1%. Direct discriminant function analysis, correct estimated sex for the clavicle was 100% in males and 95% in females with a total accuracy of 98.1%.
Conclusions: Present study exhibited better classification accuracy for multiple variables than those of single variables, the most discriminating variables in stepwise analysis are the weight, total length, transverse diameter of head, circumference of midshaft, trochlear width, capitulum width. In direct analysis, the single most useful variable was the transverse diameter of head.

Keywords: Capitulum width, Circumference of midshaft, Transverse diameter of head, Trochlear width

INTRODUCTION

Sex estimation is a foundational element of the biological profile, as the accuracies of the other parameters are reliant on the sex, and also the ancestry of the deceased individual.[1,2] Therefore, the accuracies of the methods, the availability of population-specific standards, as well as the availability and preservation of the bones often dictate the morphological and osteometric methods utilized to assess sex from the human skeleton.[3] 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.[4-6]

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 humerus, so present study made a sincere effort to enhance the accuracy of sex determination from adult human humerus using various parameters by applying discriminant function analysis on population of Marathwada region of Maharashtra.

METHODS

The bones used in this study were obtained from Government Medical College, Aurangabad (Maharashtra). For the study, fully ossified dry bones, free of damage or deformity were used. Total 265 bones were selected for the study out of which 165 were of males and 100 were of females. Present study was done on dry human bones, so ethical issues were not raised.

Humerus measurements

- Weight (W): weight of each dried humerus is recorded with the help of scientific balance and weight, it is recorded in grams.
- Total length (L): Direct distance from most superior point on head of humerus to most inferior point on trochlea is measured with the help of Osteometric board.
- Vertical diameter of head (VDH): direct distance between the most superior and inferior points on the border of the articular surface is measured with Vernier calipers.
- Transverse diameter of head (TDH): direct distance between the most anterior and posterior points on the border of the articular surface is measured with Vernier calipers.
- Circumference of midshaft (MSC): midpoint of shaft is measured with Osteometric board while measuring its length and marked. Circumference is measured with non-elastic thread and thread length is measured on scale.
- Bi epicondylar distance (BED): distance of the most laterally protruding point on the lateral epicondyle from the corresponding projection of the medial epicondyle is measured with Vernier calipers.
- Trochlear width (TWD): transverse diameter of trochlea is measured with Vernier calipers.
- Capitulum width (CWD): transverse diameter of capitulum 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: Means, standard deviations, univariate F-ratio and demarking points for the humerus.

Variable Descriptions	Males (n =165)			Females (n = 100)					
	Mean	SD	SE	Mean	SD	SE	F- ratio	t -test	p value
Humerus									
W	104.50	14.50	1.12	68.48	12.54	1.25	424.33	20.59	0.000
L	310.79	14.10	1.09	278.15	15.43	1.54	310.32	17.61	0.000
CA	131.27	5.51	0.42	112.78	8.07	0.80	489.65	22.12	0.000
VDH	42.97	1.93	0.15	37.06	3.03	0.30	375.65	19.38	0.000
TDH	39.84	1.62	0.12	33.75	2.61	0.26	549.24	23.43	0.000
MSC	60.87	3.69	0.28	51.71	3.74	0.37	378.84	19.46	0.000
BED	60.50	3.05	0.23	52.17	3.78	0.37	386.36	19.65	0.000
TWD	24.70	1.12	0.08	20.96	1.58	0.15	500.61	22.37	0.000
CWD	22.95	1.07	0.08	20.69	1.72	0.17	173.22	13.16	0.000

The greatest differences in mean values appeared to be in Transverse diameter of head (males: 39.84 mm, females: 33.75 mm), trochlear width (males 24.70 mm, females: 20.96 mm), anatomical neck circumference (males 131.27 mm, females: 112.78 mm), and weight (males: 104.50 gm, females: 68.48 gm)

A statistically significant difference ($p < 0.001$) was found between males and females for the osteometric variables of humerus. As can be seen in Table 1, the univariate F-ratio scores were the highest in the transverse diameter of head, trochlear width, Anatomical neck circumference and weight of humerus.

Stepwise discriminant analysis of Humerus (Table 2, 3 and 4)

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

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

Table 2: Variable wise calculation of discriminant functions of Humerus (stepwise analysis).

Function	Variable	Unstandardized coefficient	Standard coefficient	Structured coefficient	Wilks lambda	Eigen value	Canonical correlation
1 All variables	W	0.042	0.582	0.615	0.190	4.267	0.900
	L	-0.031	-0.457	0.526			
	TDH	0.270	0.553	0.700			
	MSC	0.094	0.348	0.581			
	TWD	0.693	0.914	0.668			
	CWD	-0.593	-0.806	0.393			

Table 3: Discriminant function equation for determining sex of Humerus (stepwise analysis).

Function	Variable	Constant	Discriminant equation	Group centroid		Sectioning point
				Male	Female	
1 All variables	W, L, TDH, MSC, TWD, CWD	-13.019	D = -13.019 + 0.042 × W - 0.031 × L + 0.270 × TDH + 0.094 × MSC + 0.693 × TWD - 0.593 × CWD	1.602	-2.643	0.000113

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

Function	Variable	% of bones Correctly classified					
		Male (n =165)		Female (n =100)		Total (n=265)	
		Original	Cross validated	Original	Cross validated	Original	Cross validated
1	W, L, TDH, MSC, TWD, CWD	165	165	95	95	260	260
		100	100	95	95	98.1	98.1

When all nine variables were entered for the Humerus (Function 1), selected variables included: Weight, total length, transverse diameter of head, circumference of midshaft, trochlear width, capitulum width showed largest metric discrimination between the sexes.

Discriminant function score formula for Function 1 analysis of Humerus is:

D = -13.019 + 0.042 × W - 0.031 × L + 0.270 × TDH + 0.094 × MSC + 0.693 × TWD - 0.593 × CWD

The classification accuracy of the Humerus for the discriminant function formulae are presented in Table 4. For the Humerus, Function 1 analysis (Table 4) showed that 165 males out of 165 cases were correctly classified with no individuals misclassified as females, thus resulting in 100 % accuracy. 95 females out of 100 cases were correctly classified with 5 individuals misclassified as males, thus resulting in 95% accuracy. Total 260 out of 265 cases were correctly classified with total accuracy of 98.1%. Cross validation showed similar result with original analysis.

Direct discriminant analysis of Humerus (Function 1 to 9, Tables 5, 6 and 7, each variable separately)

A direct analysis was carried out on all individual variables of humerus separately to identify the most constructive variable in statistically discriminating between the sexes. The results of the direct analyses and discriminant function score formula for each variable appear in Tables 5, 6 and 7 as Function 1 to 9.

By direct analysis, transverse diameter of head is the best discriminant variable among all variables with 97% for males and 84% for females.

A direct discriminant analysis was applied to evaluate the diagnostic ability of individual variables that were previously selected as best discriminators of sex during the stepwise analysis.

The results of the direct analyses appear in Tables 5, 6 and 7 as function 1, function 2, function 5, function 6, function 8 and function 9 and refer to analyses of the weight, total length, transverse diameter of head, circumference of midshaft, trochlear width, capitulum width respectively.

Table 5: Variable wise calculation of discriminant functions of Humerus (direct analysis).

Function	Variable	Unstandardized coefficient	Standard coefficient	Structured coefficient	Wilks lambda	F ratio	Eigen value	Canonical correlation
1	W	0.072	1	1	0.383	424.33	1.613	0.786
2	L	0.068	1	1	0.459	310.32	1.180	0.736
3	CA	0.152	1	1	0.349	489.65	1.862	0.807
4	VDH	0.415	1	1	0.412	375.65	1.428	0.767
5	TDH	0.487	1	1	0.324	549.24	2.088	0.822
6	MSC	0.269	1	1	0.410	378.84	1.440	0.768
7	BED	0.299	1	1	0.405	386.36	1.469	0.771
8	TWD	0.758	1	1	0.344	500.61	1.903	0.810
9	CWD	0.736	1	1	0.603	173.22	0.659	0.630
10 All variables	W	0.044	0.604	0.603	0.184	-	4.442	0.903
	L	-0.033	-0.486	0.515				
	CA	-0.114	-0.749	0.647				
	VDH	0.235	0.567	0.567				
	TDH	0.348	0.714	0.686				
	MSC	0.110	0.408	0.569				
	BED	-0.021	-0.069	0.575				
	TWD	0.771	1.017	0.655				
	CWD	-0.569	-0.774	0.385				

Table 6: Discriminant function equation for determining sex of Humerus (direct analysis).

Function	Variable	Constant	Discriminant equation	Group centroid		Sectioning point
				Male	Female	
1	W	-6.588	D = -6.588 + 0.072 × W	0.985	-1.625	0.000094
2	L	-20.412	D = -20.412 + 0.068 × L	0.842	-1.390	-0.00026
3	CA	-18.843	D = -18.843 + 0.152 × CA	1.058	-1.746	-0.00011
4	VDH	-16.917	D = -16.917 + 0.415 × VDH	0.927	-1.529	0.000208
5	TDH	-18.302	D = -18.302 + 0.487 × TDH	1.121	-1.849	0.000245
6	MSC	-15.457	D = -15.457 + 0.269 × MSC	0.931	-1.536	0.000056
7	BED	-17.135	D = -17.135 + 0.299 × BED	0.940	-1.551	0
8	TWD	-17.644	D = -17.644 + 0.758 × TWD	1.070	-1.766	-0.00019
9	CWD	-16.257	D = -16.257 + 0.736 × CWD	0.629	-1.039	-0.00043
10	All variables	-13.081	D = -13.081 + 0.044 × W - 0.033 × L - 0.114 × CA + 0.235 × VDH + 0.348 × TDH + 0.110 × MSC - 0.021 × BED + 0.771 × TWD - 0.569 × CWD	1.634	-2.697	-0.00034

Direct discriminant analysis of Humerus (Function 10, Tables 5,6 and 7, all variables entered together)

A direct discriminant analysis was applied to evaluate the diagnostic ability of all variables entered together in direct discriminant analysis (Function 10, Tables 5,6 and 7). D= Discriminant function score.

Discriminant function score formula for Function 10 analysis is of Humerus.

D = -13.081 + 0.044 × W - 0.033 × L - 0.114 × CA + 0.235 × VDH + 0.348 × TDH + 0.110 × MSC - 0.021 × BED + 0.771 × TWD - 0.569 × CWD

The classification accuracy of the Humerus for the discriminant function formulae are presented in Table 7. For the humerus, Function 10 analysis showed that 165 males out of 165 cases were correctly classified with no individuals misclassified as females, thus resulting in 100% accuracy.

95 females out of 100 cases were correctly classified with 5 individuals misclassified as males, thus resulting in 95% accuracy. Total 260 out of 265 cases were correctly classified with total accuracy of 98.1%. Cross validation showed similar results of original analysis.

Table 7: Percentage of predicted group membership and cross validation for the Humerus (direct analysis).

Function	Variable	% of bones correctly classified					
		Male (n =165)		Female (n =100)		Total (n=265)	
		Original	Cross validated	Original	Cross validated	Original	Cross validated
1	W	158	158	89	89	247	247
		95.8	95.8	89	89	93.2	93.2
2	L	154	154	79	79	233	233
		93.3	93.3	79	79	87.9	87.9
3	CA	160	160	79	79	239	239
		97	97	79	79	90.2	90.2
4	VDH	160	160	74	74	234	234
		97	97	74	74	88.3	88.3
5	TDH	160	160	84	84	244	244
		97	97	84	84	92.1	92.1
6	MSC	150	150	73	73	223	223
		90.9	90.9	73	73	84.2	84.2
7	BED	156	156	79	79	235	235
		94.5	94.5	79	79	88.7	88.7
8	TWD	165	165	76	76	241	241
		100	100	76	76	90.9	90.9
9	CWD	151	151	70	70	221	221
		91.5	91.5	70	70	83.4	83.4
10	All variables	165	165	95	95	260	260
		100	100	95	95	98.1	98.1

DISCUSSION

Among all the various population groups studied type II Sex determination is the most significant information which can be obtained from bones.

In previous studies, morphologic methods were mostly used to determine sex. However, metric measurements were preferred due to their easy repeatability, high accuracy, and no requirement for special skills.

The sexual dimorphism of the humerus has been assessed by various investigators. Many morphological features have been examined and the reliability of each criterion for sex allocation evaluated.

Frutos who examined forensic specimens from rural Guatemala, Mall et al, who looked at contemporary skeletal material from Cologne and Munich, Sakaue examined modern Japanese, Steyn and Iscan investigated skeletons from South Africa dating from 1863 to 1963, Iscan et al, focused on 20th century samples from Thailand, China and Japan, Dittrick and Suchey studied the remains from Central California belonging to three cultural groups from 2500 BC, 1000-500 BC and after 500 AD.[10,12-16]

Finally, Kranioti investigated contemporary specimens from Crete and France European Americans, African Americans and Native Americans from the Tennessee data bank and found discriminant function analysis involving maximum length, head vertical diameter, minimum midshaft diameter and epicondylar breadth gave an accuracy of 91.1%.[17]

Present study shows, the most discriminating variables included in the stepwise analysis are weight, total length, transverse diameter of head, circumference of midshaft, trochlear width and capitulum with 100% accuracy in males, 95% accuracy in females and 98.1% overall accuracy.

In, direct analysis, the single most useful variable was the Transverse diameter of head with 97% accuracy in males, 84% accuracy in females and 92.1% overall-accuracy.

Table 8: Comparison of Humerus metric analysis for sex determination between previous studies and our study.

Study	Country	Year	TDH	VDH	EB	MLH
Dittrick and Suchey[10]	Prehistoric central California	1986	89.5	89.0	85.2	79.5
France[11]	Americans	1997	91	89	86	-
	Euro-Americans		92	89	85	-
	Native Americans		89	91	86	-
Iscan et al[12]	Chinese	1998	-	80.5	77.9	-
	Japanese	1998	-	87.3	89.9	-
	Thai	1998	-	90.4	93.3	-
Steyn and Iscan[13]	South African White	1999	-	84	89	-
	South African Black	1999	-	91	88.5	-
Mall et al[14]	German	2001	-	90.4	88.5	80.6
Sakaue[15]	Japanese	2004				70
Rios Frutos[16]	Guatemalan	2005	-	95.5	91.1	83.0
Kranioti and Michalodimitrakis[17]	Cretan	2009	-	89.9	85.1	85.1
Ross and Manneschi[18]	Chile	2011		87	-	-
Girish Patil et al[19]	India	2011	-	58	80	90
Je-Hun Lee et al[20]	Korean	2013	82.9	87.0	74.7	80.8
Jonathan Barnes and Daniel J Wescott[21]	Columbia	-	84.4	-	-	81.3
Present study	India	2013	92.1	88.3	88.7	87.9

TDH= transverse diameter of humeral head, VDH = vertical diameter of humeral head, EB= epicondylar breadth of humerus, MLH = maximum length of humerus.

CONCLUSION

In summary, the measurements of the humerus appear to be good discriminators of sex in present sample analyzed by stepwise and direct discriminant function analysis.

ACKNOWLEDGEMENTS

The author would like to thank Dr. Mrs. C. V. Diwan, professor and head, department of anatomy, GMC, Aurangabad. Also, would like to thank Dr. Mrs. Gaonkar, Controller of examinations, KIMS University, Karad, Maharashtra, India.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

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Cite this article as: Reddy BB, Doshi MA. Sex determination from adult human humerus by discriminant function analysis. Int J Res Med Sci 2017;5:3891-7.