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RESEARCH ARTICLE

DETERMINATION OF SEX OF ADULT HUMAN SCAPULA BY DISCRIMINANT FUNCTION ANALYSIS

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ABSTRACT

Background: Sex determination 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 scapulae can be done by applying values of morphometric parameters and formulae generated by present study on adult human scapulae of known sex and to find out the best parameters for sex determination.

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

Results: Sex was correctly estimated by using stepwise analysis, for the scapula 95% of males and 96.3% of females with a total accuracy of 95.6%

Direct discriminant function analysis, correct estimated sex for the scapula was 97 % in males and 96.3 % in females with a total accuracy of 96.7%.

Conclusion: Present study exhibited better classification accuracy for multiple variables than those of single variables. In the scapula, the most discriminating variables in stepwise analysis are the Maximum scapular breadth, Glenoid cavity maximum length, Glenoid cavity maximum breadth. In direct analysis, the single most useful variable was the Maximum scapular breadth.

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 Scapulae, so present study made a sincere effort to enhance the accuracy of sex determination from adult human scapula using various parameters by applying

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 180 bones were selected for the study out of which 100 were of males and 80 were of females. All the measurements were measured in millimeters. Present study was done on dry human bones, so ethical issues were not arised.

Scapula Measurements

1. Maximum scapular length (L): maximum distance from superior angle of the scapula to the inferior angle of scapula is measured with vernier calipers.
2. Maximum scapular breadth (Wd): maximum distance between the middle of the dorsal border of the glenoid fossa to the end of the spinal axis at the vertebral border is measured with vernier calipers.
3. Glenoid cavity maximum length (GCL): maximum distance between the superior border and the inferior border of the glenoid cavity is measured with vernier calipers.
4. Glenoid cavity maximum Breadth (GCW): maximum distance between the anterior border and the posterior border of the glenoid cavity at mid point of glenoid cavity 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).

The greatest differences in mean values appeared to be in Maximum scapular breadth (males 101.92 mm, females: 87.62 mm.), Glenoid cavity maximum Breadth (males 25.09 mm, females: 20.56 mm.) and Glenoid cavity maximum length (males 36.25 mm, females: 31.21 mm.)(Table 1)

A statistically significant difference ($p < 0.001$) was found between males and females for the osteometric variables of scapula. As can be seen in Table 1, the univariate F-ratio scores were the highest in the Maximum scapular breadth and Glenoid cavity maximum Breadth.

Stepwise discriminant function analysis of Scapula

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

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

When all four variables were entered for the Scapula (Function 1), selected variables included: Maximum scapular breadth, Glenoid cavity maximum length, Glenoid cavity maximum Breadth showed largest metric discrimination between the sexes. (Table 2,3 & 4)

A direct analysis was then carried out on these above-mentioned variables, as they appeared to be the most constructive in statistically discriminating between the sexes (Table 5, 6 and 7, direct Functions) Discriminant function score formula for Function 1 analysis is of Scapula

$$D = -21.184 + 0.122 * Wd + 0.200 * GCW + 0.143 * GCL$$

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

For the Scapula, Function 1 analysis (Table 4) showed that 95 males out of 100 cases were correctly classified with 5 individuals misclassified as females, thus resulting in 95% accuracy.

77 females out of 80 cases were correctly classified with 3 individuals misclassified as males, thus resulting in 96.3% accuracy.

Total 172 out of 180 cases were correctly classified with total accuracy of 95.6 %.

Cross validation showed similar result of original analysis.

Direct discriminant analysis of Scapula (Function 1 to 4, Tables 5, 6 & 7) (each variable separately)

A direct analysis was carried out on all individual variables of Scapula 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 4. By direct analysis, Maximum scapular breadth is the best discriminant variable among all variables with 89% for males and 98.8% 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 Table 5, 6 and 7 as Function 2, Function 3, Function 4 and refer to analyses of the Maximum scapular breadth, Glenoid cavity maximum length and Glenoid cavity maximum Breadth respectively.

Direct discriminant analysis (Function 5 Tables 5, 6 & 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 5, Table 5,6 & 7)

Discriminant function score formula for Function 5 analysis of Scapula is

$$D = -21.942 + 0.022 * L + 0.107 * Wd + 0.138 * GCL + 0.172 * GCW$$

The classification accuracy of the scapula for the discriminant function formulae are presented in Table 7. For the Scapula, Function 5 analysis showed that 97 males out of 100 cases were correctly classified with 3 individuals misclassified as females, thus resulting in 97 % accuracy.

77 females out of 80 cases were correctly classified with 6 individuals misclassified as males, thus resulting in 96.3 % accuracy.

Total 174 out of 180 cases were correctly classified with total accuracy of 96.7 %. Cross validation showed similar results of original analysis.

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

Variable Descriptions	Males (n =100) Mean	SD	SE	Females (n = 80) Mean	SD	SE	F- ratio	t -test	p value
SCAPULA									
L	144.48	8.29	0.82	126.01	8.12	0.90	224.42	14.98	.000
Wd	101.92	4.91	0.49	87.62	4.65	0.51	394.09	19.85	.000
GCL	36.25	2.24	0.22	31.21	1.89	0.21	257.33	16.04	.000
GCW	25.09	1.60	0.16	20.56	1.73	0.19	328.34	18.12	.000

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

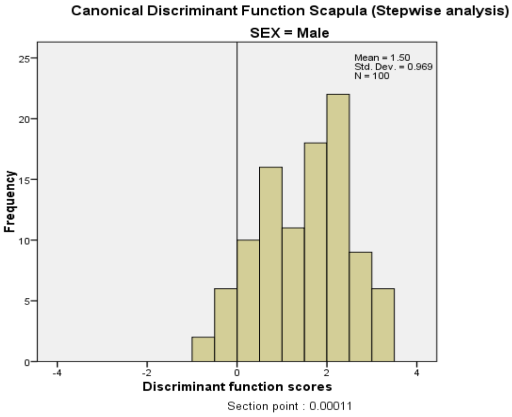
Function	Variable	unstandardized co efficient	standard coefficient	structured coefficient	Wilks Lambda	eigen value	canonical correlation
1	Wd	0.122	0.587	0.882			
All variables	GCW	0.200	0.333	0.805	0.260	2.847	0.860
	GCL	0.143	0.300	0.713			

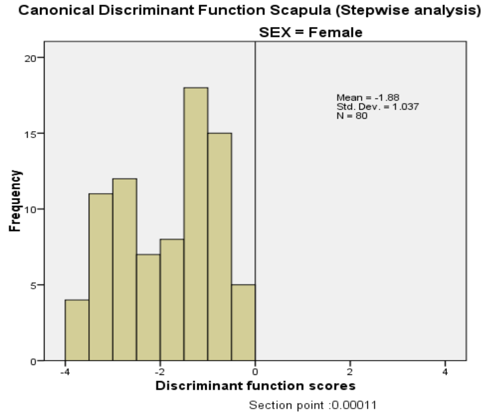
Table 3 Discriminant function equation for determining sex of Scapula (Stepwise analysis)

Function	Variable	Constant	Discriminant equation	Group centroid Male	Female	Sectioning point
1	Wd GCW GCL	-21.184	D = -21.184 + 0.122* Wd + 0.200* GCW + 0.143* GCL	1.501	-1.876	0.000111

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

Function	Variable	% of bones Correctly classified: Male (n =100) original	Cross validated	Female (n =80) original	Cross validated	Total (n = 180) original	Cross validated
1	Wd	95	95	77	77	172	172
	GCW GCL	95	95	96.3	96.3	95.6	95.6





Graph 1 Discriminant scores of scapula by sex using multivariate equation
(D = -21.184 + 0.122* Wd + 0.200* GCW + 0.143* GCL)

Table 5 Variable wise calculation of discriminant functions of Scapula (direct analysis)

Function	Variable	unstandardized co efficient	standard coefficient	structured coefficient	Wilks Lambda	F ratio	eigen value	canonical correlation
1	L	0.122	1	1	0.442	224.42	1.261	0.747
2	Wd	0.208	1	1	0.311	394.09	2.214	0.830
3	GCL	0.478	1	1	0.409	257.33	1.446	0.769
4	GCW	0.600	1	1	0.352	328.34	1.845	0.805
	L	0.022	0.183	0.658				
5	Wd	0.107	0.515	0.871	0.255	-	2.915	0.863
All Variables	GCL	0.138	0.289	0.704				
	GCW	0.172	0.286	0.795				

Table 6 Discriminant function equation for determining sex of Scapula (direct analysis)

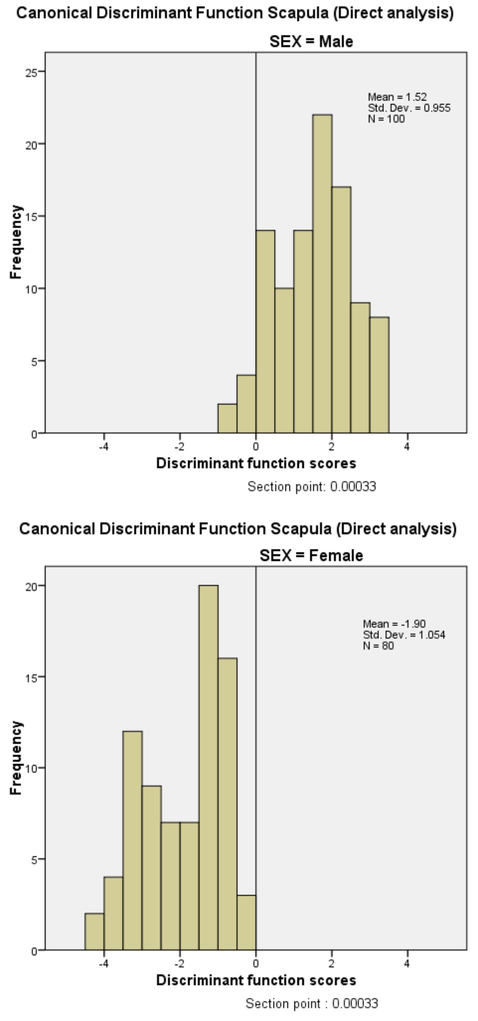
Function	Variable	Constant	Discriminant equation	Group centroid Male	Female	Sectioning point
1	L	-16.582	D = -16.582 + 0.122*L	0.999	-1.248	0.000333
2	Wd	-19.907	D = -19.907 + 0.208*Wd	1.323	-1.654	-0.00011
3	GCL	-16.246	D = -16.246 + 0.478*GCL	1.069	-1.337	-0.00033
4	GCW	-13.855	D = -13.855 + 0.600*GCW	1.208	-1.510	0
5	All Variables	-21.942	D = -21.942 + 0.022* L + 0.107* Wd + 0.138* GCL + 0.172* GCW	1.519	-1.898	0.000333

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

Function	Variable	% of bones Correctly classified: Male (n =100) original	Cross validated	Female (n =80) original	Cross validated	Total (n=180) original	Cross validated
1	L	90	90	66	66	156	156
		90	90	82.5	82.5	86.7	86.7
2	Wd	89	89	79	79	168	168
		89	89	98.8	98.8	93.3	93.3
3	GCL	93	93	69	69	162	162
		93	93	86.3	86.3	90.0	90.0
4	GCW	96	96	69	69	165	165
		96	96	86.3	86.3	91.7	91.7
5	All variables	97	97	77	77	174	174
		97	97	96.3	96.3	96.7	96.7

Table 8 Comparison of Scapula metric analysis for sex determination between previous studies and our study

Study	Country	Year	Method	Overall accuracy	Accuracy in males	Accuracy in females
Giancarlo Di Vella [12]	Italy	1994	length of glenoid cavity, maximum scapular breadth	90%	-	-
Luis Rios Frutos [17]	Central America	2002	glenoid cavity breadth, glenoid cavity length	85.6 to 94.8	-	-
Ozer et al [15]	Turkey	(2006)	maximum scapular height, maximum scapular breadth, glenoid cavity height, glenoid cavity breadth	82.9% to 95.0%	-	-
Dabbs, G.R., and P.H. Moore-Jansen [18]	Egypt	2010	maximum length of the scapula, maximum length of the scapular spine, breadth of the infraspinous body, height of the glenoid fossa, breadth of the glenoid fossa.	84.0 to 88.0%	-	-
Macaluso JP Jr [16]	South Africa	2010	area of the glenoid fossa glenoid fossa breadth	88.3% to 85.8%	-	-
Dabbs, G and Moore-Jansen [18]	South Africa	2010	maximum length of the scapula, maximum breadth of the scapula,	71.4% to 88.9%	-	-
Present study	India	2013	Maximum scapular breadth, Glenoid cavity maximum length, Glenoid cavity maximum Breadth	95.6	95	96.3



Graph 2 Discriminant scores of scapula by sex using multivariate equation

D = -21.942 + 0.022* L + 0.107* Wd + 0.138* GCL + 0.172* GCW

CONCLUSION

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.

One of the first metric studies conducted on the variation of the human scapula was published in 1887 by a medical professor named Thomas Dwight. Dwight collected statistics on scapular indices for people of different ancestries, Native American, White European, and Black African. The two scapular indices were defined as the breadth of the scapula and the infra-spinous index.[10]

In 1956, Bainbridge and Genovese-Tarazaga[11] examined human scapulae for differences related to sexual dimorphism. The results showed that the breadth of the glenoid fossa, the maximum breadth of the scapula, and the maximum length of the scapula are good discriminators in sexual dimorphism. The breadth of the glenoid cavity was a significant variable for estimating sex from the scapula.

In 1994, Di Vell1[12] and colleagues used a contemporary Italian skeletal population and measured seven areas of the scapula to examine sexually dimorphic traits. The researchers conducted multivariate discriminate function analyses on the three most sexually dimorphic measurements (maximum distance between the acromion and coracoid, maximum length of the coracoid, and length of the glenoid cavity) and achieved an accuracy rate of 95% on classifying an individual as either male or female.

Prescher and Klumpen (1995)[13] examined the total area of the glenoid cavity and its relationship to estimating sex from human skeletal remains. The researchers found that glenoid cavities larger than 9.57 cm would be estimated as male and scapulae smaller than 6.83 cm would be estimated as female. The researchers suggested that those individuals who fell between 6.83 cm and 9.57 cm be classified as indeterminate. Murphy (2002)[14] and Ozer and colleagues (2006)[15] used scapular measurements and statistical analyses to develop estimation of sex methodologies for unknown individuals. Murphy (2002) used a prehistoric New Zealand population and Ozer and colleagues (2006) used a medieval bone collection from East Anatolia. All studies employed the length and breadth of the glenoid cavity but Ozer and colleagues (2006) also used the maximum length and breadth of the scapula. The research concluded that high accuracy rates for estimating sex were population specific.

Macaluso (2010)[16] measured the height and breadth of the glenoid cavity by using a standard sliding caliper. He reported that the measurements obtained by the two techniques, i.e. digital photographs and sliding caliper measurements were not statistically different. Frutos (2002)17 used a contemporary Guatemalan population, employed the length and breadth of the glenoid cavity and concluded that high accuracy rates for estimating sex were population specific. Dabbs and Moore-Jansen (2010) 18 developed and tested the five- and two-variable models against scapular measurements of contemporary cadaveric sample of unknown ancestry, the accuracies of the five variable and two-variable models in identifying the sex of an individual ranged from 71.4% to 88.9%

In conclusion, in forensic anthropological cases in which the skull and pelvic bones are fragmentary or missing, sex can be assessed with a high degree of accuracy using other regions of the skeleton. The present study has confirmed that the accuracy of sex determination using scapular measurements of the can be improved by deriving a discriminant function.

Present study shows, the most discriminating variables included in the stepwise analysis are Maximum scapular breadth, Glenoid cavity maximum length, Glenoid cavity maximum Breadth with 95% accuracy in males, 96.3% accuracy in females and 95.6% overall accuracy.

In, direct analysis, the single most useful variable was the Maximum scapular breadth with 96% accuracy in males, 86.3% accuracy in females and 91.7% overall accuracy.

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