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Research Article

SEXUAL DIMORPHISM IN HUMERUS: A MORPHOMETRIC STUDY IN THE NORTH INDIAN POPULATION

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ABSTRACT
Determination of sex is vital to medico-legal studies. It is the first step to identify the biological profile of an individual. Humerus has rarely been tapped as a resource to determine sex though it has demonstrated a greater accuracy than other long bones like femur. This study was planned with an objective to set up baseline standards and parameters for determination of sex from humerus. 294 humeri were studied for maximum length of bone, vertical diameter of head, epicondylar breadth, maximum and minimum midshaft circumference. All parameters were analysed statistically using student t test, Hotelling t test for multivariate analysis and discriminant function analysis. The difference between males and females was highly significant for all parameters. Using discriminant function analysis, 95% bones could be correctly classified into male and female. Vertical diameter of head was the single best parameter. Anthropometric measurements are a very useful tool to establish the identity of an individual from the skeletal remains. Sexual dimorphism is exhibited by various parameters of humerus and hence humerus can be used as one of the bones to determine the sex from skeletal remains.

Keywords: *Sexual Dimorphism, Morphometric, Humerus, Vertical Diameter of Head, Epicondylar Breadth, Discriminant Function Analysis*

INTRODUCTION
The determination of sex is a very important component of any human skeletal analysis. Sex estimation in a complete human skeleton is usually easy by the observation of morphological traits (Patil *et al.*, 2011). If the whole skeleton is available, there should be no difficulty in arriving at an accurate diagnosis of sex, but when only a part of the skeleton is available, it poses increasing difficulty in assessment (Reddy *et al.*, 2014). Once the skeletal remains are uncovered, anthropologists initially aim to reconstruct the biological profile of the person which includes sex, age and height estimation (Dibennardo and Taylor, 1982). Sex determination is one of the first and basic steps of assessment because subsequent methods of age and stature determination are highly sex dependent (Ross and Manneschi, 2011). The general anatomical regions used for sex determination are the pelvic girdle, the skull, and long bones. Many times the pelvis, skull or other body parts that point to fairly accurate conclusions regarding sex may be absent. Therefore, it is necessary to formulate parameters for other bones especially long bones that are frequently found in the collection (Devi *et al.*, 2013).
Skeletal remains can be used to infer the subject's sex via two methods, morphological and anthropometric. Morphological methods are based on the examination of bones and are very important for a preliminary sex assessment. The second approach is based on anthropometric analysis which relies on the bone measurements.
The analysis of DNA is the most reliable method for sex determination but it is also the most expensive and time consuming method, which can also be hindered by local conditions (Basic *et al.*, 2013).
Determination of sex from the skeleton is vital to medicolegal investigations. There is no longer any question that populations differ in size and proportions and these differences affect the metric assessment of sex (Wu, 1989). Since the osteometric methods for the determination of sex are population specific, researchers from around the world have conducted studies to establish group specific standards of assessment.
Long bones alone can be used to predict the sex with an accuracy of 80% (Krogman, 1986). Muscle attachments tend to be larger in males than females, and long bones tend to be longer and more robust in

males than females. However, because of the variation in the activities performed by each sex, the possibility that some females may develop larger muscle attachments than males, and variation in height within populations, long bone morphology is not always reliable for use in sex determinations. In such instances, the use of osteometry is often preferred (Iscan *et al.,* 1998). The femur is the most studied of all human long bones (Kranioti *et al.,* 2009).

The humerus has rarely been tapped as a site for sex determination, though it has often demonstrated an even greater accuracy than other long bones such as femur (Wu, 1989). The main aim of this study was to test if the humeral measurements were a reliable sex indicator and also to develop baseline parameters for sexual dimorphism in humerus for the North Indian population.

MATERIALS AND METHODS

The present study was carried out on 294 humeri of known sex (212 male and 82 female). Dry adult bones were included in the study whereas deformed, damaged or broken bones were excluded from this study. Measurements were taken using an osteometric board and vernier callipers. Following parameters were measured for each bone.

- ***Maximum Length of Humerus (MLH):*** The direct distance from the most superior point on the head of the humerus to the most inferior point on the trochlea.
- ***Vertical Diameter of the Head of Humerus (VDH):*** The direct distance between the most superior and inferior points on the border of the articular surface of the head.
- ***Epicondylar Width of the Humerus (ECB):*** The distance between the most laterally protruding point on the lateral epicondyle and the corresponding projection on the medial epicondyle.
- ***Maximum Mid Shaft Diameter:*** The maximum diameter of the midshaft.
- ***Minimum Mid Shaft Diameter:*** The least diameter of the midshaft (Basic *et al.,* 2013).

All parameters were measured in centimetres (cms), noted, tabulated and analysed statistically. Statistical tests used were student's t test, Hotelling t test for multivariate analysis and discriminant function analysis.

The main analytic approach is based on discriminant function analysis, which attempts to classify subjects into each of the sexes, by using one or more parameters (Basic *et al.,* 2013).

RESULTS AND DISCUSSION

Two hundred ninety-four humeri of known sex were studied for various parameters to find out the presence of sexual dimorphism. There were 212 male bones and 82 female bones.

Table 1: Descriptive Analysis of Different Parameters in Males and Females

	Maximum Length		**Vertical Diameter of Head**		**Epicondylar Width of the Humerus**		**Maximum Mid Shaft Diameter**		**Minimum Mid Shaft Diameter**	
	M*	**F***	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Mean (cm)	33.11	29.68	4.50	3.81	5.98	5.17	2.11	1.75	1.80	1.43
S.D.†	1.69	1.29	0.20	0.27	0.36	0.28	0.18	0.12	O.16	0.08
p	< 0.001		< 0.001		< 0.001		< 0.001		< 0.001	

*M: males; F: females; †S.D.: standard deviation

As is evident from table 1, the mean values for all parameters are greater in males as compared to females. Using student's t test, it was found that this difference in the mean values of males and females is highly significant for all parameters. The standard deviation is also higher in males for all parameters except vertical diameter of head. This denotes that males exhibit more variability for all the parameters except vertical diameter of head where greater variability was observed in females.

On using the Hotelling t test for multivariate analysis, the calculated variance at $F_{5\ 294}$ is 133.0, which is highly significant with $p < 0.001$.

Using discriminant function analysis, the best parameter with maximum accuracy of classification was vertical diameter of head with a percentage of 89.8%. When two parameters were taken together i.e. vertical diameter of head and epicondylar breadth, 94% bones could be classified correctly. Considering all the five parameters together, 95% bones could be correctly classified into males and females.

Determination of sex is an integral first step in development of the biological profile in human osteology (Reddy *et al.,* 2014). However, standard approaches do not always meet the need of crime or death scenes, especially when highly decomposed or skeletonised cadavers are concerned (Kranioti *et al.,* 2009; Kranioti and Tzanakis, 2015). Identification of sex from skeletal remains is of great medico-legal and anthropological significance. The first and most vital biological characteristic under consideration is sex since it reduces the number of possible matches in the population by 50% (Wu, 1989; Rios, 2005). Sex determination of skeletons has always been of importance in the field of Forensic and Physical Anthropology, Bioarchaeology, Palaeodemography and Anatomy (Devi *et al.,* 2013). Morphological methods are very important for a preliminary sex assessment, they additionally rely on the experience of the examiner and are therefore rather subjective and unreliable (Basic *et al.,* 2013). Hence, osteometric methods have been developed. The most popular method employed in osteometry is discriminant function analysis which is based on the development of effective discriminant functions for the separation of groups (e.g. males and females) achieving high accuracies (Kranioti and Tzanakis, 2015).

Pelvis and skull were traditionally considered as the most dimorphic elements of the skeleton; hence many studies in the past are focussed on producing sex estimation methods from these bones. Lately, several postcranial elements have proven to be more effective predictors than skull (France, 1998; Kranioti and Tzanakis, 2015). Of the human skeleton, the humerus often remains in good condition and is especially favourable for metric sex determination (Lee *et al.,* 2014). Hence, this study was undertaken to produce population specific standards to determine the sex from the humerus in the North Indian population.

In the present study all the parameters considered showed a highly significant difference between males and females. The mean values were found to be more in males as compared to females. These findings are in conformity with findings of previous authors who also concluded that mean values were higher in males as compared to females (Reddy *et al.,* 2014; Devi *et al.,* 2013; Basic *et al.,* 2013; Kothandaraman, 2014).

Sexual dimorphism can be explained on the basis of the fact that during adolescence, cortical bone is laid down at a greater rate in males than females. In males, a larger proportion of growth is at subperiosteal surface, so male tubular bone increase their circumference more than those of females during adolescence (Gran, 1970). Most sexually dimorphic features of the human skeleton develop as secondary sex characteristics during adolescence (Rogers, 1999). Testosterone brings about a direct increase in size and mass of muscles and bones (Devi *et al.,* 2013). Stature based sexual dimorphism peaks in societies that are at the extremes of protein consumption, both high and low (Kothandaraman, 2014). Shape measurements are of major significance for the correct diagnosis of sex, because the functional demands of weight bearing and musculature affect the circumferential measurements more than the length (Dibennardo and Taylor, 1982).

While doing osteometric studies, sexual dimorphism is seen more prominently in widths, diameters, circumferences and areas as compared to bone lengths. This may be because differential cortical remodelling has its maximal impact on breadth and circumference measurements. Also length of a bone, stops to grow with epiphyseal fusion, width-wise growth continues potentially unlimited. The cortical remodelling that continues throughout life of an individual bearing the effect of physical activities related to occupation, nutrition etc. (in the period of late growth) may result in subsequent dimorphism in diameters and width measurements (Rios, 2005; Thakur *et al.,* 2015).

Using discriminant function analysis, 95% bones could be correctly classified. When considering one function at a time, vertical diameter of head was the most accurate parameter followed by epicondylar breadth.

The most effective single dimension, as determined by the direct discriminate analysis, was the vertical head diameter in the Chinese (81%) and epicondylar breadth in the Japanese and the Thai populations (90% and93% respectively) (Iscan *et al.,* 1998). It has been reported that the greatest dimorphism is seen in the proximal and distal bone dimension in a study on the north eastern Chinese population. The humeral head diameter was the most common sex discriminator (84%) (Wu, 1989). An accuracy of 92.3% in determining the sex was found in a study on 168 left humeri and the single most effective dimension was the vertical head diameter of the humerus (89.9%). The length of the humerus, among the long bones of the human body, is a good predictor, but the vertical diameter of head of this bone is also an accurate predictor of gender.

The value for humerus breadth is a better predictor than the value of humerus length but the best predictor for sex determination is vertical diameter of head (87.0%) (Ross and Manneschi, 2011; Kranioti *et al.*, 2009; Kranioti and Michalodimitrakis, 2009; Lee, 2014; Rios, 2005). This is in concordance with our study. Proximal epiphysis has given more accurate results than distal epiphysis (Devi *et al.*, 2013) which is similar to our study. This is opposite to France's results who concluded that distal measurements are likely to reflect more sexual dimorphism in the humerus because this bone is subjected to greater functional or occupational stress (Wu, 1989).

When two parameters were taken together i.e. vertical diameter of head and epicondylar breadth, 94% bones could be correctly classified. On considering all five parameters together, this increased to 95%. Hence, more the number of parameters considered, more is the probability of correct classification. Many other researchers have concluded the same (Dibennardo and Taylor, 1982; Iscan *et al.,* 1998; Thakur *et al.,* 2015).

In cross validation tests, classification accuracies decreased in all cases where a formula from one group was applied to another (Iscan *et al.,* 1998). Hence this study provides metric standards of assessment of sex from humerus in the North Indian Population.

Conclusion

Anthropometric measurements are a very useful tool to establish the biological profile of an individual from the skeletal remains. Humerus has rarely been tapped as a bone for sex determination though it often demonstrates a greater accuracy than other long bones. The mean values are greater in males as compared to females. These differences are more prominent in widths and diameters as compared to lengths. The parameter with greatest accuracy in determining the sex is the vertical diameter of the head. It is always better to consider multiple parameters as the accuracy of correct classification increases with multiple parameters.

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