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PAPER

ANTHROPOLOGY

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A Study of Sexual Dimorphism in the Femur Among North Indians*

ABSTRACT: Determination of sex of unknown skeleton remains is the most important step in the identification process. Racial and regional differences in the populations create and maintain specificity in their dimorphic characteristics. Moreover, considering continued secular changes in the population structure, constant revision of osteometric standards becomes mandatory. In an effort to establish osteometric standards for the femur of contemporary North Indian populations, 122 adult femora of known sex (M: 94; F: 28) were collected in the Department of Forensic Medicine, IMS, BHU, Varanasi. Eight standard parameters were measured and analyzed by discriminant function analysis using SPSS 16. The accuracy of sex prediction ranged from 70.5% to 83.6% with single variables. In stepwise analysis, epicondylar breadth, proximal breadth, and antero-posterior diameter of the lateral condyle were found to be the most discriminating variables providing an accuracy of 90.2%. The results clearly indicate the importance of the ends of femur in the determination of sex.

KEYWORDS: forensic science, sexual dimorphism, femur, osteometry, North Indian population, discriminate function analysis

With increasing levels of violence, accidents, and disasters in India, encountering human skeletal remains has become a common sight. The role of the forensic anthropologist in these circumstances is to assist with the identification of human remains by creating a biological profile through the analysis of sex, ancestry, age, and stature. Among them, sex determination is considered as the first and most important step as the subsequent methods of age and stature estimation are highly sex dependent (1–3).

Sexual dimorphism can also be recognized as a consequence of three factors, namely reproductive function as expressed in the morphology of the pelvis, genetic differences that influence body size and proportions, and lastly differences in musculature between the sexes (4). Unfortunately, most of the obvious characters remain localized in limited bony structures such as the pelvis or skull. By virtue of these characteristics, these bones are considered to be the most dimorphic parts of human skeleton (2,5,6). However, in their absence, sex must be determined from other available bones of the skeleton as finding decapitated body or fragmented parts of a skeleton is not uncommon. In addition, recovering considerable number of isolated limbs in cases of mass disasters requires development of useful and precise dimorphic standards for other skeletal parts. Long bones from upper and lower extremities have especially been found useful because of the ease of defining measurements, which makes them favorable for metric analysis (7,8). Dimorphism in long bones is generally reflected by the larger size and robusticity because of stronger muscular attachment in men (2,9).

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Sexual dimorphism of the femur has been very well studied in different populations with diverse and interesting results (7,10–29). Owing to its robustness and strength, it is most likely to resist environmental effects and animal activities and hence frequently recovered intact. Some researchers have stated that the femur is as diagnostic for sex determination as the skull and even in some cases providing better accuracy than the complete skull (13). As the magnitude of sex-related differences depends on the particular regional population, skeletal biologists have long recognized that each population requires its own specific standards for accurate determination of sex, and caution must be taken when applying these standards to other populations (11,13,30,31). India, a country harboring nearly all types of geographical and climatic conditions, is characterized by wide variation in anthropometric dimensions among its population types. This necessitates the study of sexual dimorphism in a more localized way to establish specific osteometric standards for different regions in India. Although researchers have focused on this issue and have been involved in developing standards (14–16,20,32–37), the field remains in its nascent state. Besides, metric analysis has become the most preferred technique for identification of sex from skeletal materials because of its objectivity, reproducibility, and low level of inter- and intra-observer error. Therefore, the purpose of this study is to establish osteometric standards for sex determination in a North Indian population and to develop mathematical functions to be applied on fragmentary femora, using discriminant function analysis.

Materials and Methods

A total of 122 nonpathological femora of known sex (94 men and 28 women) and age ranging from 25 to 67 years were collected in the Department of Forensic Medicine, BHU, Varanasi, from January 2007 to December 2009. The bones were macerated

in water, cleaned of adhering soft tissue, and air-dried. The following measurements of the femur were taken:

Maximum length (ML)—the straight distance between the highest point of the head and the deepest point on the lateral medial condyle (38,39).

Proximal breadth (PB)—the projective distance from most medially placed point on the head to the most laterally placed point on greater trochanter (40). The femur is placed on the osteometric board on its posterior surface with most medial point of head touching the long wall. The moveable cross piece touches the most laterally projected point on the greater trochanter. The shaft of the bone lies parallel to the long wall.

Vertical diameter of head (VDH)—straight distance between the highest and the lowest point of the head (38).

Transverse diameter of head (TDH)—straight distance between the most laterally projected points perpendicular to the VDH (38).

Vertical diameter of neck or supero-inferior diameter of neck (VDN)—minimum diameter of femoral neck in a plane perpendicular to the head–neck midline (41).

Epicondylar breadth (EB)—maximum distance between two most projecting points on lateral and medial epicondyles (38).

Antero-posterior diameter of lateral condyle (APDLC)—projected distance between the most posterior point on the lateral condyle and the lateral lip of the patellar surface taken perpendicular to the axis of the shaft (40). The bone is placed vertically on the horizontal surface in such a manner that the two condyles, the short vertical wall and the moveable cross-piece, touch the most projected point on the patellar surface of lateral condyle.

Antero-posterior diameter of medial condyle (APDMC)—projected distance between the most posterior point on the medial condyle and the medial lip of the patellar surface taken perpendicular to the axis of the shaft (40). Taken in the same manner as for APDLC.

ML, PB, APDLC, and APDMC were measured using Reid's osteometric board in millimeters. All other parameters were measured using digital sliding calipers in millimeters. Left femora were measured but replaced by the right if left was not available.

Statistical Analysis

The data were subjected to SPSS 16 discriminant function analysis (SPSS Inc., Chicago, IL). Univariate analysis of variance (ANOVA) was used to measure the variation within and between the groups. Stepwise discriminant analysis was applied to know the variables that provided best discrimination of sexes. Cross-validation using the leave-one-out procedure was performed to test the accuracy rate of the original sample. This method successively classifies all cases but one to develop a discriminant function and then categorizes the case that was left out. This process is repeated with each case left out in turn. Demarking points were calculated using the formula mean ± 3 × SD, where mean + 3 × SD gives the maximum value, and mean – 3 × SD gives the minimum value. Here, the demarking point for men is the maximum value of women (above which no female femur can be found) and that for woman is the minimum value of men (below which no male femur can be found) (42).

Results

Table 1 presents the means and standard deviations along with the results of univariate ANOVA for each independent variable and their predictive accuracies. As expected, all the measurements were significantly higher in men than in women. This is indicated by Wilk's lambda that is significant by the *F*-test for all the variables. The results of the stepwise analysis are shown in Table 2. Of the eight variables entered into the function, three variables—EB, APDLC, and PB—were selected. The Wilk's lambda shows the percentage contribution of each measurement and determines the order of variables to enter the function. Lambda ranges between 0 and 1. The values close to 0 indicate that the means of two groups are different, and values close to 1 indicate that there is no difference between the two groups. Here, the EB is the first measurement to be selected by stepwise discriminant analysis. Once the

TABLE 2—*Results of stepwise discriminant analysis.*

Step Variable Entered	Wilk's Lambda	Equivalent *F*-Ratio	Degrees of Freedom
All variables			
EB	0.568	91.241	1,120
APDLC	0.541	50.398	2,119
PB	0.520	36.246	3,118
Variables from proximal end			
PB	0.634	69.214	1,120
TDH	0.600	39.628	2,119
Variables from distal end			
EB	0.568	91.241	1,120
APDLC	0.541	50.398	2,119

EB, epicondylar breadth; PB, proximal breadth; TDH, transverse diameter of head; APDLC, antero-posterior diameter of lateral condyle.

TABLE 1—*Means, standard deviations, and results of ANOVA with predictive accuracies of each variable.*

	Male (n = 94)		Female (n = 28)				Accuracy	
Parameters*	Mean	SD	Mean	SD	Wilk's λ	*F*-value†	M (%)	F (%)
ML	435.5	26.26	404.1	20.55	0.780	33.79	70.2	71.4
PB	85.72	5.83	75.29	5.80	0.634	69.21	83.0	71.4
VDH	43.77	2.70	39.40	2.48	0.672	58.52	80.9	85.7
TDH	43.86	2.75	39.52	2.53	0.684	55.33	80.9	85.7
VDN	29.96	2.54	26.48	1.60	0.720	46.68	78.7	85.7
EB	76.83	4.19	68.28	4.05	0.568	91.24	85.1	78.6
APDLC	60.27	3.75	55.56	3.36	0.771	35.59	72.3	78.6
APDMC	59.38	3.29	54.05	3.19	0.687	54.66	80.9	78.6

ML, maximum length; PB, proximal breadth; VDH, vertical diameter of head; VDN, vertical diameter of neck or supero-inferior diameter of neck; TDH, transverse diameter of head; EB, epicondylar breadth; APDLC, antero-posterior diameter of lateral condyle; APDMC, antero-posterior diameter of medial condyle.

*All the measurements are in millimeters.

†Significant at $p < 0.000$.

variables that provided maximum discrimination were obtained, various other functions were generated by using direct discriminant analysis. This was done keeping in mind the various fragmentary conditions of femora encountered in forensic cases. Here, special attention was given to develop functions from the ends of femur useful for determination of sex when only one end is available. The variables of the proximal end and distal end were subjected separately to stepwise analysis, the results of which are given in Table 2.

Table 3 lists all the functions, coefficients, sectioning points, and accuracies from the original and cross-validated samples. The raw (unstandardized) coefficient is used to calculate the discriminant scores for all functions. The standardized coefficient indicates the relative contribution of each dimension to the function. As in function 1, EB contributes most to the function. The structure coefficients show the correlations of each variable with each discriminant function. In functions 2, 4, and 5, PB has the highest correlation. A discriminant score is obtained by multiplying each dimension with its raw coefficients and adding them together along with the constant. Sectioning points are calculated as the average of male and female centroids. If the score is greater than the sectioning point, the individual is considered male, while a lower score indicates a female.

Table 4 shows the demarking points for each variable as it is easier to compare the dimensions of the analyzed specimen to the demarking point and identify its sex. The percentage of bones correctly identified using demarking points is also mentioned.

Discussion

The results of the present study clearly reaffirm the marked sexual dimorphism exhibited by femur. The prediction accuracies for determination of sex using the femur ranged from 70.5 to 83.6% in the North Indian population. On performing the stepwise procedure, EB, APDLC, and PB were selected producing higher

TABLE 4—*Demarking points for single variables.*

Parameters	Male	Female	Percentage Beyond Demarking Point	
			Male (%)	Female (%)
ML	>465.65	<356.72	14.89	0
PB	>92.69	<68.23	7.1	8.5
VDH	>46.84	<35.67	8.5	14.28
TDH	>47.11	<35.61	2.1	14.28
VDN	>31.28	<22.34	31.9	0
EB	>80.43	<64.26	21.3	14.28
APDLC	>65.64	<49.02	2.04	7.14
APDMC	>63.62	<49.51	14.28	7.14

ML, maximum length; PB, proximal breadth; EB, epicondylar breadth; VDH, vertical diameter of head; TDH, transverse diameter of head; VDN, vertical diameter of neck or supero-inferior diameter of neck; APDLC, antero-posterior diameter of lateral condyle; APDMC, antero-posterior diameter of medial condyle.

TABLE 3—*Canonical discriminant function coefficients and accuracies from original and cross-validated samples.*

Function and Variables	Raw Coefficients	Standard Coefficients	Structure Coefficients	Sectioning Points	Average % Accuracy	
					Original	Cross-Validation
1. PB	0.068	1.139	0.908	−0.612	90.2	90.2
EB	0.274	0.394	0.791			
APDLC	−0.167	−0.612	0.567			
(Constant)	−16.281					
2. PB	0.116	0.676	0.931	−0.520	86.9	82.0
TDH	0.165	0.446	0.832			
(Constant)	−16.743					
3. EB	0.305	1.268	0.929	−0.599	86.9	86.9
APDLC	−0.204	−0.747	0.719			
APDMC	0.106	0.355	0.580			
(Constant)	−16.947					
4. ML	0.091	0.229	0.685	−0.499	83.6	82.0
PB	0.148	0.860	0.981			
(Constant)	−16.201					
5. PB	0.109	0.634	0.934	−0.519	82.0	83.6
VDH	0.160	0.425	0.859			
ML	0.026	0.066	0.652			
(Constant)	−17.057					
6. EB	0.066	0.382	0.893	−0.623	90.2	88.2
APDLC	−0.214	−0.786	0.558			
APDMC	0.099	0.330	0.691			
PB	0.246	1.023	0.778			
(Constant)	−16.918					
7. PB	0.059	0.341	0.969	−0.575	85.2	83.6
EB	0.177	0.736	0.844			
(Constant)	−18.120					
8. EB	0.240	1	1	−0.557	83.6	83.6
(Constant)	−18.004					
9. VDH	0.377	1	1	−0.446	82.0	82.0
(Constant)	−16.129					
10. TDH	0.370	1	1	−0.433	82.0	82.0
(Constant)	−15.861					
11. PB	0.172	1	1	−0.485	80.3	80.3
(Constant)	−14.307					

ML, maximum length; PB, proximal breadth; EB, epicondylar breadth; TDH, transverse diameter of head; VDH, vertical diameter of head; APDLC, antero-posterior diameter of lateral condyle; APDMC, antero-posterior diameter of medial condyle.

accuracy of 90.2% (man: 91.5% and woman: 85.7%). Of the several combinations made during direct discriminant analysis, none could provide accuracy more than 90.2% (except function 6 using four variables) showing that the best combination to obtain maximum separation of sexes was EB, APDLC, and PB. Reliability of sex determination depends on the magnitude of sexual dimorphism exhibited in a population, availability of skeletal elements, anatomical areas of a bone preserved, and degree of preservation (2,15). In the present study, functions are developed for proximal and distal ends of the femur, highlighting the emphasis given by previous workers on the ends of long bones (7,11,13,29). Stepwise analysis of variables from the proximal end provided an accuracy of 86.9% using PB and TDH. Similar accuracy is obtained when variables from the distal end were subjected to stepwise analysis selecting EB and APDLC (Table 2). The variables suited most for identifying sex vary in different populations demonstrating the population-specific nature of sexual dimorphism. Yet, studies have revealed that the ends of the femur appear to be a better indicator of sex in most populations sampled. Wu (23) studied 17 anthropometric measurement of the femur in Chinese and found the maximum head diameter to be the best single variable for the determination of sex. Slaus (11), while studying the femora from medieval archaeological sites in continental Croatia, showed that the maximum diameter of the head and EB were prominent among the size differences between men and women producing an accuracy of 91.7 and 85.5%, respectively. Similarly, in a Thai sample, the combination of these two variables provided 94.2% accuracy (18). On the other hand, a study on a German sample by King et al. (13) found the midshaft diameter and head circumference to be the best variables, providing accuracy of 91.7%. A comprehensive study by Sakaue (7) investigating sexual dimorphism in long bones from both lower (femur and tibia) and upper extremities (humerus, radius, and ulna) using 47 variables pointed out that breadths of elbow and knee joints were much better discriminators of sex. The fact put forth by researchers that dimorphism is reflected better in width measurements and circumference than in length (18,25,31,43) is well supported in the present study. Here, the breadth measurements are among the highest discriminating variables (Table 1), while the accuracy obtained from ML is lowest (70.5%). This may be due to the differential cortical remodeling that has its maximum impact on breadth and circumference measurements (44). Humphrey (45) observed that the early-growing regions of skeleton are less dimorphic as compared to the later-growing parts. While length of a long bone stops to grow at an earlier age, that is with complete fusion of epiphyseal plates, widthwise growth continues potentially unlimited (46). The cortical remodeling that continues throughout the 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.

In addition, one cannot overlook the significance of single variables, which facilitates quick separation of bones in commingling of bones (e.g., in mass disasters, mass graves, etc.). The femoral head, for this reason, has received most attention because of its substantial durability in forensic as well as archaeological cases, and head diameter is assigned as the best femoral trait for determination of sex (12,16,17,26,47,48). But in the present study, both vertical and transverse diameters of the head produced an average accuracy of 82% using discriminant function analysis. However, most studies on the femoral head have utilized the demarking point method for classifying sex because of its ability to provide 100% accuracy, which is most desirable in medico-legal cases (18,20). Demarking points were calculated for all the femoral measurements in this study.

Another univariate method employed the supero-inferior (vertical) diameter of neck producing an accuracy of 85–90% (22,24,41), which is higher than the present study (80.3%).

One noteworthy point is that the sex-prediction accuracies obtained in the present study are slightly lower than those obtained in most of the previous studies on different populations (7,10–13,16,21,25). This may be due to lower degree of sexual dimorphism exhibited in the North Indian population possibly contributed by existing malnutrition (49,50). However, these differences between populations could also be ascribed to environmental and genetic factors affecting bone growth as well as the result of sample heterogeneity as suggested by Cunha and Van Vark (cf. in [51]). The population (forensic sample) studied here is biologically more heterogeneous because of different socioeconomic levels and nutrition.

Conclusion

In conclusion, the present study fulfills the need to update the osteometric standards that can be used in determining sex, in the identification process, with high accuracy rates for North Indian population. Especially, the functions obtained for the ends of the femur are of much practical use in cases of fragmented femora, as commonly observed in forensic and archaeological contexts. However, caution is necessary in applying these functions, as in the present study, female sample size is small. Collection of more samples is in progress to improve the sex ratio. Also, we are currently in the process of collecting data from additional local populations using new parameters to facilitate a comprehensive analysis of sexual dimorphism in long bones.

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