TECHNICAL NOTE

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Measurements of Ulna—A New Method for Determination of Sex*

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ABSTRACT: Identification of sex from skeleton parts is of paramount importance to medicolegal investigations. The present study makes an attempt to assess sex from the ulna by devising new measurements for fragmentary bones. Dry and adult ulnae (100 male and 60 female) of Madhya Pradesh, India were subjected to three measurements (Olecranon—coronoid angle, length, and width of inferior medial trochlear notch) that were devised specifically for this study. The data were analyzed using discriminant function analysis. Direct analysis using single or multiple variables revealed the Olecranon-Coronoid angle as the best single parameter, yielding 85% accuracy. Measurements of the inferior medial trochlear notch have an additional advantage of being used in fragmentary bone where only the upper end is available. The calibrated discriminant functions correctly classified 90.6% of all males and females in an independent test sample.

KEYWORDS: forensic science, forensic anthropology, sex assessment, ulna, India

Determination of sex from human skeletal remains plays a very important role in establishing the identity of any individual. It is said that a very high prediction accuracy can be reached if a well preserved entire skeleton is available (1). But many times the pelvis, skull, or other bony parts that point to fairly accurate conclusions regarding sex may be absent. Therefore it is necessary to formulate functions for other bones, especially long bones that are frequently found in the collection. The present study has been undertaken to assess sexual dimorphim in an upper limb bone, the ulna. As the fragmentary condition of the bone adds to the problem of sexing, an attempt has been made to devise special measurements for the proximal end of the ulna, which is less prone to destruction with the passage of time and environmental degradation.

As early as 1957 Godycki (2), followed by Maia Neto (3), studied the Sigmoid notch of the ulna and attempted to assess sex on the basis of a groove dividing the notch, a feature which is mostly present in males. The physical dimensions like length, midshaft circumference, width of lower end, and weight were used by Steel (4), Singh et al. (5), and Oliver (6) to discriminate sex. Steel (4) formulated a discriminant formula for the ulna whereas Singh et al. (5) evolved a demarking point for all the parameters to determine sex with 100% accuracy, although the number identified was small.

The aim of this work is to obtain discriminant functions to be applied to fragmentary forensic material based on the different variables that give us high reliability in sex determination. An emphasis is put on taking anthropometric measurements by identifying anatomical landmarks to avoid human error while taking measurements (7).

Materials and Methods

The study was conducted at the Bhopal Medicolegal Institute in Madhya Pradesh, India. Data for the present study is comprised of 160 completely dry adult ulnae; 100 were males and 60 were females. The bones belonged to middle class people who were residents of the state of Madhya Pradesh. Abnormal or pathologically deformed bones were excluded from the present study. The mean age was 45.4 years (ranging from 24 to 62 years) for males and 43.6 years (ranging from 22 to 55 years) for females.

The Medicolegal Institute has a collection of bones from unclaimed specimens and medicolegal cases. A majority of the sample consists of medicolegal specimens. When the bones are sent to the institute for medicolegal opinion, they are first examined then classified, registered, and stored systematically in separate iron boxes.

In a pilot study, measurements of 20 left and 20 right ulnae belonging to 20 individuals were subjected to a paired t-test to study the bilateral difference. As the difference was found to be insignificant at the 0.05 level, the bones of both sides were grouped together. Only one bone of either the left or right ulnae from each individual was included in the sample.

The two linear measurements were recorded to the nearest 0.05 mm using a Mitutoyo Dial caliper.

Olecranon-Coronoid Angle

The ulna was placed with its medial surface in contact with a board designed for the purpose of measuring this angle (Fig. 1). The bone was placed in such a position on the board that the point projecting most posteriorly on the styloid process "D" touched the lateral wall of the board (Fig. 1).

The thread was adjusted to lie parallel to the line joining the upper lip of the olecranon process "A" and the "beak" of the coronoid

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process "B". The angle was measured between the lateral wall of the board as a base, and the thread joining the line AB (Figs. 1 and 2) extended to meet the base line. The angle was measured with a protractor.

Length and Width of the Inferior Medial Trochlear Notch

The ulna was held facing anteriorly and the deepest constriction along the medial and lateral borders of the trochlear notch were labeled medially as "P" and laterally as "Q" (Fig. 3). The highest point on the "beak" of the coronoid process was labeled as "B" and the line along the ridge from the point "B" extending proximally to meet the line PQ at "C" dividing the coronoid articular surface into a larger medial and a smaller lateral part.

The length of the inferior medial trochlear notch was measured with the help of a Dial caliper between the point "C" and the highest point "B" on the coronoid "beak." The width was measured at right angles to the length between "MN"; "N" being the point projecting most medially on the border of trochlear notch on the "Sublime Tubercle" and "M" the line drawn laterally from point "N" meeting the line at right angles.

Apart from the routine statistical analysis i.e., mean, standard deviation, and *F*-ratio, the data were analyzed using SPSS subroutine package. Stepwise discriminant function analysis employing all the measurements was used to select the combination of variables that best discriminates between sexes. Variables alone were subjected to direct analysis to develop formulae to allow sex determination from fragmentary remains. To further test the efficiency of the discriminant functions derived from the previous analysis they were applied to a randomly chosen test group of 68 ulnae (34 males and 34 females). The test group was not a part of the original sample but consisted of bones of the same age group, class, and population as the original one.

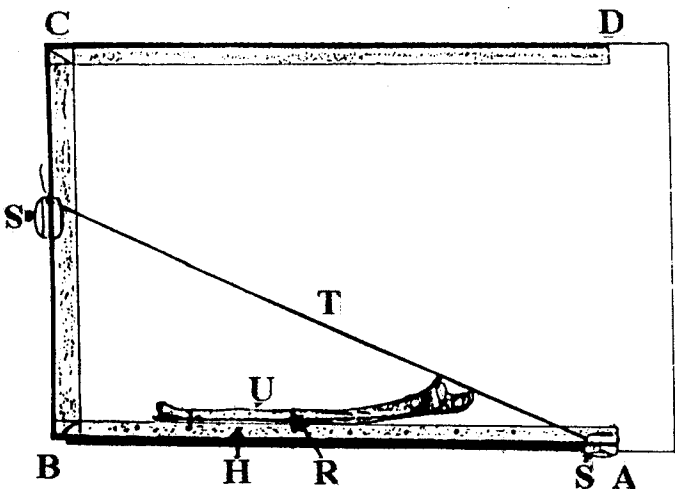

FIG. 1*a—ABCD is a 50 × 30 cm rectangular board. This has been provided with a side wall of 3 cm height on all the sides except for AD. The AB side has been provided with 4 mm diameter holes at 3 cm intervals where the ulna is approximated as shown with the help of a rubber band.*

FIG. 1*b—An enlarged cross section view of the AB wall with a hole through which the method of passing the rubber band holding the bone is shown. H = Holes, R = Rubber band, S = Slider, T = Thread, U = Ulna bone, and W = Wooden stay.*

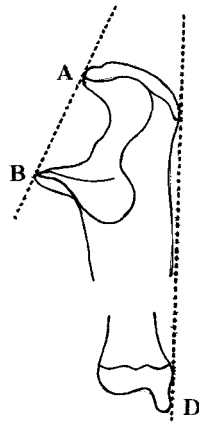

FIG. 2—*Left ulna viewed from a lateral aspect showing the olecranon coronoid angle. The line "AB" joins the apex of projecting a "beak" of processes, olecranon and coronoid are marked "A" and "B" respectively. The bone is aligned with the posteriomost surface of the styloid process "D" touching the horizontal side wall of the board.*

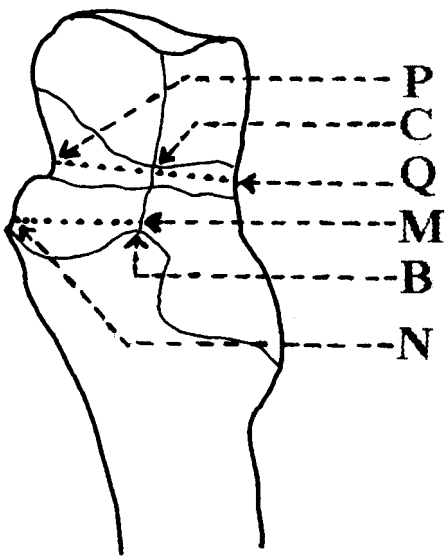

FIG. 3—*Diagram of anterior view of the upper end of the left ulna—indicating the various landmarks for measurements.*

Results

Table 1 presents the simple descriptive statistics of the data for the three measurements of ulna. The male ulnae exhibit greater dimensions than the female ones and the sex differences, using F-ratio, are highly significant ($P < 0.001$) for all the measurements.

The results of the stepwise discriminant function analysis appear in Table 2. All the measurements entered into the function were selected. In this case, the F-ratio gives the quantum of variation that exists within and between the sexes and the significance level of the variance. Wilks' Lambda calculates how useful a given vari-

TABLE 1—*Routine statistical analysis.*

Variables (mm)	Males ($N = 100$) Mean	Males ($N = 100$) S.D.	Females ($N = 60$) Mean	Females ($N = 60$) S.D.	*F*-Ratio†	Sex Diff. in Stand. Unit‡
Olec.-Cor. angle*	22.26	3.47	14.73	4.46	141.90	1.96
Length IMTN	16.01	1.40	14.39	0.98	62.30	1.30
Width IMTN	14.10	1.24	12.47	1.59	52.02	1.89

* in degrees.
† All significant at $P < 0.001$ level.
‡ = Sex difference in mean/Pooled standard deviation.
Olec.-Cor. angle = Olecranon coronoid angle.
IMTN = Inferior medial trochlear notch.

TABLE 2—*Summary of stepwise discriminant function analysis.*

Variables Entered	Wilks' Lambda	Equivalent *F*-Ratio	Degrees of Freedom
Olec.-Cor. angle	0.52679	141.9280	1158
Width of IMTN	0.44352	98.4938	2157
Length of IMTN	0.43918	66.4031	3156

able is in the stepwise discriminant function. Table 3 presents all the functions and their coefficients. Values of group centroids are also given. Table 4 presents the matrices for accuracies of prediction for each function. The single best discriminator is the Olecranon Coronoid angle giving 85% accuracy. When two variables (Olecranon coronoid angle and length of inferior medial trochlear notch) were combined into a function, the accuracy showed a considerable increase (90.6%). The measurements of the inferior medial trochlear notch show comparatively low accuracy but when combined into a function, the accuracy registered a slight increase (75.6%). When all three variables are included in the function, it could correctly assign sex to 96% of males and 80% of females.

The discriminant functions of the original sample were applied on the test cases; these results are presented in Table 5. The success rate of identification was higher in most of the functions compared to the original sample (Table 4). This may be because of less variation, and that the sex difference in the standard unit is higher in the test group as compared to the original sample (2.6761, 2.2679 and 1.9755 for olecranon-coronoid angle, length and width of inferior medial trochlear notch respectively).

TABLE 3—*Canonical discriminant function coefficients.*

Variables in Function	Unstand.	Stand.	Struc.	Group Centroids
Olec.-Cor. Angle	0.25847	1.00000	1.00000	M = 0.97313
constant	−4.78040			F = −0.97313
Length IMTN	0.79317	1.00000	1.00000	M = 0.64247
constant	−12.05618			F = −0.64247
Width IMTN	0.72275	1.00000	1.00000	M = 0.58904
constant	−9.60173			F = −0.58904
Olec. Cor. angle	0.21416	0.82855	0.84613	M = 1.14892
length IMTN	0.42297	0.53327	0.56058	F = −1.14892
constant	−10.39003			
Olec. Cor. angle	0.22249	0.86078	0.95842	M = 1.01534
width IMTN	0.21799	0.30161	0.58026	F = −1.01534
constant	−7.01095			
Length IMTN	0.54156	0.68279	0.81738	M = 0.78715
width IMTN	0.42759	0.59161	0.74695	F = −0.78715
constant	−13.91224			
Olec. Cor. angle	0.20054	0.77588	0.83871	M = 1.15913
length IMTN	0.39457	0.49746	0.55566	F = − 1.15913
width IMTN	0.10367	0.14344	0.50778	
constant	−11.08371			

TABLE 4—*Percentage of correct group membership.*

Functions	Males (100)	Females (60)	Average
Olec. Cor. angle	89.0 (89)	78.3 (47)	85.0
Length IMTN	68.0 (68)	83.3 (50)	73.8
Width IMTN	72.0 (72)	68.3 (41)	70.6
Olec. Cor. angle+ length IMTN	95.0 (95)	83.3 (50)	90.6
Olec. Cor. angle+ width IMTN	91.0 (91)	76.7 (46)	85.6
Length IMTN+ width IMTN	76.0 (76)	75.0 (45)	75.6
Olec. Cor. angle+ length IMTN+ width IMTN	96.0 (96)	80.0 (48)	90.0

TABLE 5—*Percentage of correct group prediction for test sample.*

Functions	Males (34)	Females (34)	Average
Olec.-Cor. angle	91.2 (31)	82.4 (28)	86.8
Length IMTN	70.6 (24)	79.4 (27)	75.0
Width IMTN	73.5 (25)	70.6 (24)	72.1
Olec. Cor. angle+ length IMTN	97.1 (33)	88.2 (30)	92.7
Olec. Cor. angle+ width IMTN	94.1 (32)	76.4 (26)	85.3
Length IMTN+ width IMTN	76.4 (26)	73.5 (25)	75.0
Olec. Cor. angle+ length IMTN+ width IMTN	97.1 (33)	79.4 (27)	88.2

Discussion

In the method of measuring the olecranon-coronoid angle, we affixed the posterior border and styloid process of the ulna to the side wall of the ulna board, permitting the proximal end to be elevated to its free position. The proximal and distal medial surfaces of the ulna lie in contact along the flat surface of the board. We have no literature on any similar type of work and as such there can be no comparative discussion on the results. The results show high statistical significance with males exhibiting an 8.26° greater angle than females. When the accuracy of a single variable was considered, the Olecranon-Coronoid angle could classify the maximum number of bones with a prediction accuracy of 85%.

The conventional anthropometric method of measuring (8,9) this angle is only different as far as the base line is concerned. In the conventional method, the long axis of the ulna is extended to meet the line joining the tips of olecranon and coronoid process. For the purpose of screening, we took some measurements as per the traditional anthropometric method but the results were not statistically significant and therefore we devised the method described and the results are highly significant.

Length and Width of the Infero-Medial Trochlear Notch

The olecranon and coronoid process that forms the articular surface of the trochlear notch are actually the superior and inferior ar-

ticular surface of the trochlear notch, respectively. These are divided by a vertical ridge into medial and lateral parts. We are actually naming and concerned with the inferior medial articular facet, which is the medial articular surface of coronoid process. Length and width of inferior medial trochlear notch was measured and when a test of significance was applied, it yielded highly significant differences (Table 1). Both of these measurements have not been used for sexual dimorphism by earlier researchers. An advantage of measuring the length and width of inferior medial trochlear notch for sex determination is that the measurements can be taken on fragmentary bone where only the upper end is available. When the measurements were combined into a function during discriminant analysis, together they could classify 76% of male and 75% of female bones.

Though our conclusions must be limited to the population sampled, the results show that the measurements on the ulna might prove equally effective in sexing other populations as well.

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