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TECHNICAL NOTE

ANTHROPOLOGY

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Sex Estimation from the Mastoid Process Among North Indians*

ABSTRACT: Determination of sex from fragmentary crania is a critical problem in forensic anthropology. Osteometric analysis of mastoid can serve forensic anthropologists better in sex identification by virtue of the noticeable dimorphic characteristics. The present study aims to develop population-specific, sex-differentiating anthropometric standards for the mastoid process of North Indian skulls. Eight parameters of the mastoid region were measured on 138 adult crania (M/F 104:34, 22–65 years) and analyzed using SPSS 16.0. All parameters showed significant sexual dimorphism ($p < 0.000$). In stepwise analysis, asterion-mastoidale and mastoid breadth have provided an accuracy of 87%. Receiver operating characteristic curves were obtained for each variable to observe their overall performance in sex determination. Posterior end of incisura mastoidea-depression of suprameatal triangle was found to be the best variable with maximum area under curve and highest predictive accuracy (82.6%).

KEYWORDS: forensic science, anthropology, dimorphism, mastoid process, Indian population, receiver operating characteristic curve

The highest accuracy in sex determination is achieved when the complete skeleton is available (1). It is often difficult to identify sex in fragmented remains, as no isolated characteristic of any particular bone can perfectly determine the sex of a skeleton. Therefore, it becomes essential then to observe the sex-specific characteristics from as many bones as possible.

The skull is a very useful alternative to determine sex in the absence of the pelvis because of its prominent morphological differences between the two sexes, attributed to different genetic makeup as well as the acquired changes that occur during pubertal growth (2,3). Metric studies have yielded useful results and have proved to be of great help in cases of fragmentary skulls (4,5). Practical relevance of these studies enhances in situations of either intentional destruction of skull or also where ongoing taphonomic processes affect the intactness of the skull.

In many such instances, attempts have been made for sex assessment from isolated parts of the skull such as the mandible (6–8), foramen magnum (9–13), occipital bone (14,15), glabellar region (16), zygomatic bone (17), and piriform aperture (18) using metric and morphological approaches with satisfactory results. Sex-discriminating functions thus obtained are very useful in solitary homicidal cases, mass-disasters, and multiple burials leaving mere charred and mixed incomplete remains to be recovered (19). In the process of developing new aspects for identification of sex, the mastoid process of the skull has attracted attention from various researchers. Because of its protected position at the base of skull and compact structure, the mastoid process usually remains in one piece (20,21). The mastoid process is typically more robust in males. Sex differences in the shape and size of the mastoid process are investigated using traditional morphological and metric methods and new approaches such as the mastoid triangle method (1,4,20–26) initially yielded very promising results but later found to be inconsistent for sex differentiation (27,28).

The existence of population variation in skeletal morphology, because of genetic and environmental differences, necessitates the development of population-specific osteometric standards (23,29,30). Review of literature yielded no reports of sex determination using mastoid process in North Indians. The aim of this study is to validate the use of mastoid process morphometry for sex discrimination and development of new standards for assessment in fragmentary crania refined through study of intra-observer errors.

Materials and Methods

The study sample comprises 138 adult crania, 104 males (25–65 years, mean age 38.58 years) and 34 females (22–55 years, mean age 31.75 years), collected in the Department of Forensic Medicine, Institute of Medical Sciences, Banaras Hindu University, Varanasi. The samples were derived from the North Indian population during the period of January 2007–January 2010. As all were forensic samples, so the sex was known, and age was estimated from physical appearance, third molar eruption (31,32), molar attrition (33), and cranial (1,32–37) and palatal sutures (38–41). Skulls were cleaned by water maceration and dried naturally. The crania having any pathology, fracture or deformation in temporal region, or presence of wormian bone were excluded from the study. The lesser number of female samples as compared to males was in accordance with the incidence of forensic cases observed in this locality.

Each measurement was taken three times by the same observer on the left side of crania using a sliding caliper (0.05 mm precision), and the average values are used for the analysis. The following measurements were taken:

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1. Mastoid length (ML): It is the length of mastoid process measured from its tip to the upper rim of the zygomatic arch, perpendicular and superior to the Frankfurt plane (Fig. 1).
2. Mastoid breadth (MB): It measures the straight distance from the posterior end of the incisura mastoidea (PEIM) to the nearest point on the posterior border of the external auditory meatus (Fig. 2).
3. Asterion-porion (Ast-Po): It is the length of the mastoid process measured from the asterion to the porion (20,28) (Fig. 1).
4. Posterior end of incisura mastoidea-depression of suprameatal triangle (PEIM-DSMT): It measures the straight distance from the posterior end of incisura mastoidea to the depression in the supra meatal triangle (Fig. 2).
5. Posterior end of incisura mastoidea-porion (PEIM-Po): The length of mastoid process measured from the porion to the posterior end of the incisura mastoidea (21) (Fig. 2).
6. Asterion-depression of suprameatal triangle (Ast-DSMT): It measures the straight distance from asterion to the depression of the suprameatal triangle (Fig. 1).
7. Asterion-mastoidale (Ast-Ms): It measures the straight distance from asterion to the mastoidale (20,28) (Fig. 1).
8. Mastoidale–porion/mastoid height (Ms-Po): The height of the mastoid process from Mastoidale to porion. The measurement is perpendicular to the Frankfort plane (20,22) (Fig. 1).

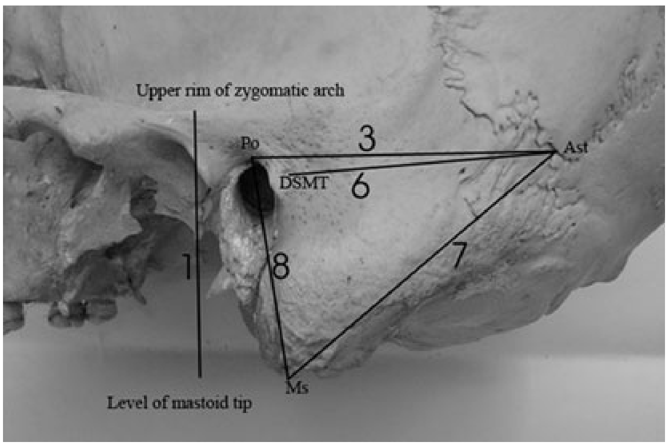

FIG. 1—*Figure showing measurements of mastoid region: 1. ML, 3. Ast-Po, 6. Ast-DSMT, 7. Ast-Ms, 8. Ms-Po.*

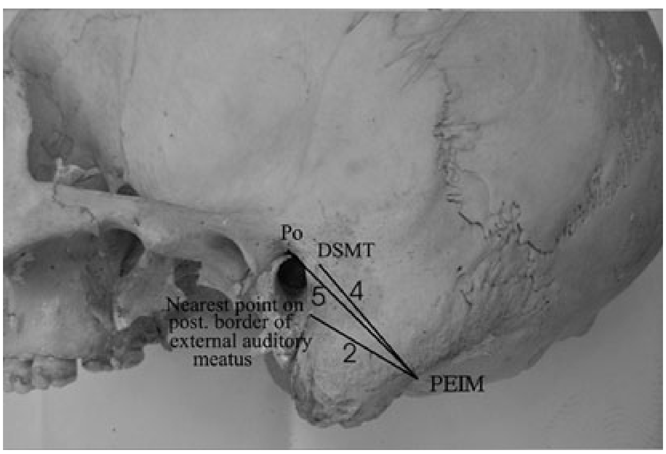

FIG. 2—*Figure showing measurements of mastoid region: 2. MB, 4. PEIM-DSMT, 5. PEIM-Po.*

Statistical Analysis

The statistical procedures were computed with SPSS (v. 16.0; SPSS Inc., Chicago, IL). Both stepwise and direct discriminant analysis were used to calculate specific discriminant formulae that can be applied to fragmentary remains. Observation errors in measuring any parameter and error of measurements may occur because of ill-defined landmarks (42). A paired *t*-test was performed so, to determine intra-observer error for all variables including the four newly developed measurements (parameters 1,2,4,6).

Receiver Operating Characteristic Curve

The receiver operating characteristic (ROC) curve was used to classify the sex by using a continuous variable. This method has been in wide use in medical/clinical research since the 1970s for measuring the discriminatory ability of diagnostic or prognostic tests (43,44). The ROC curve is a process to find out the value of the test variable having maximum sensitivity (true-positive rate) and specificity (true-negative rate). This method is basically applied for classification between the groups (e.g., males and females) to minimize the misclassification (45), especially when a single variable is to be used. The continuous scale of measurements in the present study results in the different cut-off points with their corresponding sensitivity and specificity. Generally, as the cut-off point rises, the sensitivity will increase, with a corresponding decrease in the specificity (46,47). A summary of this relationship can be shown in a graph referred to as an ROC curve. Using this graph, an optimal cut-off point is determined for the classification of male and female.

Results

The descriptive statistics for all the measurements with *t*-values and *p*-values are presented in Table 1. The *t*-value shows that there are highly significant differences between male and female measurements ($p < 0.000$).

There are instances where because of biological variation in skulls, visualization of certain landmarks becomes difficult which may lead to subjective errors in measurements. To assess such errors, intra-observer error analysis was performed using paired *t*-test. The results are presented in Table 2. No statistically significant difference is observed between the measurements recorded at first and second occasions except PEIM-Po. This may be the consequence of difficulty arising in visualization of the landmark "Po" and identifying the PEIM. This lack of intra-observer repeatability and inter-observer reproducibility in the variables associated with mastoid notch has also been mentioned by Nagaoka et al. (21).

Table 3 provides the results of the stepwise analysis. In this process, two variables "MB" and "Ast-Ms" were selected.

Discriminant function statistics and correct prediction accuracies for all variables including the results of the stepwise analysis are given in Table 4. In addition, direct analysis is employed to obtain the classification accuracy of single variables. The standardized coefficients indicate the relative importance of each variable in contributing to discrimination between the groups; the higher the coefficient the more it contributes to the discriminant score relative to the other variables. The structure coefficient gives an idea as to what a variable contributes to a function on its own. It defines the relationship between the function and the variables irrespective of the group difference.

The sectioning point is the average of male and female centroids. For each cranium, a discriminant score is obtained by multiplying

TABLE 1—*Descriptive statistics with t-values.*

	Male (n = 104)		Female (n = 34)			
Variables	Mean*	±SD*	Mean*	±SD*	t-Value	Significance (2 Tailed)
ML	35.823	3.556	31.869	3.326	5.714	0.000
MB	25.582	1.896	22.771	2.374	7.035	0.000
Ast-Po	47.894	3.173	44.696	3.756	4.869	0.000
PEIM-DSMT	28.022	2.418	24.952	2.410	6.433	0.000
PEIM-Po	35.585	2.693	31.685	3.100	7.058	0.000
Ast-DSMT	41.049	3.011	38.255	3.522	4.500	0.000
Ast-Ms	47.837	4.068	43.002	4.324	5.924	0.000
Ms-Po	31.775	3.076	27.987	3.471	6.036	0.000

Ast-Po, Asterion-porion; PEIM-DSMT, Posterior end of incisura mastoidea-depression of suprameatal triangle; PEIM-Po, Posterior end of incisura mastoidea-porion; Ast-DSMT, Asterion-depression of suprameatal triangle; Ast-Ms, Asterion-mastoidale; MS-Po, Mastoidale–porion/mastoid height; MB, Mastoid breadth; ML, Mastoid length.

*All measurements are in millimeters.

TABLE 2—*Showing results of paired t-test (intra-observer error).*

Variables	Correlation	t-Values	Significance (2 Tailed)
ML	0.978	−1.38	0.172
MB	0.970	−0.413	0.681
Ast-Po	0.993	−0.152	0.879
PEIM-DSMT	0.948	0.133	0.985
PEIM-Po	0.993	−2.180	0.033
Ast-DSMT	0.994	1.033	0.305
Ast-Ms	0.995	−1.142	0.258
Ms-Po	0.985	1.050	0.298

Ast-Po, Asterion-porion; PEIM-DSMT, Posterior end of incisura mastoidea-depression of suprameatal triangle; PEIM-Po, Posterior end of incisura mastoidea-porion; Ast-DSMT, Asterion-depression of suprameatal triangle; Ast-Ms, Asterion-mastoidale; MS-Po, Mastoidale–porion/mastoid height; MB, Mastoid breadth; ML, Mastoid length.

TABLE 3—*Result of stepwise discriminant analysis.*

Step Variable Entered	Wilk's Lambda	Equivalent f-Ratio	Degrees of Freedom
Ast-Ms	0.643	37.468	2135
MB	0.589	31.211	3134

Ast-Ms, Asterion-mastoidale; MB, Mastoid breadth.

each variable with its raw coefficient, summing them, and adding the constant. If the score is greater than the sectioning point, it is classified as male and otherwise a female. Stepwise selection of Ast-Ms and MB yielded an overall accuracy of 87%. Male crania are more correctly identified than female crania (males 92.3%, females 70.6%). The prediction accuracies range from 68.1% to 75.4% using a single variable in direct discriminant analysis.

Table 5 summarizes the demarking points for all eight measurements with classification rates. The demarking point is the average of male and female mean values. The value of a measurement higher than the demarking point indicates male, while a measurement lower than or equal to the demarking point indicates female (4,5). The average accuracies using demarking points ranged from 68.11% to 75.36%.

The outcome of ROC analysis is presented in Table 6 and Fig. 3. The ROC curve is a plot between sensitivity and 1-specificity or false-positive rate at different cut-off points. The curve begins at the (0, 0) coordinate, corresponding to the cut-off point whereby all test results are negative, and it ends at the (1, 1) coordinate, corresponding to the most lenient cut-off value whereby all test results are positive (Fig. 3). The line connecting the (0, 0) and (1, 1) coordinates is called the "chance diagonal." An ROC curve that lies above the chance diagonal has some diagnostic ability. The further away an ROC curve is from the chance diagonal, and therefore, the closer to the upper left-hand corner, the better discriminating power demonstrated by the test variable (48). Using an ROC curve, one can examine the trade-offs in sensitivity versus specificity for various cut-off values. Here, an optimal cut-off point is chosen to obtain highest sensitivity and specificity for different variables that plot at the left upper most corner. This optimal cut-off point is then used to classify the sexes. The optimal cut-off points for each variable along with their sensitivity, specificity, and predictive accuracies are given in Table 6. The highest accuracy is obtained from PEIM-DSMT (82.61%). Another criterion that helps to compare the accuracy of different variables in the determination of sex is the area under the curve (AUC). If AUC value of a test is >0.5 (AUC of chance diagonal), then it is considered better than relying on pure chance and has some ability to discriminate between sexes. The higher the AUC, the better is the overall performance of that variable. Here, PEIM-DSMT has the highest value of AUC (= 0.836).

Discussion

The results of the present study are interesting and reveal the marked sexual dimorphism in the dimensions of the mastoid region and establish its value as a sex indicator for North Indian population. As high as 87% correct classification has been achieved using stepwise discriminant function analysis with selection of two variables, Ast-Ms and MB. It is similar to, and in some cases considerably better, those of conventional cranial measurements used previously (4,5,49–54).

The accuracies obtained for identifying sex using only the mastoid region in the present study is higher than many other populations as in Germans and Portuguese (27), Brazillians (20,28), and American Whites (55,56). However, among the Japanese population, the accuracy found was much higher (85%) from a single variable (mastoid width) and 92% using mastoid height and width together (21). The most effective single measurement in our study was Ast-Ms (75.4%) (Table 4), which is contrary to the observation of Kemkes and Gobel (27), who found the Ast-Ms distance insignificant for the purpose of sexual dimorphism. The diversity in achieved accuracy observed in different populations can be attributed to population-specific variability in cranial size and shape and sample heterogeneity (27). Other potential cause may be the "asterion" position, which was found to vary with progression of age in a population-specific manner in many anatomical and clinical/neurological studies (57–59).

TABLE 4—*Canonical discriminant function coefficients for stepwise and direct analysis with correct prediction accuracy.*

						Prediction Accuracy %		
Function and Variables	Raw Coefficient	Standardize Coefficient	Structure Matrix	Centroids	Sectioning Point	Males	Females	Overall
*MB	0.391	0.792	0.730	M = 0.469	−0.483	92.3	70.6	87
Ast-Ms	0.166	0.686	0.615	F = −1.435				
(Constant)	−17.49							
F1 ML	0.286	1	1	M = 0.278	−0.286	75	64.7	72.5
(Constant)	−9.951			F = −0.851				
F2 MB	0.494	1	1	M = 0.342	−0.352	75	70.6	73.9
(Constant)	−12.304			F = −1.047				
F3 Ast-Po	0.301	1	1	M = 0.237	−0.244	73.1	70.6	72.5
(constant)	−14.171			F = −0.725				
F4 PEIM-DSMT	0.414	1	1	M = 0.313	−0.322	69.2	76.5	71
(Constant)	−11.284			F = −0.958				
F5 Po-PEIM	0.357	1	1	M = 0.344	−0.353	73.1	64.7	71
(Constant)	−12.378			F = −1.051				
F6 Ast-DSMT	0.318	1	1	M = 0.219	−0.225	69.2	64.7	68.1
(Constant)	−12.842			F = −0.670				
F7Ast-Ms	0.242	1	1	M = 0.288	−0.297	75	76.5	75.4
(Constant)	−11.291			F = −0.882				
F8 Ms-Po	0.315	1	1	M = 0.294	−0.302	71.2	64.7	69.6
(Constant)	−9.708			F = −0.899				

Ast-Po, Asterion-porion; PEIM-DSMT, Posterior end of incisura mastoidea-depression of suprameatal triangle; PEIM-Po, Posterior end of incisura mastoidea-porion; Ast-DSMT, Asterion-depression of suprameatal triangle; Ast-Ms, Asterion-mastoidale; MS-Po, Mastoidale–porion/mastoid height; MB, Mastoid breadth; ML, Mastoid length.

*Selected in stepwise.

TABLE 5—*Demarking points for single variables including correct classification percentages for males and females.*

		Correctly Identified Males (*n* = 104)		Correctly Identified Females (*n* = 34)		
Variables	Demarking Points	No	%	No	%	Overall Accuracy %
ML	Female≤33.846<male	78	75.0	22	64.7	72.46
MB	Female≤24.176<male	78	75.0	24	70.6	73.91
Ast-Po	Female≤46.295<male	76	73.1	24	70.6	72.46
PEIM-DSMT	Female≤26.487<male	72	69.2	26	76.5	71.01
PEIM-Po	Female≤33.635<male	76	73.1	22	64.7	71.91
Ast-DSMT	Female≤39.652<male	72	69.2	22	64.7	68.11
Ast-Ms	Female≤45.419<male	78	75.0	26	76.5	75.36
Ms-Po	Female≤29.882<male	74	71.2	22	64.7	69.56

Ast-Po, Asterion-porion; PEIM-DSMT, Posterior end of incisura mastoidea-depression of suprameatal triangle; PEIM-Po, Posterior end of incisura mastoidea-porion; Ast-DSMT, Asterion-depression of suprameatal triangle; Ast-Ms, Asterion-mastoidale; MS-Po, Mastoidale–porion/mastoid height; MB, Mastoid breadth; ML, Mastoid length.

TABLE 6—*Showing area under the curve (AUC), optimal cut-off point, sensitivity, specificity, correctly identified males and females with overall accuracy using ROC method.*

					Male Identified *n* = 104		Female Identified *n* = 34		
Variables	AUC	Cut-Off Value	Sensitivity	Specificity	No	%	No	%	Overall % Accuracy *N* = 138
ML	0.795	♀≤34.095<♂	75.0	76.5	78	75.0	26	76.5	75.4
MB	0.824	♀≤23.796<♂	82.7	70.6	86	82.7	24	70.6	79.7
Ast-Po	0.744	♀≤46.112<♂	76.9	70.6	80	76.9	24	70.6	75.4
PEIM-DSMT	0.836	♀≤25.570<♂	84.6	76.5	88	84.6	26	76.5	82.6
PEIM-Po	0.812	♀≤33.954<♂	73.1	70.6	76	73.1	24	70.6	72.5
Ast-DSMT	0.739	♀≤39.208<♂	76.9	64.7	80	76.9	22	64.7	73.9
Ast-Ms	0.798	♀≤45.066<♂	80.8	70.6	84	80.8	24	70.6	78.3
Ms-Po	0.787	♀≤29.987<♂	71.2	70.6	74	71.1	24	70.6	71.0

Ast-Po, Asterion-porion; PEIM-DSMT, Posterior end of incisura mastoidea-depression of suprameatal triangle; PEIM-Po, Posterior end of incisura mastoidea-porion; Ast-DSMT, Asterion-depression of suprameatal triangle; Ast-Ms, Asterion-mastoidale; MS-Po, Mastoidale–porion/mastoid Height; MB, Mastoid breadth; ML, Mastoid length; ROC, receiver operating characteristic.

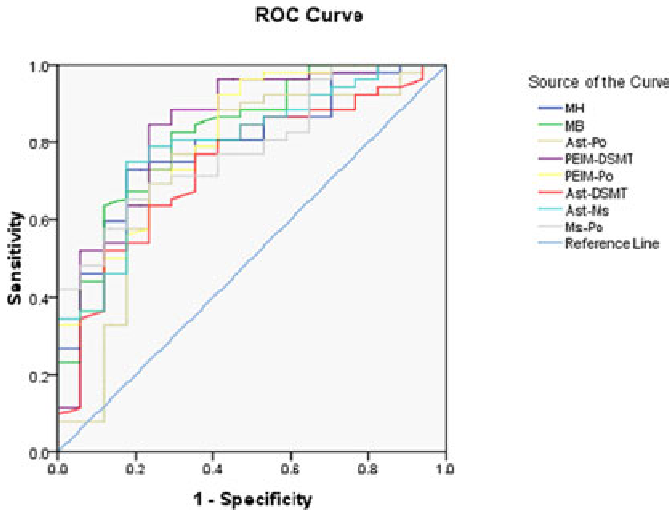

FIG. 3—*Graph showing senstibity, specificity and area under the curve for all variables.*

The variable, Ms-Po (mastoid height), which was found to be very dimorphic and highly discriminant (21), has provided only an accuracy of 69.6% in the present study. This could again be attributed to the highly variable position of porion and also to its population specificity, as shown by Schulter (c.f. Bernard [55]). In addition, because the measuring of mastoid height or Ms-Po involves sighting for the establishment of landmark "porion," its measurement was shown to be less consistent (55,56).

Mastoid region is one of the slowest and later growing regions of cranium (60) and such regions show higher degree of sexual dimorphism in adulthood (3,61). Moreover, the differences in size of the mastoid process between sexes could be attributed to the variable duration of growth in males and females, along with relatively greater development of the mastoid process in males in response to stronger muscle action of the sternocleidomastoideus, splenius capitis (the posterior belly of the digastric muscle), and longissimus capitis (3). Also, these muscles are attached over a relatively larger area in males (51). The morphological features, whose formation is related to insertion and action of major muscle groups, for example, size and general architecture of the skull, mastoid process, zygomatic bone, ridges of the occipital bone, and general appearance of the mandible, are found to be the best indicators for sex determination (51,62).

However, the mastoid process was found to be of little importance in identifying sex in individual forensic cases by Rogers (3) who visually assessed the sex of crania using 17 morphological traits including the robusticity of mastoid process. She stated that the trait has sex-discriminating potential in larger sample size, where the variations in the population are known (3). In contrary, results achieved in the present study show an overall accuracy of 87%, which is reasonably good for identification in forensic anthropology. Also, the mastoid process was found to be a good discriminator of sex even in condition of severe malnutrition with 87.3% accuracy (63).

The variations in the results obtained from different populations can be a consequence of differences in robusticity of the skeleton in response to population-specific and sex-specific ontogenic trajectories and scaling (64). Besides, environmental influences and nutritional differences have also been shown to affect craniofacial growth, especially the zygomatic process, mastoid region, and ridges of the occipital bone (63). The variability in the position of landmarks of the skull in different populations may be another reason for these discrepancies.

ROC and Classification Accuracy

If only one dimension is used for analysis, this approach provides an excellent method to identify sex with high-predictive accuracy. An increase of 2–10% in classification accuracy was observed in comparison with the conventional direct discriminant analysis and demarking point method (see Tables 4–6). We have not come across any study that makes use of the ROC curve method to find out an optimal cut-off point for discrimination of sex using a single variable. This technique has the additional advantage of comparing the performance of each variable using its AUC in the determination of sex.

Conclusion

The results of this study are encouraging, offering a better opportunity to identify the sex using the mastoid process. In addition, we have introduced a very simple, convenient, and more logical method (cut-off point by ROC) of sex identification with good predictive accuracy, especially in cases of fragmentary crania. The newly developed parameters also have potential possibilities for sex discrimination (ML, MB, and PEIM-DSMT) but need to be tested on larger sample sizes. The unequal sex ratio and small number of female skulls were the limitations of the present study. We are currently in the process of collecting data from larger sample size to facilitate a comprehensive analysis of sexual dimorphism in the North Indian population. We suggest that while taking measurements of mastoid region, the landmarks (especially, porion and asterion) must be clearly identified and measured with utmost caution. Crania with unapparent landmarks should be excluded from the study to achieve higher accuracy.

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