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PAPER

ANTHROPOLOGY; ODONTOLOGY

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Mandibular Ramus: An Indicator for Sex in Fragmentary Mandible*

ABSTRACT: Mandible is the hardest and most durable bone of the skull exhibiting a high degree of sexual dimorphism. Especially ramus of mandible is subjected to greater stress than any other bone of the skull because of the process of mastication. This study has been performed to establish the osteometric standards for practical use in forensic context over Indian population using mandibular ramus. The sample consists of 116 mandibles of Northern Indian population (M:F; 92:24, mean age 37.4 years), collected from the Department of Forensic Medicine, IMS, BHU, Varanasi. Osteometric informations about five metric parameters (coronoid height, projective height, condylar height, and maximum breadth and minimum breadth of ramus) were taken with sliding calipers. These parameters were subjected to different discriminant function analysis using SPSS 16.0. All parameters showed significant sexual dimorphism ($p < 0.001$ in all cases) with an overall accuracy of 80.2%, and coronoid height was the single best parameter providing an accuracy of 74.1%.

KEYWORDS: forensic science, mandibular ramus, sexual dimorphism, skeletal remains, Indian population, discriminant function analysis, fragmentary mandible

Sex determination of human skeletal remains is considered an initial step in its identification and is crucial for further analysis, because estimation of age at death and stature follows markedly different pattern in males and females (1). In present forensic scenario, dismemberment or mutilation of body has become the frequent method to conceal the identity of victim. When entire adult skeleton is available for analysis, sex can be determined up to 100% accuracy (2), but in cases of mass disasters where usually fragmented bones are found, sex determination with 100% accuracy is not possible and it depends largely on the available parts of skeleton. A number of literatures have shown sexual dimorphism in almost every bone of human skeleton. As evident from the past studies, skull is the most dimorphic and easily sexed portion of skeleton after pelvis, providing accuracy up to 92% (2–6). But in cases where intact skull is not found, mandible may play a vital role in sex determination as it is the most dimorphic bone of skull (7). Also, the maturation rate and growth pattern differs in male and female as skeletal maturity occurs earlier in females than males. Therefore, sexual difference may manifest themselves in the skull and mandible of females earlier than in the later and longer maturing males (8).

Mandible is the largest and strongest bone of the face (8). Presence of a dense layer of compact bone makes it very durable and hence remains well preserved than many other bones. Dimorphism in mandible is reflected in its shape and size. The shape of the mandible is created by the sequential structural modeling while the bone is increasing in size (9). As mandible is the last skull bone to cease growth (10), it is sensitive to adolescent growth spurt (11).

Mandibular ramus can differentiate between sexes as the stages of mandibular development, growth rates, and duration are distinctly different in both sexes. In addition, masticatory forces exerted are different for males and females, which influences the shape of the mandibular ramus (9,12).

When skeleton sex determination is considered, metric analyses are often found to be of superior values owing to their objectivity, accuracy, reproducibility, and lower level of inter- and intra-observer errors, in comparison with descriptive traits (13–15). Weidenreich (1936) evaluated the sexual dimorphism in mandible and reported that modern human female mandible size averaged 92.4% of male size (cited in Humphrey et al. [16]). Most of the differentiating points cannot be seen until adulthood when all sex-differentiating features become clearly visible. Humphrey et al. (16) pointed out that during growth, mandibular ramus and condyle are the sites, which are associated with greatest morphological changes in size and remodeling, hence most dimorphic.

A number of studies have been conducted to test the efficiency of mandible in determining sex worldwide (3,8,12,16–20). To date, no such study has been carried out on mandible in northern part of India. However, studies have been performed on the long bones of both upper and lower limbs (21–26) in which demarking points of these bones were worked out for this region. So, this study was undertaken to evaluate and compare the various parameters of mandibular ramus as well as to produce new discriminant function in fragmented mandibles. The findings of this study will provide a platform to evaluate the ability of selected parameters to determine the sex in forensic sample.

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Material and Methods

The sample comprising 116 dry adult mandibles, 92 males (25–65 years, mean age 38.58 years) and 24 females (23–50 years, mean age 31.75 years), were collected from Department of Forensic Medicine, IMS, BHU, Varanasi, India. All pathological, fractured, deformed, or edentulous mandibles were excluded from the study. The number of females was limited when compared to males, because all samples were forensic cases and female skeletons are limited in our forensic cases.

To minimize the intra-observer error, all the measurements were taken with sliding calipers (0.1 mm precision) three times and the average values were utilized for the analysis. The following measurements were taken.

Maximum Ramus Breadth

The distance between the most anterior point on the mandibular ramus and a line connecting the most posterior point on the condyle and the angle of jaw (27) (Fig. 1).

Minimum Ramus Breadth

Smallest anterior–posterior diameter of the ramus (27) (Fig. 1).

Condylar Height/Maximum Ramus Height

Height of the ramus of the mandible from the most superior point on the mandibular condyle to the tubercle, or most protruding portion of the inferior border of the ramus (16) (Fig. 1).

Projective Height of Ramus

Projective height of ramus between the highest point of the mandibular capitulum and lower margin of the bone (27) (Fig. 1).

Coronoid Height

Projective distance between coronion and lower wall of the bone (27) (Fig. 1).

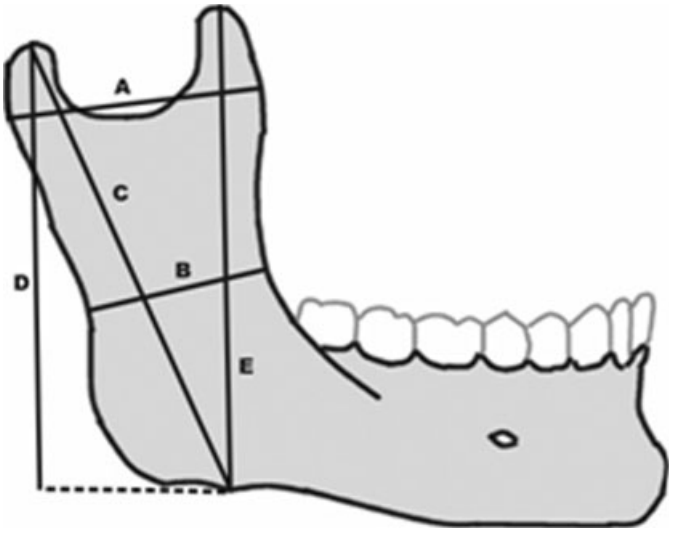

FIG. 1—*Figure showing all the five measurements. (A) Maximum ramus breadth. (B) Minimum ramus breadth. (C) Condylar height/maximum ramus height. (D) Projective height of ramus. (E) Coronoid height. Originally obtained from Vodanovic et al. (19).*

Statistical Analysis

The data were analyzed using the discriminant procedure of the statistical package SPSS 16.0 (SPSS Inc., Chicago, IL). Discriminant function analysis is used to determine which continuous variables discriminate between male and female. This approach is particularly helpful in those bones in which no single variable gives adequate sexual differentiation like mandible.

Results

Descriptive statistics of five mandibular ramus measurements and associated univariate F ratio for both sexes are summarized in Table 1. All measurements are found to be statistically significant between the sexes (at $p < 0.001$). Comparison of mean values shows that all dimensions are higher for male measurements than females. The F-statistic values indicate that mandibular measurements expressing the greatest dimorphism are coronoid height, condylar height, and projective height of ramus.

Table 2 shows the standardized and unstandardized discriminant function coefficients, structure matrix, group centroids, and sectioning points in original samples. The sex can be calculated from these functions by multiplying the values of mandibular ramus dimensions by the corresponding coefficients plus the constant which is the discriminant equation for that particular function.

For example, the discriminant equation for function 2 is given as

$$\begin{aligned} D = &(\text{maximum ramus breadth} \times 0.155) \\ &+ (\text{minimum ramus breadth} \times -0.135) \\ &+ (\text{Coronoid height} \times 0.191) - 13.887 \end{aligned}$$

A discriminant value is obtained by using this formula. A discriminant score greater than sectioning point indicates male and less than sectioning point indicates female.

Table 3 presents the percentage of correct group membership. This gives the accuracy of prediction for each function. The classification accuracy ranged from 60.3 to 80.2% using direct discriminant analysis.

Table 4 shows the indices of sexual dimorphism and demarking points of variables. Demarking point is the average of male and female mean values. If the value of measurement is higher than the demarking point, it indicates male, while a measurement lower than or equal to the demarking point indicates female. If only one dimension is used for analysis, sex can be predicted by evaluating the measurement of unknown according to the demarking point (mean of both sexes). In this study, index of sexual dimorphism is taken out by using the formula: (male mean/female mean) × 100. This index indicates the level of difference between sexes: values

TABLE 1—*Descriptive statistics and sexual dimorphism of the mandible in the analyzed sample.*

	Male = 92		Female = 24			
Variable	Mean	SD	Mean	SD	Wilk's Lambda	F Ratio*
Max. ramus br.	42.81	3.59	40.34	3.76	0.928	8.859
Min. ramus br.	31.29	2.99	29.65	1.96	0.946	6.517
Condylar ht.	60.67	5.32	54.46	4.97	0.811	26.625
Projective ht. of ramus	53.89	6.93	47.45	4.63	0.860	18.537
Coronoid ht.	61.68	5.45	54.89	3.54	0.773	33.525

*All measurements are in millimeters. **All significant at $p < 0.001$ level.

TABLE 2—*Standardized and unstandardized discriminant function coefficients, structure matrix, sectioning points in original samples.*

Functions and Variables	Raw Coefficients	Standardized Coefficients	Structure Coefficients	Centroids	Sectioning Points
F1Max.ramus br.	0.117	0.423	0.443	M = 0.319	−0.451
Min. ramus br.	−0.113	−0.317	0.380	F = −1.222	
Condylar ht.	0.095	0.500	0.768		
Projective ht.	−0.045	−0.295	0.641		
Coronoid ht.	0.167	0.857	0.862		
(Constant)	−14.814				
F2Max.ramus br.	0.155	0.652	0.468	M = 0.302	−0.427
Min. ramus br.	−0.135	−0.379	0.401	F = −1.156	
Coronoid ht.	0.191	0.977	0.910		
(Constant)	−13.887				
F3 Condylar ht.	0.122	0.643	0.805	M = 0.304	−0.430
Projective ht.	−0.062	−0.406	0.672	F = −1.165	
Coronoid ht.	0.163	0.836	0.904		
(Constant)	−13.843				
F4Coronoid ht.	0.195	1	1	M = 0.275	−0.389
(Constant)	−11.774			F = 1.053	
F5 Condylar ht.	0.190	1	1	M = 0.245	−0.346
(Constant)	−11.309			F = −0.938	
F6 Projective ht. of ramus	0.153	1	1	M = 0.204 F = −0.783	−0.289
(Constant)	−8.048				
F7Max.ramus br.	0.267	1	1	M = 0.141	−0.2
(Constant)	−11.672			F = −0.541	
F8Min. ramus br.	0.355	1	1	M = 0.121	−0.171
(Constant)	−10.999			F = −0.464	

TABLE 3—*Percentage of correct classifications for the discriminant functions.*

Functions and Variables	Males		Females		Average Accuracy %
	n = 92	%	*n* = 24	%	
Max. ramus br. + min. Ramus. br. + condylar ht. + projective ht. + coronoid ht.	73	79.3	20	83.3	80.2
Max. ramus br. + min. ramus br. + coronoid ht.	73	79.3	20	83.3	80.2
Condylar ht + projective ht + coronoid ht.	69	75	20	83.3	76.7
Coronoid ht.	68	73.9	18	75	74.1
Condylar ht.	68	73.9	16	66.7	72.4
Projective ht.	60	65.2	19	79.2	68.1
Max ramus br.	57	62	15	62.5	62.1
Min ramus br.	55	59.8	15	62.5	60.3

TABLE 4—*Showing the indices of sexual dimorphism and demarking points (in mm).*

Variables	Index of Sexual Dimorphism	Demarking Points
Coronoid ht.	112.37	Female ≤ 58.29 < male
Condylar ht.	111.40	Female ≤ 57.56 < male
Projective ht.	113.57	Female ≤ 50.67 < male
Min. ramus br.	105.53	Female ≤ 30.47 < male
Max. ramus br.	106.12	Female ≤ 41.58 < male

close to 100 indicate low level of sexual difference and on the other side the level of sexual difference increases with the increase of the distance from 100 (19).

Discussion

Consistent differences have been found between male and female mandibles from diverse range of human groups by Hrdlicka (cited in [16]). Statistically significant differences between male and female mandibles are well established, and these differences can be used to predict sex in unidentified mandible. It is well established that discriminant function derived from one specific population cannot be applied to another as magnitude of sex-related differences vary significantly among regional populations (3,28,29). So, there is always a need to develop population-specific standards for accurate sex determination from a skeleton deriving from that population. Hence, standards have been developed for different populations worldwide.

In the present study, direct discriminant analysis was employed, testing each combination of variables. Each of the five variables measured on mandibular ramus of the Indian population showed statistically significant sex differences between sexes, indicating that ramus expresses strong sexual dimorphism in this population. The ramus shows greatest univariate sexual dimorphism in terms of coronoid height followed by condylar height. The best parameters are coronoid height and condylar height for males and projective height for females. The variables of least use for discrimination are maximum and minimum ramus breadth. Overall prediction rate using all five variables was 80.2%, with females slightly more accurately determined than males. Same accuracy was also achieved by the combination of three measurements, i.e., maximum ramus breadth, minimum ramus breadth, and coronoid height.

Earliest studies on mandible by Morant et al. (1936), Martin (1936), and Hrdlicka (1940) (cited in Humphrey et al. [16]), have established the usefulness of mandible for determination of sex. They found that the sexual differences were highest in height of the ramus. This has been confirmed in subsequent studies by De Villiers (30) and Humphrey et al. (16). Measurements of the height of mandibular ramus tend to show higher sexual dimorphism than measurements of body height and breadth. Thus, emphasizing that sex differences are more pronounced in mandibular ramus than body. Mandibular ramus flexure, though contentious, was proved to be very useful in the determination of sex up to an accuracy of 94–99% in combined African and Americans samples by Loth and Henneberg (12). A number of metric studies performed on mandible have also confirmed that the ramus of mandible is most dimorphic. Giles (3) reported mandibular ramus height, maximum ramus breadth, and minimum ramus breadth as highly significant with classification accuracy of 85% in American white and Negro. Steyn and Iscan (17) achieved an accuracy of 81.5% with five mandibular parameters (i.e., bigonial breadth, total mandibular length, bicondylar breadth, minimum ramus breadth, and gonion-gnathion) in South African whites that is comparable with the current study. Dayal et al. (20) found mandibular ramus height the best parameter in their study with 75.8% accuracy. Previously, Franklin et al. (18) reported a very high accuracy of 95% with 10 variables employing geometric morphometric technique on South African population. They reported that in South African blacks, the regions of mandible expressing the greatest sexual dimorphism are condyle and ramus. In their study, both ramus height and coronoid height showed an average accuracy of 87.5%, which is higher than the present study.

It is interesting to note that breadth measurements which were usually found to be very dimorphic in other osteometric studies (3,19) are not very dimorphic in this sample. The lower prediction accuracy in height and breadth measurements may be because of population differences in size and expression of dimorphism which is of low degree in Indian population (31). It has been established

that socio-environmental factors (e.g., malnutrition, climate, pathologies, occupation etc.), influences the development and the appearance of bones. The studies have been conducted on Asian (Indians) (32–34) subjects where malnutrition was prominently found contributing to the lower degree of dimorphism that may result in false identification of males as demonstrated by Galdames et al. (35) who studied the effect of severe malnutrition on morphological determinants of sexual dimorphism in skull.

Conclusion

This preliminary study on mandibles from the Northern Indian population clearly indicates that the ramus part of mandible has satisfactory potential for determination of sex. It can especially be used for forensic cases where damaged and partially preserved mandibles are frequently found. It is a limitation of this study that the female sample size was small in comparison with that of male. We suggest that larger samples and populations from more diverse geographic regions may enhance the effectiveness of these parameters.

Conflict of interest: The authors have no relevant conflicts of interest to declare.

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