ORIGINAL ARTICLE

Assessment of sexual dimorphism using digital orthopantomographs in South Indians

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Abstract

Introduction: The identification of human skeletal remains plays a crucial role in forensic investigation and its accuracy depends on the available parts of the skeleton. The mandible is the hardest and strongest bone of the skull, which exhibits a high degree of sexual dimorphism and helps to identify the sex in human remains. The aim of this study was to develop discriminant function to determine sex from the mandibular radiographs in a South Indian (Visakhapatnam) population. **Materials and Methods:** This retrospective study consisted of 384 (192 males and 192 females) digital orthopantomographs (OPGs) divided into five groups according to age. Ten mandibular variables were measured using Planmeca Romexis software. The data were tabulated and subjected to discriminant function analyses using Statistical Package for the Social Sciences (SPSS) software (version 20.0) package. **Results:** All the parameters showed a significant sexual dimorphism ($P < 0.001$) except for the gonial angle. An overall accuracy of 75.8% was achieved and coronoid height (CrH) was the single best parameter providing an accuracy of 74.1%. **Conclusion:** All the mandibular variables except for the gonial angle (GA) were found to be reliable in determining the sex in South Indians for forensic purposes.

Key words: Discriminant function, forensic dentistry, mandible, orthopantomographs, sex determination

Introduction

The identification of human skeletal remains is a critical problem and is very important in medicolegal work and anthropological work. In criminal cases, war atrocities and a wide variety of large scale disasters, human remains encountered by forensic experts are often highly decomposed and fragmentary, requiring a battery of different interpretative techniques. The teeth and bones,

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being composed of tissues, are more resistant than soft tissues to the effects of degradation, and are of utmost importance in the process and often serve as a key tool in forensic identification. When skeletal remains are found, it is necessary to reconstruct a biological profile in order to understand the demographics of the population and the individual represented. This includes estimating the age, sex, ancestry, and stature. The determination of sex of an individual is important and necessary both in the living and the dead for medicolegal purpose.

Sex is defined as a "biological category based on reproductive attributes and roles in sexually reproducing species," which consequently may be used in the "classification of individuals into categories based on the types of gamete production."[1] In the adult skeleton, sex determination is usually the first step of identification. When an entire adult skeleton is available for analysis, sex can be 100% accurately determined but in cases of mass disaster, it cannot be achieved as fragmented bones are found.

The sex can be more accurately determined after attainment of puberty. The sex differences are well-marked in the skull after a bony pelvis, providing an accuracy of 92%.[2-4] But in cases where the intact skull is not available, the mandible plays a vital role in sex determination as it is the most dimorphic and strongest bone of the skull, with different maturational patterns in males and females during growth.

Sex estimation from skeletal remains is crucial in the identification of human remains as it halves the number of possible matches. Furthermore, other biological reconstruction variables, such as age at death, rely on the knowledge of the sex of the individual. Sex estimation based on the morphological characteristics of skeletal elements is population-specific and thus, the establishment of regional criteria is one of the imperatives for modern forensic anthropology.

Traditionally, physical anthropologists have used two methods of skeletal sex estimation, namely, morphological (nonmetrical) and metrical including geometric morphometrics. The morphological method involves the visual observation of sexual traits on the bones that exhibit sexual dimorphism. The recognition of these traits by an experienced observer can produce an accurate classification of sex.[5]

The metrical method involves subjecting a suite of measurements of the bones to various forms of metrical analyses including the Student's *t*-test, indices, use of demarking and identification points, and discriminant function analysis. Discriminant function analysis proved to be the most reliable approach and is therefore, the most widely used metrical method. The use of the metrical approach in the estimation of sex is more structured than morphological evaluation and does not require vast experience on the part of the scientist. Furthermore, it can be repeated to validate the obtained results.[5]

Discriminant function analysis has been widely used in forensic science for the purpose of sex estimation. This method explores the differences between groups by determining which combination of variables can best predict group membership. It therefore, requires a suite of measurements to be taken on a bone in order to ascertain which measurements or combination of measurements is the best predictor of sex.

Panoramic radiographs have wide, complementary clinical radiological applications in dentistry. The accuracy of panoramic radiography in providing anatomic measurements has been established. Several studies have reported that panoramic radiographs are reproducible and accurate for the linear and angular measurements on the mandible.[6-10] The limitations of this technique are magnification and geometric distortion and also sensitive to positioning errors. But this limitation does not affect our results since all images were uniformly magnified.

As the results obtained from discriminant function analysis for the determination of sex were population-specific and the same result cannot be applied to other geographical areas due to population differences and temporal changes, they require revision from time to time. The present study was an attempt to develop discriminant function to determine sex from the mandible in a South Indian population.

Materials and Methods

A retrospective study was conducted using 384 digital orthopantomographs (OPGs) of 192 males and 192 females of Visakhapatnam's population in the age group of 7–75 years, who were divided into five groups of 15 years each.

Ideal OPGs of completely dentate patients were selected for the study. Radiographs with pathological, deformed, fractured, and developmental disturbances in the mandible and with missing teeth were excluded from the study. As the study was retrospective, the ethical committee's approval was not required. Radiographs taken by Planmeca Proline Panoramic x-ray machine, Helsinki, Uusimaa, Finland (64–70 kVp, 7–14 mA,16s) were used for the study.

Mandibular measurements were performed using Planmeca Romexis software (PROMAX digital Planmeca Machine (Planmeca OY, Asentajankatu 6, FIN00880 Helsinki, Finland). All measurements were done in millimeters and all the values were read out to two decimal places. All the variables were measured on both sides of the mandible but as there was no statistically significant difference between

the right side and left side, only measurements obtained on the right side of the mandible were used for further analysis.

The following 10 parameters [Figure 1] were measured on the radiographs utilizing the mouse-driven method to determine sex.

1. Minimum ramus breadth (MnRB): Smallest anteroposterior diameter of the ramus
2. Maximum ramus breadth (MxRB): 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 the jaw.
3. Mandibular length (ML): It is the distance from the center point of symphysis region on a projected straight line placed along the posterior border to the most inferior point on the angle of the mandible.
4. Bicondylar breadth (BB): It is the straight distance between the most lateral points on the two condyles.
5. Mandibular index (MI): Mandibular length × 100/BB
6. Ramus height (RH): It is the distance from the most superior lateral point on the ramus to the most inferior lateral point on the ramus tangent.[11]
7. Mandibular body height (MBH): It is the direct distance from the alveolar process to the inferior border of the mandible, perpendicular to the base at the level of the mental foramen.
8. Gonial angle (GA): A mandibular line was drawn tangential to the two lowest points on the anterior and posterior borders of the mandible and a ramus line was drawn tangential to the posterior border of the ramus and the condyle. The intersection of these two lines formed the gonial angle.[12]
9. Bigonial width (BGW): It is the distance measured horizontally from the right gonion to the left gonion.
10. Coronoid height (CrH): Projective distance between the coronion and lower wall of the bone.

All the variables were measured by two dentomaxillofacial radiologists who were trained to use the same reference points required for obtaining the measurements of the angles and linear distances on each radiograph. The data were analyzed using Statistical Package for the Social Sciences computer software (SPSS, version 20.0, SPSS Inc., Chicago, IL, USA). Descriptive statistics for the mandibular measurements were calculated; sexual difference was analyzed by the Student's *t*-test and the demarking point for each variable was also calculated. Sexual dimorphism indices were calculated to assess the general pattern of sexual dimorphism. Stepwise and direct discriminant function analyses were performed to determine the sex and finally sensitivity and specificity for all the variables were measured using receiver operating characteristic (ROC) analysis. It was observed that the measurements were reproducible without any significant intra- and interobserver errors. The level of significance was set at $P < 0.05$.

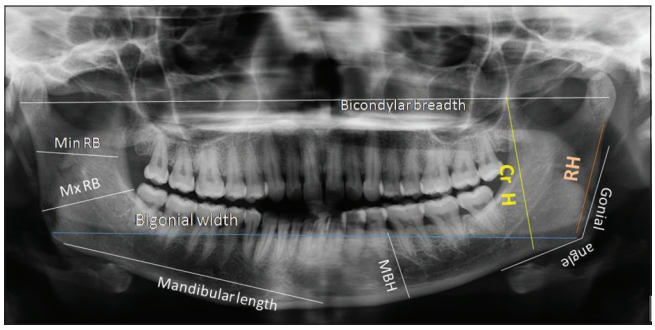

Figure 1: Digital orthopantomograph showing assessed mandibular variables. MinRB = Minimum ramus breadth, MxRB = Maximum ramus breadth, MBH = Mandibular body height, CrH = Coronoid height, RH = Ramus height

Results

Table 1 summarizes the descriptive statistics for both the sexes in five different age groups. The mean values for all variables except for GA were higher for males compared to females in the whole sample, indicating that the parameters chosen account for sex differentiation. It also shows the sexual dimorphism ratios and independent sample *t*-test values for male and female samples. The sexual dimorphism indices for all the variables were greater than 100 except for GA, indicating that males had greater mandibular measurements than females. The *t* values show that all the mandibular measurements except for GA and MI were significantly higher ($P < 0.001$) in males compared to females.

For all variables, the within-group correlation matrices were generated and are shown in Table 2. Variables showing a strong and positive correlation were MnRB and MxRB (0.744), BGW and Mn RB (0.567), BGW and ML (0.594), and CrH and RH (0.753).

Tables 3 and 4 present the eigenvalue, canonical correlation, Wilks's lambda, Chi-square, and significance level for derived discriminant function for all variables and the two best variables for determining the sex. When the canonical correlation is large, there is a high correlation between the discriminant function and the variables, as seen with CrH (0.46), RH (0.454), and MBH (0.379). In case of a damaged or incomplete mandible, the sex can be determined by using a single variable by comparing the specific dimension of the mandible with the demarking point [Table 3]. While using the demarking point, a higher value indicates male and a lower value indicates female.

Direct discriminant function analyses of all variables were generated and are shown in Tables 5 and 6. Standardized discriminant function coefficients indicate the relative importance of each variable in predicting the gender. In Table 5, CrH makes the greatest contribution and MI the least. Unstandardized discriminant function coefficients are

Table 1: Sexual dimorphism and descriptive statistics (in mm) of the mandible for the analyzed sample divided in to six groups according to age and sex

Age (years)	Sex	*N*	MnRB	MxRB	ML	BB	MI	RH	MBH	GA	BGW	CrH
0-15	M	10	23.80±3.3	28.58±2.66	78.24±9.44	167.66±16.73	46.48±16.7	53.04±10.29	24.54±3.63	120.26±9.56	152.64±19.44	44.4±8.17
	F	12	23.85±3.27	27.22±3.83	77.95±7.5	170.85±15.1	45.72±3.9	57.3±4.7	23.98±3.81	124.1±7.05	152.23±12.0	47.95±3.9
	T	22	23.83±3.21	27.84±3.35	78.08±8.24	169.4±15.6	46.15±4.08	55.36±7.87	24.2±3.65	122.35±8.31	152.42±15.41	46.34±6.34
t value (significance)			0.036 (0.97)	0.948 (0.35)	0.08 (0.93)	0.46 (0.64)	0.54 (0.06)	1.28 (0.21)	0.348 (0.73)	1.08 (0.29)	0.06 (0.95)	1.33 (0.19)
16-30	M	85	27.11±3.07	31.94±3.26	88.17±6.34	184.64±23.6	46.55±3.1	67.89±5.63	28.97±2.79	124.96±8.71	173.77±11.2	55.22±4.79
	F	84	25.38±3.01	31±3.03	84.9±5.6	185.06±9.9	45.9±2.95	62.3±5.57	26.06±2.64	124.37±7.6	166.9±11.1	49.9±4.89
	T	169	26.25±3.16	31.47±3.18	86.55±6.17	184.85±18.12	46.23±3.04	65.12±6.24	27.5±3.08	124.67±8.17	170.4±11.6	52.62±5.49
t value (significance)			3.68 (0.000)*	1.92 (0.05)	3.54 (0.001)*	0.152 (0.8)	1.41 (0.16)	6.47 (0.000)*	6.97 (0.000)*	0.46 (0.64)	3.93 (0.000)*	7.02 (0.000)*
31-45	M	51	27.75±2.98	33.14±3.28	89.32±6.85	193.85±12.47	46.05±2.33	69.3±3.72	28.1±2.0	120.99±8.9	177.08±13.1	57.19±3.92
	F	64	25.46±2.56	30.75±3.07	82.72±16.27	184.48±10.1	46.37±3.6	62.31±3.78	25.97±2.93	122.93±8.27	168.95±12.2	51.12±3.78
	T	115	26.47±2.97	31.81±3.37	85.65±13.33	188.63±12.1	46.23±3.09	65.41±5.11	26.9±2.76	122.07±8.57	172.56±13.2	53.8±4.88
t value (significance)			4.42 (0.000)*	4.02 (0.000)*	2.7 (0.008)*	4.45 (0.000)*	0.55 (0.58)	9.92 (0.000)*	4.43 (0.000)*	1.207 (0.23)	3.42 (0.001) *	8.409 (0.000)
46-60	M	30	26.88±2.62	32.24±3.06	89.27±5.34	195.03±6.53	45.77±2.78	69.25±3.63	28.52±2.61	119.05±8.56	175.65±9.1	57.01±4.66
	F	26	23.78±3.43	29.03±3.83	85.25±3.38	182.45±10.6	46.82±3.01	61.27±5.95	26.77±4.02	125.47±7.25	164.85±9.32	49.98±4.8
	T	56	25.44±3.37	30.75±3.77	87.41±4.93	189.19±10.6	46.25±2.91	65.54±6.26	27.7±3.42	122.03±8.54	170.64±10.64	53.75±5.87
t value (significance)			3.817 (0.000)*	3.478 (0.001)*	3.301 (0.002)*	5.415 (0.000) *	1.352 (0.18)	6.14 (0.000)*	1.95 (0.05) *	-3.0 (0.004)*	4.35 (0.000) *	5.53 (0.000)
60-75	M	16	28.29±2.13	33.59±3.05	90.23±5.78	195.1±10.85	46.27±3.21	66.86±2.40	28.07±3.31	122.31±11.5	176.3±13.6	55.5±2.24
	F	6	25.23±3.02	33.83±3.5	81.3±6.79	184.17±14.02	44.07±1.42	63.67±2.65	24.33±3.8	122.26±3.65	158.67±13.7	53.7±5.09
	T	22	27.45±2.71	33.65±3.09	87.79±7.21	192.12±12.4	45.67±2.97	65.99±2.81	27.04±3.77	122.29±9.92	171.5±15.5	55.01±3.22
t value (significance)			2.67 (0.01) *	0.16 (0.87)	3.05 (0.006)*	1.94 (0.06) *	1.607 (0.12)	2.7 (0.01) *	2.26 (0.03) *	0.01 (0.99)	2.7 (0.01) *	1.17 (0.25)
Total	M	192	27.17±3.03	32.27±3.33	88.3±6.87	188.7±19.04	46.28±2.94	67.62±6.11	28.37±2.82	122.52±9.24	174.06±13.1	55.48±5.34
	F	192	25.09±2.99	30.5±3.41	83.68±10.51	183.6±11.04	46.11±3.23	61.9±5.09	25.94±3.1	123.96±7.66	166.17±12.0	50.1±4.55
	T	384	26.13±3.18	31.39±3.48	85.99±9.16	186.15±15.75	46.19±3.09	64.76±6.3	27.15±3.2	123.24±8.51	170.9±13.2	53.0±5.58
t value (significance)			6.76 (0.000)*	5.12 (0.000)*	5.09 (0.000)*	3.21 (0.001) *	0.53 (0.590)	9.95 (0.000)*	8.01 (0.000)*	1.66 (0.097)	6.12 (0.000)*	10.12 (0.000)*
Sexual dimorphism ratio			108.29	105.80	105.52	102.78	100.37	109.24	109.37	98.84	104.75	110.74
F-test			5.086	9.778	5.045	9.269	0.169	14.981	6.010	2.170	12.239	10.536
Significance			0.001*	0.000*	0.001*	0.000*	0.954	0.000*	0.000*	0.072	0.000*	0.000*

N: Number of subjects, M: Male, F: Female, T: Total sample, MnRB: Minimum ramus breadth, MxRB: Maximum Ramus breadth, ML: Mandibular length, BB: Bicondylar breadth, MI: Mandibular index, RH: Ramus height, MBH: Mandibular body height, GA: Gonial angle, BGW: Bigonial width, CrH: Coronoid height *$P<0.05$-statistically significant

Table 2: Within group correlation matrices for the analyzed variables

Variable	MinRB	MxRB	ML	BB	MI	RH	MBH	GA	BGW	CrH
MinRB	1	0.744*	0.426	0.452	0.149	0.418	0.222	−0.149	0.567*	0.467
MaxRB	0.744*	1	0.333	0.515	0.024	0.363	0.149	−0.056	0.445	0.38
Mandible length	0.427	0.333	1	0.304	0.406	0.394	0.268	−0.15	0.594	0.351
BB	0.452	0.515	0.304	1	−0.233	0.33	0.09	−0.016	0.529	0.325
MI	0.149	0.024	0.406	−0.23	1	0.073	0.229	−0.094	0.315	0.154
RH	0.418	0.363	0.394	0.33	0.073	1	0.477	−0.127	0.514	0.753
MBH	0.222	0.149	0.268	0.09	0.229	0.477	1	−0.015	0.34	0.365
GA	−0.149	−0.056	−0.15	−0.016	−0.094	−0.12	−0.015	1	−0.275	−0.214
BGW	0.567*	0.445	0.594*	0.529	0.315	0.51	0.34	−0.275	1	0.510
CrH	0.467	0.380	0.351	0.325	0.154	0.753*	0.365	−0.214	0.51	1

MnRB: Minimum ramus breadth, MxRB: Maximum ramus breadth, ML: Mandibular length, BB: Bicondylar breadth, MI: Mandibular index, RH: Ramus height, MBH: Mandibular body height, GA: Gonial angle, BGW: Bigonial width, CrH: Coronoid height *$P<0.05$-statistically significant

Table 3: Stepwise discriminant function analyses for sex determination from the mandible

Variable	Eigenvalue	Canonical correlation	Wilks's lamda	Chi-square	df	Significance	Demarking point
MinRB	0.12	0.327	0.893	43.164	1	0.000*	26.13
MaxRB	0.069	0.253	0.936	25.321	1	0.000*	31.38
Mandible length	0.068	0.252	0.936	25.110	1	0.000*	85.99
BB	0.027	0.162	0.974	10.154	1	0.001*	186.15
MI	0.001	0.028	0.999	0.290	1	0.59	46.20
RH	0.260	0.454	0.794	88.0404	1	0.000*	64.76
MBH	0.168	0.379	0.856	59.257	1	0.000*	27.15
GA	0.007	0.085	0.993	2.754	1	0.097	123.24
BGW	0.098	0.299	0.911	35.68	1	0.000*	170.11
CrH	0.268	0.460	0.788	90.659	1	0.000*	52.79

MnRB: Minimum ramus breadth, MxRB: Maximum ramus breadth, ML: Mandibular length, BB: Bicondylar breadth, MI: Mandibular index, RH: Ramus height, MBH: Mandibular body height, GA: Gonial angle, BGW: Bigonial width, CrH: Coronoid height: df- degree of freedom *$P<0.05$-statistically significant

Table 4: Eigenvalue, canonical correlation, and significance level for the two best variables (CrH and MBH)

Discriminant function	Eigenvalue	Canonical correlation	Wilks's lamba	Chi-square	df	Significance
Function	0.325	0.495	0.755	107.07	2	0.000*

*$P<0.05$-statistically significant, CrH: Coronoid height, MBH: Mandibular body height; df- degree of freedom

Table 5: Unstandardized and standardized discriminant function coefficients, structure matrix, centroids, and constant for direct discriminant function analyses

Variable	Unstandardized coefficient	Standardized coefficient	Structure matrix	Centroids	Constant
Minimum ramus breadth	0.081	0.243	0.572	Females	−8.584
Maximum ramus breadth	−0.002	−0.007	0.433	−0.604	
Mandibular length	0.016	0.143	0.431	Male	
BB	−0.014	−0.222	0.271	0.604	
MI	−0.091	−0.283	0.046		
RH	0.037	0.209	0.842		
MBH	0.128	0.379	0.677		
GA	0.004	0.033	−0.141		
BGW	0.001	0.015	0.517		
CrH	0.103	0.856	0.856		

MnRB: Minimum ramus breadth, MxRB: Maximum Ramus breadth, ML: Mandibular length, BB: Bicondylar breadth, MI: Mandibular index, RH: Ramus height, MBH: Mandibular body height, GA: Gonial angle, BGW: Bigonial width, CrH: Coronoid height

used to construct the actual prediction equation in order to calculate the discriminant scores that can be used to classify new cases from the raw data. To calculate this, the means of each variables are first multiplied with their unstandardized coefficients and the results are then added together to the constant. The sum is finally compared with the sectioning point (0.604), which indicates the score of separation. If the result is a negative value, the person is female and *vice versa*. The canonical correlation of 0.518 was found when all 10 variables were used with high significance ($P = 0.000$).

Discriminant function formula derived for selected population

-8.584 + Mn RB × 0.081 -Mx RB × 0.002 + ML × 0.016 - BB × 0.014-MI × 0.091 + RH × 0.037 + MBH × 0.128 + GA × 0.004 + BGW × 0.001 + Cr H × 0.103

For example, when the mean values of 10 variables [Table 1] are substituted in the formula,
-8.584 + 23.85 × 0.081-27.22 × 0.002 + 77.95 × 0.016-170.85 × 0.014-45.72 × 0.091 + 57.3 × 0.037 + 23.98 × 0.128 + 124.1 × 0.004 + 152.23 × 0.001 + 47.95 × 0.103

The resultant value is -1.237, which indicates female gender (-1.237 < 0.604).

Multivariate and cross-validation classification using "leave-one-out" method was used for all calculations. Table 7 shows the classification accuracy of the original and cross-validated samples. Independently, each variable provides a certain percentage of certainty about the sex of the mandible in an unknown sample. It was noted that MnRB alone could classify the sex in 60.7% of the cases, MxRB in 55.5% of the cases, ML in 62.5% of the cases, BB in 64.1% of the cases, MI in 50% of the cases, RH in 70.6% of the cases, MBH in 67.4% of the cases, GA in 51.6% of the cases, BGW in 62% of the cases, and CrH in 74.7% of the cases (highest accuracy). The average accuracy in determining sex by using all the ten variables was 75.8%.

ROC analyses make it easy to rank the mandibular measurements according to their validity in discriminating males from females. The larger the ROC area from 0.6, the more valid the variable was, as shown in Table 8. All the parameters measured were found to be good in sex differentiation except for GA and MI (<0.6 ROC area). The sensitivity and specificity for all the 10 variables were provided for three cutoff values; the highest sensitivity, specificity, and the optimum cutoff value taken as the best value that separate male from female [Table 9]. For instance, when MnRB was ≥19.85 mm, it was 100% sensitive in predicting the male gender and as it increased to 32 mm, it was 100% specific in establishing the diagnosis of the male gender. Similarly, when CrH was ≥32.1 mm, it was 100% sensitive in predicting the male gender and as it increased to 67.25 mm, it was 100% specific in establishing the diagnosis of the male gender.

Discussion

The accurate and reliable estimation of biological sex has a growing demand for the identification of unknown human remains in forensic cases. Marked significant differences have been found between male and female mandibles in various populations studied previously,[13] and this helps us to predict the sex in unidentified mandibles. All the sexually dimorphic variables are influenced by the size of the mandible. It can be explained by genetically determined factors such as the size of teeth and by local environmental factors such as muscle forces exerted during mastication.[13,14] Ten mandibular variables have been measured in the present study and discriminant function analysis was performed to determine sex in the South Indian (Visakhapatnam) population.

Table 6: Eigenvalue, canonical correlation, and significance level for the direct discriminant function of all variables

Discriminant function	Eigenvalue	Canonical correlation	Wilks's lamba	Chi-square	df	Significance
Function	0.366	0.518	0.732	117.663	10	0.000*

*$P < 0.05$-statistically significant

Table 7: Classification accuracy of the original and cross validated samples in analyzed sample

Variable	Predicted group membership (original) %		Predicted group membership (cross-validation) %		Accuracy (original) %	Accuracy (cross-validation) %
	Male	Female	Male	Female		
MinRB	57.80	63.50	57.80	63.50	60.70	60.70
MaxRB	53.60	57.30	53.60	57.30	55.50	55.50
Mandible length	65.60	59.40	65.60	59.40	62.50	62.50
BB	70.30	57.80	70.30	57.80	64.10	64.10
MI	52.60	47.40	52.60	47.40	50.00	50.00
RH	72.40	68.80	72.40	68.80	70.60	70.60
MBH	64.60	70.30	64.60	70.30	67.40	67.40
GA	52.60	50.50	52.60	50.50	51.60	51.60
BGW	66.10	57.80	66.10	57.80	62.00	62.00
CrH	75.50	74.00	75.50	74.00	74.70	74.70
All variables together	76.60	75.00	75.50	71.90	75.80	73.70

MnRB: Minimum ramus breadth, MxRB: Maximum Ramus breadth, ML: Mandibular length, BB: Bicondylar breadth, MI: Mandibular index, RH: Ramus height, MBH: Mandibular body height, GA: Gonial angle, BGW: Bigonial width, CrH: Coronoid height

Table 8: ROC area for selected tested parameters when used to predict sex

Variable	Area under the curve (ROC area)	*P*
MnRB	0.678	0.000*
MxRB	0.633	0.000*
ML	0.660	0.000*
BB	0.689	0.000*
MI	0.513	0.656
RH	0.798	0.000*
MBH	0.728	0.000*
GA	0.442	0.051
BGW	0.678	0.000*
CrH	0.797	0.000*

MnRB: Minimum ramus breadth, MxRB: Maximum ramus breadth, ML: Mandibular length, BB: Bicondylar breadth, MI: Mandibular index, RH: Ramus height, MBH: Mandibular body height, GA: Gonial angle, BGW: Bigonial width, CrH: Coronoid height *$P<0.05$-statistically significant

Table 9: Validity parameters for selected cutoff values for all tested variables when used to predict

Positive if ≥cutoff value	Sensitivity	Specificity
Minimum ramus breadth		
19.85 (Highest sensitivity)	100.00	7.30
25.25 (Typical cutoff)	72.40	49.00
32.00 (Highest specificity)	6.80	100.00
Maximum ramus breadth		
23.30 (Highest sensitivity)	100.00	4.20
30.55 (Typical cutoff)	70.30	47.90
38.95 (Highest specificity)	4.20	100.00
Mandibular length		
32.00 (Highest sensitivity)	100.00	1.0
83.75 (Typical cutoff)	71.90	42.70
99.15 (Highest specificity)	4.20	100.00
Bicondylar breadth		
78.70 (Highest sensitivity)	100.00	0.00
183.55 (Typical cutoff)	77.60	50.50
217.40 (Highest specificity)	1.0	100.00
Mandibular index		
40.00 (Highest sensitivity)	100.00	3.10
44.55 (Typical cutoff)	72.40	31.80
55.20 (Highest specificity)	0.00	100.00
Ramus height		
36.20 (Highest sensitivity)	100.00	0.00
63.70 (Typical cutoff)	83.30	63.50
76.15 (Highest specificity)	5.70	100.00
Mandibular body height		
18.15 (Highest sensitivity)	100.00	1.00
25.95 (Typical cutoff)	81.30	50.00
33.95 (Highest specificity)	2.10	100.00
Gonial angle		
102.99 (Highest sensitivity)	100.00	1.00
118.47 (Typical cutoff)	67.20	37.60
146.74 (Highest specificity)	2.10	100.00
Bigonial width		
120.00 (Highest sensitivity)	100.00	0.00
167.45 (Typical cutoff)	73.40	50.50
193.40 (Highest specificity)	8.90	100.00
Coronoid height		
32.10 (Highest sensitivity)	100.00	0.00
50.15 (Typical cutoff)	86.50	50.50
67.25 (Highest specificity)	2.10	100.00

In the present study, each of the 10 variables except GA showed higher mean values in males compared to females ($P < 0.05$), indicating that the selected variables express strong sexual dimorphism in South Indians. To ensure the reliability and validity of measurements, intraobserver errors were assessed and they showed good reliability. Moreover, considering the sexual dimorphism ratios, the variables CrH, MBH, RH, MnRB, MxRB, and ML showed high index values, CrH being the highest with a value of 110.74. The best parameters are CrH, similar to a previous study,[11] and MBH followed by RH. The variables of least use for discrimination are GA and MI; this might be because of population differences in size and the expression of dimorphism.

The accuracy of sexing a mandible while using a single variable varies from 50% (MI) to 74.7% (CrH). Overall, the prediction rate using all 10 variables was 75.8%, with females more accurately determined than males. Previous studies[13,15] conducted for assessing the sex using the mandible had shown that sexual differences were highest in RH.

A number of metric studies have been performed using dry mandibles or radiographs of the mandible measuring different parameters to determine the sex and the results of these studies cannot be strongly compared with the present study as the mandibular variables measured in individual studies varied.

Giles[2] reported RH, MxRB, and MnRB that accounted for an accuracy of 85% in American Whites and African Americans for sex identification. Dayal *et al*.[16] found RH as the best parameter with an accuracy of 75.8% in sex determination, which is higher than the present study (70.6%). Steyn and Iscan[17] achieved an accuracy of 81.5% with five parameters (bigonial breadth, total mandibular length, BB, MnRB, gonion-gnathion) of the mandible in South African Whites and showed that bigonial breadth was the most dimorphic. Franklin *et al*.[18] reported a very high accuracy of 95% with 10 variables in South Africans and also showed that RH and CrH achieved an accuracy of 87.5%, which is higher than the present study.

It was also observed that breadth measurements, which were usually found to be more dimorphic,[2,19] did not show high sexual differences in the present study, similar to the study of Saini *et al*.,[11] which reported an overall accuracy

of 80.2% with five parameters (CrH, projective height of ramus, condylar height, MxRB, MnRB) and also found that CrH was the best variable providing an accuracy of 74.1%, in agreement with the present study.

Thakur *et al*.[20] found that the mean values of GA and RH were found to be greater in males compared to females but in the present study, GA values were greater in females than males and were not statistically significant ($P > 0.05$), in agreement with previous studies.[21,22]

In the present study, MnRB showed significant differences between males and females ($P < 0.05$) in agreement with previous studies[14,23] and showed an accuracy of 60.7%. Pokhrel and Bhatnagar[24] achieved an accuracy of 82.9% with MnRB and MxRB in Indians using four variables, which was higher compared to the present study.

Saini *et al*.[25] reported a high accuracy of 67.4% with MBH, similar to the present study and got 65.3% accuracy with MxRB and 63.2% with MnRB in the North Indian population using five variables, slightly higher compared to the present study. Vodanovic *et al*.[19] found that MBL, GA, MnRB were highly significant for differentiating sex providing an accuracy of 88.2% in the Croatian population, which was higher compared to the present study.

Marinescu *et al*.[26] reported an accuracy of 80.5% with BGW in the Romanian population, which was higher than the present study (62%). Sharma *et al*.[21] utilized three variables (MBL, GA, MnRB) and achieved an overall accuracy of 60% in determining sex in the Indian population, which was lower than the present study.

Indira *et al*.[23] did a study using five variables (MxRB, MnRB, condylar height, projective height of ramus, CrH) in a population in Bangalore, Karnataka, India and achieved an accuracy of 76% in determining sex. Wankhede *et al*.[27] did a study in the Central Indian population using 10 mandibular variables and achieved an accuracy of 75.6% with BB, 70.7% with BGW, 80.5% with MnRB, and an overall accuracy of 85.4% with 10 parameters, which were higher compared to the present study.

Kharoshah *et al*.[28] stated that BB, GA, and MnRB showed significant differences between males and females in the modern Egyptian population. Al-shamout *et al*.[5] investigated three mandibular parameters (GA, RH, and BGW) and showed that these variables were higher in males compared to females in the Jordanian population.

In agreement with previous studies,[14,29-31] Vinay *et al*.[32] found that the mean values of bigonial breadth, BB, ML, and MI were higher in males compared to females, as observed in the present study. Kranioti *et al*.[33] reported a high accuracy of 71% with bigonial breadth and 69% accuracy with BB for sex determination using five variables in the Greek population, which were higher compared to the present study.

In agreement with previous studies,[23,34,35] an overall accuracy of 75.8% was achieved using 10 variables in the present study, which was lower compared to previous studies[2,11,17,19,24,26,36] conducted with different numbers of variables in different populations.

Analyzing the demarking point plays an important role in identifying the sex when a single variable is available as in incomplete or mutilated mandibles. It can be observed from the means of the variables that the minimum and maximum ranges of males were higher than those of females [Table 1]. Therefore, statistically one can find whether the given sample is of a male or a female by comparing with the stated dimension and referring the demarking point.

Also, in the present study high sensitivity and specificity with typical cutoff values for each variable have been assessed and it was also concluded that these measurements were sensitive parameters to predict the male gender and differentiate it from the female gender and could be applied successfully in forensic dentistry.

It has been established that inherited hormonal or endocrine growth factors and socioeconomic factors may contribute to a lower degree of sexual dimorphism.[37] As the present study was conducted retrospectively, these factors were not controlled in this study.

Conclusion

Sex determination is of great importance in anthropological and medicolegal aspects. The mandible is unique and contains significantly distinctive variables for sex identification, even in badly burnt bodies. In the present study, every parameter, independent of other parameters provided a certain percentage of certainty about the sex of the mandible of a person of unknown sex. All the variables in this study exhibited great sexual dimorphism except for GA and were found to be reliable in the sex prediction of unknown skeletal remains, providing an overall accuracy of 75.8% in the selected population.

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Conflicts of interest
There are no conflicts of interest.

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