Sexual dimorphism and population variation in mandibular variables: a study on a contemporary Indian population

Vineeta SAINI1,*, Aman CHOWDHRY2, Mitalee MEHTA3

1Department of Forensic Science, Faculty of Science, Shree Guru Gobind Singh University, Gurugram, Haryana-122005, India
2Department of Oral & Maxillofacial Pathology, Faculty of Dentistry, Jamia Millia Islamia (Central University), Jamia Nagar, New Delhi-110025, India
3School of Internal Security and Police Administration, Rashtriya Raksha University, Gandhinagar, Gujarat-382305, India

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Abstract  Sexual dimorphism in a population varies over time due to temporal changes and data on this need to be updated regularly. Further, each population needs its own sex-discriminating anthropometric standards, which can be used on unknown skeletal remains of that population. Sex estimation of fragmented, buried, or burnt remains in which sex-discriminating morphological traits are often impossible to discern presents a huge problem for anthropologists, archaeologists, and forensic experts. The mandible—a strong bone usually found with other skeletal remains—is considered highly sexually dimorphic.

In the current study, we investigated the reliability of mandibular dimorphism for sex estimation using 17 variables in the contemporary Indian population. The study included 385 adult mandibles of known sex and age collected from the two medical colleges in northern India. After the measurement of all variables, they were subjected to discriminant function analysis. All variables showed significantly larger dimensions in males except one. The most dimorphic variables included length measurements followed by height; breadth measurements were the least dimorphic. The gonion–gnathion length emerged as the most dimorphic parameter, with sexing of 79.5%. The stepwise and direct analysis resulted in 81.1% and 84.7% accuracy, representing the mandible as highly dimorphic. Factors that affect sexing accuracy and selection of the best variables are also explored and discussed.

Key words: population variation, sexual dimorphism, fragmentary mandible, discriminant function analysis, forensic anthropology

Introduction

Sex estimation from fragmented or isolated skeletal remnants is of prime significance in forensic science, anthropology, and archaeology. In forensic anthropology, it is also a necessary step for creating the biological profiling and the artistic recreation of facial structures from an unknown skull to establish identity (Iscan and Kennedy, 1989; Chowdhry, 2018). Despite advances in DNA fingerprinting, anthropometric methods are still in demand because the molecular techniques are highly sophisticated, invasive, expensive, complicated, time-consuming, and require high-level skills to interpret the results (Adel et al., 2019). Alternatively, anthropometric studies are pivoted on the sexual dimorphism in the body/skeletal dimensions of both sexes. These studies frequently use diverse statistical methodologies to derive discriminant equations that can be utilized to determine sex even in fragmentary and burnt bone cases, and their results are easy to interpret (Adel et al., 2019; Cavazzuti et al., 2019).

From the human evolutionary perspective, the study of sexual dimorphism explains the reasons for the lesser dimorphism in *Homo sapiens* compared to their pre-human ancestors (Kittoe, 2013). In addition, bioarchaeologists try to re-create the demographic information of historic and ancient populations by using their knowledge of sexual dimorphism (Kittoe, 2013). The fragility of facial bones makes these more prone to be destroyed intentionally or through unending taphonomic processes. In such situations, the mandible is considered the best bone because it is one of the largest, strongest, most dimorphic, and frequently recovered bones of the skull in archaeological and forensic cases. It has been extensively studied with the view of exploring population variation in different hominins and evolutionary perspectives. Studies revealed that intra- and interpopulation variability in mandibular form is created when minuscule changes develop in a geographically isolated population and the amount of stress, in the form of physical friction and changes occurring over the period, varies in both sexes (Spradley,
Some mandibular features are strongly inherited, but the shape and size are strongly influenced by dietary and environmental forces during the lifetime. The skull is considered the best skeletal element to study inherited features or features that change due to variation in diet from one generation to the next (Spradley, 2006; Green, 2007; Saini et al., 2017). A greater frequency of some anatomical structures has been observed in certain population groups, indicating a common geographical origin, e.g. rock-er shape mandibles in the Polynesian people (Dennison et al., 2007). The Polynesian population and the indigenous peoples of maritime Southeast Asia, Madagascar, and Tai-wan share the same origins. Further, the role of the mandible in chewing exposes it to various masticatory forces (depend-ing on the diet in different geographical regions) and results in inter- and intrapopulation variation in its shape and size. Thus, the study of variations in the human mandibular form may assist anthropologists in comprehending migration patterns, masticatory practices, and biological relatedness with other population groups.

To understand biological adaptation in response to chang-ing climate and environment, anthropologists traditionally research morphological variation among historically migrat-ed and diverse population groups of humans. Although most anthropologists no longer support the biological definition of defined human races, forensic anthropologists are re-quired to explore ancestral/ethnic variation among different population groups (Kitttoe, 2013). Due to extreme variabil-i-ties in climatic conditions, customs and traditions, hygiene practices, eating habits, etc., differences in anthropometric data from north to south and west to east India are apparent. Hence, it is crucial to collect population data on at least a statewise basis. Additionally, anthropometric standards for biological profiling must be developed from a large sample of the recent (contemporary) population if it is to be applied in the field of criminal justice and updated periodically. The updating of anthropometric standards is necessary to nullify the effect of temporal/secular changes and gradual evolution in progeny due to environmental changes as well as to inter-caste, inter-religion, and inter-country marriages which were not so common in the last century, at least in India.

Due to the main method of body disposal in India (cremation of the body on a funeral pyre for Hindus), it is challeng-ing to obtain skeletons for anthropometric studies. A very few minority communities prefer to bury their dead, but these bodies cannot be excavated for the sake of communal harmony. Therefore, India does not have documented skeleton collections of various periods. Most of the skeletal assem-blage in medical colleges has been collected from donat-ed or unclaimed and unidentified bodies sent for post-mortem examination. All these circumstances hinder anthropometric studies on bare bones in India. Therefore, most studies have been done in forensic or clinical contexts on contemporary living populations using various imaging techniques.

Some previous anthropometric studies performed world-wide have incorporated living populations (computed to-mography scans, cephalograms) or non-living specimens (bare mandible) (Giles, 1964; Vodanovic et al., 2006; Franklin et al., 2008; Saini et al., 2011; Adel et al., 2019). It should be noted that most of these studies have utilized dis-criminant function analysis (DFA).

DFA is utilized to derive continuous variables that can discriminate between two or more naturally occurring groups (Steyn and Işcan, 1998) and is highly suited for foren-sic sex estimation due to its simplicity and accuracy. DFA has been frequently used for developing sex discriminant functions on diverse population groups as skeletal characteristics vary by population (Poulsen and French, 2008; Dong et al., 2015; Lopez-Capp et al., 2018; Saini, 2019). Bertsatos et al. (2019) demonstrated this fact very precisely in their study. In parallel, anthropologists have advocated continu-ous updating of anthropometric standards due to secular/temporal changes (Frohlich and Pedersen, 1992; Martin and Danforth, 2009; Heim, 2013). These changes occur in a pop-ulation due to changes in heritability (intermixing of the population), economic and social reforms, better nutrition, changing food habits, etc.

In recent years, some appreciable efforts have been made to create discriminant functions, including adequate sample size (Franklin et al., 2008; Lin et al., 2014; Dong et al., 2015; Bertsatos et al., 2019). Saini et al. (2011) examined the utility of the mandible using five variables in a northern Indian population and found encouraging results, but they also ac-knowledged the limitation of their small sample size (n = 116 mandibles; male:female, 92:24). The present re-search overcomes this restriction. Hence, the present study is designed to derive sex discriminant functions for a northern Indian population using contemporary mandibles and pro-vide an overview of factors affecting sexing accuracy in a population. To prove that the used variables are quite popu-lation-specific, they are compared to other Indian (other states of India) and non-Indian populations.

Materials and Methods

A total of 385 adult mandibles from the contemporary population of northern India were selected from the Depart-ment of Forensic Medicine and Toxicology, Institute of Medical Sciences, Banaras Hindu University (BHU), Vara-nasi, and from the Anthropology Museum of Anatomy De-partment, Ganesh Shankar Vidyarthi Medical College (GSVM), Kanpur, India. The sample collected in BHU is a modern/recent forensic sample collected from 2006 to 2011. After obtaining ethics clearance, the autopsied, unclaimed bodies were taken for anatomic and forensic anthropological study. The bones of interest (mandible and cranial bones) were collected from the autopsy register maintained in the department.

The GSVM sample is a museum collection started in 1954 that mainly contains skulls of unclaimed bodies of patients who were left in the associated Hallet Hospital (Kanpur) and is an ongoing project. The experienced anatomists of the department estimated the age and sex. Both samples represent the con-temporary population of northern India. Details about the samples were provided by Saini (2014) and Saini et al. (2014). The number of males and females with age range and mean age (at the time of death) are provided in Table 1.
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Exclusion criteria
All pathological, fractured, deformed, and edentulous mandibles were excluded from the study sample. Female mandibles were limited as compared to males in the BHU sample as these were forensic samples.

Definition of mandibular measurements
In the present study 17 variables were considered, including 16 standard variables provided by various researchers (Buikstra and Ubelaker, 1994; Singh and Bhasin, 2004), and one newly developed unconventional measurement (Table 2, Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, Figure 6).

All the variables were measured with sliding calipers (0.1 mm precision) except the maximum length of the mandible (mandibulometer). All the variables were measured three times, and the mean values were used for the analysis to curtail intraobserver error.

In addition to this, an exhaustive comparison has been carried out to compare the population variation. Out of 17 variables, 10 are used for the comparison. The mean values of the present mandibular variables are compared with 7 other Indian populations and 10 non-Indian populations.

Statistical analysis
The statistical analysis was computed using SPSS v. 16.0 (SPSS Inc., Chicago, IL, USA). The one-sample Kolmogorov-Smirnov test was used to examine the normal distribution of the sample.

Descriptive statistics with independent t-test and sexual dimorphism index (SDI) were obtained for each of the variables using the formula given below.

$$\text{SDI} = \left( \frac{\text{male mean} - \text{female mean}}{\text{male mean}} \right) \times 100$$

This index shows the sexual differences in percentage (%) and is termed the sexual size dimorphism index or percentage of dimorphism (%D) (Samal et al., 2007).

An independent sample t-test is used to measure the differences between means of two groups, i.e. male and female.

### Table 1. Details of number of mandibles and age

| Samples | Males | Female | Total |
|---------|-------|--------|-------|
| BHU     | 145   | 45     | 190   |
| GSVM    | 100   | 95     | 195   |
| Total   | 245   | 140    | 385   |
| Age range | 18–70 years | 20–60 years | 18–70 years |
| Mean age at death | 38.58 years | 31.75 years |

### Table 2. Description of mandibular measurements (metric traits)

| S No | Name of the metric trait | Description |
|------|--------------------------|-------------|
| 1    | Bicondylar breadth [BConBr] | The straight distance between the most lateral points on the two condyles (cdl) (Figure 1) |
| 2    | Bicoronoid breadth [BCorBr] | The straight distance between two coronia (cr) (Figure 2) |
| 3    | Bigonial width [BGoBr] | Direct distance between gonions of both left and right side (go) (Figure 2) |
| 4    | Bimental breadth [BMbBr] | The straight distance between both mental foramens of left and right side (Figure 2). |
| 5    | Mandibular symphysis height/chin height [MSHt] | The straight distance from infradentale (id) to gnathion (gn) (Figure 2) |
| 6    | Coronoid height [CoHt] | Projective distance between coronion (cr) and lower border of mandible (Figure 3) |
| 7    | Maximum ramus height [MaxRHt] | Height of the ramus of the mandible: measured from condylion superior (cs), to the tubercle or most protruding portion of the inferior border of the ramus (Figure 3) |
| 8    | Projective height of ramus [PrRHt] | Projective height of ramus between the highest point of the mandibular capitulum (cs) and lower margin of the bone (Figure 3) |
| 9    | Mandibular body height [MBHt] | The straight distance from the alveolar process to the inferior border of the mandible perpendicular to the base at the level of the mental foramen (Figure 3) |
| 10   | Maximum ramus breadth [MaxRBr] | The straight distance between the most anterior point on the mandibular ramus and a line joining the most posterior point on the condyle and the angle of the jaw (Figure 3) |
| 11   | Minimum ramus breadth [MinRBr] | Least breadth of the mandibular ramus measured perpendicular to the height of the ramus (Figure 3) |
| 12   | Condylar height/ramus height [ConHt] | Straight distance from the highest point on the mandibular condyle (cs) to gonion (go) (Figure 4) |
| 13   | Mandibular body length [MBLt] | The straight distance between gnathion (the most basal point of the symphysis) and the most protruding portion of the inferior border of the ramus (unconventional) (Figure 4) |
| 14   | Maximum length of mandible or maximum projective length of the mandible [MaxMLt] | The distance between the points on the anterior mandible to the tangent drawn to the posterior surface of both the condyles (Figure 5) |
| 15   | Breadth of condyle [ConBr] | The straight distance between the most anterior and most posterior point of the mandibular condyle (Figure 5) |
| 16   | Length of condyle [ConL] | Distance between the most lateral and the most medial point of the mandibular condyle (Figure 5) |
| 17   | Gonion–gnathion length [GoGnLt] | The straight distance between gnathion (the most basal point of the symphysis) and gonion (point on the gonional perimetrum which crosses the bisectrix of the angle defined by the tangents to the posterior margin of the ramus and the basal border) (Figure 6) |
Figure 1. Mandibular measurements: bicondylar breadth (cdl–cdl).

Figure 2. Mandibular measurements: mandibular symphysis height (id–gn), bimalental breadth (MF–MF), bicornoid breadth (cr–cr), and bigonial breadth (go–go).

Figure 3. Mandibular measurements: projective ramus height (PrPHt), maximum ramus breadth (MaxRBr), minimum ramus breadth (MinRBr), coronoid height (CoHt), mandibular body height (MBHt), and maximum ramus height (MaxRHI).

Figure 4. Mandibular measurements: condylar height (ConHt) and mandibular body length (ManBLt).

Figure 5. Mandibular measurements: maximum length of mandible (MaxMLt), condylar length (ConLt), and condylar breadth (ConBr).

Figure 6. Mandibular measurements: goniom-gnathion length (go–gn).
and the extent of overlap between the mean values of the male and female distributions.

A descriptive analysis is followed by stepwise discriminant analysis. Subsequently, univariate and multivariate direct DFA was performed to calculate discriminant functions which can be utilized for sex estimation in fragmentary mandibles. A cross-validation procedure is used to estimate test error and reduces the high prediction accuracy. This procedure is used to test the particular discriminant function's capability to estimate the predictive classification accuracy on a set of unknown datasets. Although it does not improve the accuracy, it reduces the overfitting or overestimation and selection bias of a discriminant function. Thus, it is used to test the overall effectiveness of the function. A ‘leave one out classification’ method was used for this purpose.

To determine the population specificity of the mandibular variables, the Z-score is calculated using the following formula:

\[ Z \text{-score} = \frac{\text{observed value} - \text{population mean}}{\text{population standard deviation}} \]

where \( x \) is the observed value, \( \mu \) is the average/mean of the reference population, and \( \sigma \) is the standard deviation of the reference population (Mei and Grummer-Strawn, 2007; Jayaratne and Zwahlen, 2014). The first way to find the \( Z \)-score is to use the \( Z \)-table. In the \( Z \)-table, the left column will show values to one decimal place, while the top row will show values to two decimal places. If we have a \( Z \)-score of –1.30, we need to round this to two decimal places, or –1.30. In the left column, we will first find the first decimal place, or –1.3. In the top row, we will find the second decimal place, or 0.

The use of the \( Z \)-score also has some limitations. It always assumes a normal distribution of the data. If this assumption is not met, the scores cannot be interpreted as a standard proportion of the distribution from which they were calculated. Furthermore, the calculation of the \( Z \)-score may result in the magnification of slight differences (Mei and Grummer-Strawn, 2007).

Results

Table 3 shows the descriptive data for mandibular measurements of the contemporary population. Altogether the variables showed significantly larger dimensions in males except for ConBr. After careful observation, it has been noted that the height measurements exhibited maximum sexual dimorphic indices. The single best variable was GoGnLt followed by MaxMLt.

It has been observed that biological variations in mandibles, reading or recording mistakes by the observer, or any instrumental problem, may cause subjective errors in measurements. Therefore, a paired \( t \)-test was carried out to assess such errors committed by the observer. The result depicts (Table 4) a high correlation and non-significant differences between the two measurements of each variable, which were taken at first and second instances by the same observer.

| Variables | Male \( (n = 245) \) | Female \( (n = 140) \) | \( t \)-value | Significance | SDI | SA |
|-----------|-----------------|-----------------|-------------|-------------|-----|-----|
| BConBr    | 112.28 ± 5.74   | 106.66 ± 4.13   | 6.097       | 0.000***    | 5.01 | 67.4 |
| BGoBr     | 94.31 ± 6.24    | 86.96 ± 5.45    | 7.092       | 0.000***    | 7.79 | 73.7 |
| BMelBr    | 43.51 ± 2.92    | 42.19 ± 2.86    | 2.654       | 0.009**     | 3.03 | 57.4 |
| MaxRBr    | 42.58 ± 3.5     | 39.52 ± 3.67    | 5.122       | 0.000***    | 7.19 | 65.6 |
| MinRBr    | 31.22 ± 2.96    | 29.48 ± 2.58    | 3.649       | 0.000***    | 5.59 | 63.6 |
| BCBr      | 91.31 ± 5.53    | 87.29 ± 3.75    | 4.554       | 0.000***    | 4.4  | 69.5 |
| ConBr     | 8.49 ± 1.22     | 8.28 ± 1.18     | 1.055       | 0.297       | 2.5  | 49.2 |
| MSHT      | 30.3 ± 3.28     | 26.93 ± 3.26    | 6.025       | 0.000***    | 11.12| 69.5 |
| MaxRHT    | 63.26 ± 5.47    | 57.3 ± 3.67     | 6.835       | 0.000***    | 9.42 | 74.7 |
| ConHt     | 57.68 ± 4.62    | 52.63 ± 3.51    | 6.756       | 0.000***    | 8.76 | 71.6 |
| PrRHT     | 53.42 ± 6.53    | 48.33 ± 4.94    | 4.809       | 0.000***    | 9.53 | 68.4 |
| MBHT      | 28.89 ± 3.17    | 25.66 ± 2.98    | 5.142       | 0.000***    | 9.7  | 67.7 |
| CoHt      | 61.69 ± 5.33    | 55.73 ± 3.8     | 6.97        | 0.000***    | 9.66 | 71.1 |
| MBLt      | 75.38 ± 4.26    | 70.57 ± 3.31    | 6.949       | 0.000***    | 6.38 | 71.3 |
| GoGnLt    | 81.28 ± 4.1     | 75.35 ± 3.08    | 8.924       | 0.000***    | 7.3  | 79.5 |
| MaxMLt    | 102.2 ± 5.56    | 95.7 ± 4.49     | 7.145       | 0.000***    | 6.36 | 77.9 |
| ConLt     | 19.65 ± 1.87    | 18.46 ± 1.57    | 4.028       | 0.000***    | 6.12 | 65.8 |

* \( P < 0.05 \), significant; ** \( P < 0.01 \), moderately significant; *** \( P < 0.001 \), highly significant.
Table 5 gives the results of the stepwise analysis for mandibular measurements. Out of 17 (except the breadth of condyle), five variables (GoGnLt, MSHt, BConBr, BMeBr, MaxRHt) are selected in the stepwise analysis.

Table 6 provides the canonical discriminant functions of the mandible for the northern Indian population. We computed both univariate and multivariate discriminant functions for all the measurements. But the univariate functions did not reach more than 79.5%. In the stepwise analysis, function 1 is created and provided an accuracy of only 81.1%. Then several multivariate functions were computed using direct analysis, but functions providing accuracy ≥79.5%

Table 4. Showing results of paired *t*-test (intra-observer error).

| Variables | Correlation | *t*-values | Significance (two-tailed) |
|-----------|-------------|------------|--------------------------|
| BConBr    | 1           | 0.635      | 0.541                    |
| BGoBr     | 1           | 0.37       | 0.72                     |
| BMeBr     | 1           | -0.747     | 0.474                    |
| MaxRBr    | 1           | -0.396     | 0.701                    |
| MinRBr    | 1           | 0.409      | 0.692                    |
| BCBr      | 1           | 0.149      | 0.892                    |
| ConBr     | 1           | 0.222      | 0.83                     |
| MSHt      | 1           | -2.083     | 0.067                    |
| MaxRHt    | 0.998       | 0.791      | 0.449                    |
| ConHt     | 0.998       | 0.925      | 0.379                    |
| PrRht     | 1           | -0.413     | 0.689                    |
| MBHt      | 1           | -1.821     | 0.102                    |
| CoHt      | 0.999       | 1.874      | 0.094                    |
| MBLt      | 0.997       | -0.425     | 0.68                     |
| GoGnLt    | 0.181       | 0.703      | 0.794                    |
| ConLt     | 0.999       | 1          | 0.343                    |

Table 5. Stepwise discriminant function analysis for contemporary mandibles.

| Functions and variables | Wilks’ lambda | Eq. F ratio | Degrees of freedom |
|-------------------------|---------------|-------------|--------------------|
| GoGnLt                  | 0.702         | 79.638      | 1383               |
| MSHt                    | 0.658         | 48.609      | 2382               |
| BConBr                  | 0.634         | 35.841      | 3381               |
| BMeBr                   | 0.613         | 29.251      | 4380               |
| ConHt                   | 0.598         | 24.714      | 5379               |

Table 6. Discriminant function analysis with original (O) and cross validated (C) classification accuracies for mandibular measurements of contemporary sample.

| Functions and variables | Raw coefficients | Standardized coefficients | Structure coefficients | Centroids | Males n = 290 | Females n = 140 | Accuracy N = 385 |
|-------------------------|------------------|---------------------------|------------------------|-----------|----------------|----------------|-------------------|
|                         |                  |                           |                        |           | O              | C              | O/C               |
| Stepwise analysis       |                  |                           |                        |           |                |                |                   |
| F1 BConBr               | 0.062            | 0.337                     | 0.543                  | M = .454  | 80.7           | 91.1           | 83.2/81.1         |
| BMeBr                   | -0.129           | -0.376                    | 0.236                  | F = -1.463| 77.2           | 88.9           | 80/79.5           |
| MSHt                    | 0.104            | 0.925                     | 0.536                  | SP = -0.505|                |                |                   |
| ConHt                   | 0.063            | 0.276                     | 0.601                  |            | 82.1           | 88.9           | 83.7/82.6         |
| GoGnLt                  | 0.181            | 0.703                     | 0.794                  |            |                |                |                   |
| (Constant)              | -22.364          |                           |                        |           |                |                |                   |
| Direct analysis         |                  |                           |                        |           |                |                |                   |
| F2 Go-GnLt (Constant)   | -0.257           | 1                         | 1                      | M = .361  | 84.8           | 88.9           | 85.8/84.2         |
| CoHt                    | 0.085            | 0.427                     | 0.718                  | F = -1.264|                | 82.1           | 88.9             |
| (Constant)              | -20.631          |                           |                        |           | 83.7           | 82.6           |                   |
| F3 Go-GnLt (Constant)   | -0.194           | 0.755                     | 0.919                  | M = .392  |                |                |                   |
| CoHt                    | 0.085            | 0.427                     | 0.718                  | F = -1.264| 82.1           | 88.9           | 83.7/82.6         |
| (Constant)              | -20.631          |                           |                        |           | 83.7           | 82.6           |                   |
| F4GoGnLt (Constant)     | -0.157           | 0.61                      | 0.433                  | M = 0.433 |                |                |                   |
| CoHt                    | 0.083            | 0.417                     | 0.651                  | F = -1.394|                |                |                   |
| BGoBr                   | 0.034            | 0.206                     | -1.394                 | SP = -0.481| 84.8           | 88.9           | 85.8/84.2         |
| BConBr                  | 0.072            | 0.389                     | 0.57                   |            |                |                |                   |
| ConLt (Constant)        | -0.211           | -0.369                    | 0.376                  |            | 84.8           | 88.9           | 85.8/84.7         |
| F5 GoGnLt (Constant)    | -0.145           | 0.563                     | 0.811                  | M = 0.445 |                |                |                   |
| CoHt                    | 0.07            | 0.35                      | 0.634                  | F = -1.433|                |                |                   |
| BGoBr                   | 0.036            | 0.221                     | 0.645                  | SP = -0.494| 84.8           | 88.9           | 85.8/84.7         |
| BConBr                  | 0.067            | 0.36                      | 0.554                  |            | 84.8           | 88.9           | 85.8/84.7         |
| ConLt                   | -0.21           | -0.366                    | 0.366                  |            |                |                |                   |
| MBHt (Constant)         | 0.078            | 0.243                     | 0.466                  |            | 86.2           | 93.3           | 87.9/83.2         |
| All variables           | —                | —                         | —                      | —          | 86.2           | 93.3           | 87.9/83.2         |
were included. Function 2 provided an accuracy of 82.6%.

Interestingly, the combination of different variables with the best parameter (GoGnLt) did not prove to be better in the case of the female, as females did not show any improvement in classification rate in all created functions (remaining at 88.9% in functions 3–5). However, males were better classified after adding other variables. The highest sexing accuracy (84.7%) was achieved by function 5 using six variables. Adding up all 16 variables also did not give good results, so the discriminant function is not given.

Table 7 compares the mean values between the present study and non-Indian (foreign) mandibular variables. After the calculation of the Z-score, a P-value was found to determine whether the difference between the two values is significant or not. The table shows that the minimum ramus breadth variable exhibited the highest number of populations having no significant difference between two respective mean values, which is ‘4.’ This indicates that the presented mandibular variables are highly specific for the specific population as far as the foreign populations are concerned.

Table 8 compares the mean values of present mandibular parameters with the mean values of other Indian populations’ (different states of India) mandibular parameters. After the calculation of the Z-score, a P-value was found to determine whether the difference between the two values is significant or not. From Table 8, we can find that most of the mandibular parameters of different states of India show a significant difference with the present work. When the mean values of two parameters of the population of Uttar Pradesh are compared with the present data, both of them showed that the difference between the respective mean values is not significant for both the parameters. This can be justified because the same source of material was used in both cases, i.e. the present work also features the population of Uttar Pradesh.

Discussion

The mandible is one of the best skeletal parts to assess sexual dimorphism and population variation as the developmental stage, rate of growth, time durations, and masticatory forces vary in males and females of different population groups. Additionally, continuous remodeling due to chewing forces, age, and occlusal status makes it more suitable for such studies.

Sexual dimorphism in the mandible

The mandible is considered the most sexually dimorphic bone in the skull, and the present study also illustrates a marked sexual dimorphism in the northern Indian population. It has been proven that morphological features whose development is linked to insertion and action of major muscle groups, e.g. the mandible, are found to be the best indicators of sex discrimination (Franklin et al., 2005; Suazo et al., 2009; Deng et al., 2017). In a previous study on the same population, the expression of muscular markings on the mandible was found to be the best of four morphological traits, namely chin shape, gonial flaring, the shape of the lower border, and mandibular muscle marking (Saini, 2017). Durić et al. (1999) also found the robustness of the mandible to be the most accurate (70.93%) dimorphic trait among cranial traits. Considering size variation, it is established that contemporary human female mandible is on average 7.8% smaller than the male mandible (Humphrey et al., 1999).

Even at birth, the mandibular bone and the masticatory muscles are on average 4–12% smaller in females (Coquerelle et al., 2011). It was also observed that mandibular variables show higher SDI than the craniofacial variables of the same population (Saini, 2014), and the highest SDI has been shown by MSHt (11.12%), i.e. the mandibular symphysis height is on average 11.12% higher in males than in females (Table 3). We also observed that the increased SDI is related to increase sexing accuracy to an extent.

Previous studies on various population groups have provided sex classification ranging from 70% to 95% using different variables of the mandible (Giles, 1964; Steyn and Iscan, 1998; Rosas and Bastir, 2002; Franklin et al., 2006; Vodanovic et al., 2006; Dayal et al., 2008; Franklin et al., 2008; Poulsen and French, 2008; Saini et al., 2011; Lin et al., 2014; Dong et al., 2015; Maloth et al., 2017; Bertatos et al., 2019). Humphrey et al. (1999) mentioned some of the initial studies by pioneers of anthropology on the mandible, which found the ramus to be the most dimorphic part of the mandible. Some of the population shows comparatively higher sexual dimorphism in breadth measurements of the ramus (MinRBr and MaxRBr) than the body height and length (Giles, 1964; Rosas and Bastir, 2002; Vodanovic et al., 2006; Dayal et al., 2008; Franklin et al., 2008). However, the most dimorphic parameters in our study were length measurements (GoGnLt and MaxMLt) followed by height measurements and least by breadth measurements, i.e. MinRBr and MaxRBr (Figure 7, Table 3).

Kieser and Groeneveld (1996) found gonion–gnathion length as the most dimorphic (78%) variable, which coincides with the current study where GoGnLt provided maximum accuracy (79.5%). A South African population showed ramus height as the most dimorphic (75.8%) mandibular variable (Dayal et al., 2008), which was found to be moderately dimorphic (71.6%) in the present study (Table 3). Various levels of sexing accuracy were achieved in different populations of the world using mandibular variables, i.e. 87% in South African Blacks (Franklin et al., 2008), 81.5% in South African Whites (Steyn and Iscan, 1998), 83.5% in contemporary adult Han Chinese (Dong et al., 2015), 88.8% in Koreans (Lin et al., 2014), 83.9% in Egyptians (Kharoshah et al., 2010), 84% in Romanian (Marinescu et al., 2013), 89.6% in Iranian (Nourbaksh et al., 2018), 83.2% in European descent (Ilgiü et al., 2014), 87.4% in Chinese Han population (Zheng et al., 2018), 95% in Brazilians (Gamba et al., 2016), and 82% in South Indians (Sreelakha et al., 2020).

Studies have documented at least two determinants for sexual dimorphism in the human mandible. Primarily these are genetic variations associated with a different developmental path in both sexes and secondary differences are related to musculoskeletal development (Rosas and Bastir, 2002). A soft and processed food results in the reduction of muscle strength, a decrease in loading, and changes in mandibular shapes, especially in regions where the masticatory muscle attaches (Kono et al., 2017). Earlier publications have emphasized that a soft-food diet resulted in the reduced
Table 7. Comparison of mandibular variables with non-Indian population (Berg, 2008)

| Population name            | MSHt Z-score | P-value | MBHt Z-score | P-value | BGoBr Z-score | P-value | BConBr Z-score | P-value | MinRBr Z-score | P-value | ConHt Z-score | P-value |
|----------------------------|--------------|---------|--------------|---------|---------------|---------|---------------|---------|---------------|---------|--------------|---------|
| Present study male         | 30.30 ± 3.28 | NA      | 28.89 ± 3.17 | NA      | 94.31 ± 6.24 | NA      | 112.28 ± 5.74 | NA      | 31.22 ± 2.96  | NA      | 54.62 ± 7.68 | NA      |
| Present study female       | 26.93 ± 3.26 | NA      | 25.66 ± 2.98 | NA      | 86.96 ± 5.45 | NA      | 106.66 ± 4.13 | NA      | 29.48 ± 2.58  | NA      | 52.63 ± 3.51 | NA      |
| US White 20th century male | 33.57 ± 3.15 | 10.2    | 31.14 ± 2.70 | 7.5     | 98.41 ± 5.94 | 7.7     | 117.50 ± 6.26 | 8.3     | 30.91 ± 3.15  | -1      | 0.31731      | 64.81 ± 5.07 | 14.9   | 0.0001*      |
| US White 20th century female| 30.34 ± 3.32 | 5.2     | 28.32 ± 3.09 | 4.4     | 90.59 ± 4.73 | 3.4     | 110.44 ± 5.20 | 4.3     | 28.21 ± 2.35  | -2.54   | 0.01109*     | 57.48 ± 4.94 | 7.8     | 0.0001*      |
| US White 19th century male | 32.81 ± 3.65 | 3.1     | 31.22 ± 2.49 | 3.8     | 116.58 ± 5.41| 3.5     | 0.0047*       |         | 30.2 ± 2.75   | -0.16   | 0.872        | 63.35 ± 4.89 | 6.0     | 0.0001*      |
| US White 19th century female| 29 ± 3.16   | 1.3     | 27.60 ± 2.51 | 1.3     | 93.50 ± 6.89 | 2.4     | 0.1936        |         | 28.33 ± 3.08  | -2.54   | 0.01109*     | 57.48 ± 4.94 | 7.8     | 0.0001*      |
| US Black 19th century male | 36.60 ± 2.94 | 9.8     | 33.42 ± 2.60 | 7.3     | 99.09 ± 6.73 | 3.7     | 0.00216*      |         | 34.40 ± 2.91  | 5.3     | 0.0001*      | 61.55 ± 3.85 | 4.3     | 0.0001*      |
| US Black 19th century female| 33.06 ± 2.93 | 9.6     | 30.37 ± 2.43 | 8.12    | 90.49 ± 5.07 | 3.2     | 0.01374*      |         | 32.80 ± 3.49  | 5.7     | 0.0001*      | 55.49 ± 3.67 | 4.0     | 0.00063*     |
| US Black 20th century male | 36.46 ± 3.67 | 9.33    | 31.97 ± 2.62 | 5       | 98.33 ± 6.83 | 3.2     | 0.0137*       |         | 34.48 ± 3.46  | 5.4     | 0.0001*      | 63.43 ± 4.39 | 6.25    | 0.0001*      |
| US Black 20th century female| 33.30 ± 3.37 | 6.4     | 29.91 ± 3.02 | 4.7     | 89.63 ± 6.25 | 1.6     | 0.1936        |         | 31.81 ± 1.91  | 3.1     | 0.0014*      | 53.93 ± 5.15 | 1.2     | 0.2301       |
| Hispanic male              | 34.90 ± 3.17 | 7.0     | 31.60 ± 2.79 | 4.2     | 97.82 ± 6.48 | 2.7     | 0.0069*       |         | 32.54 ± 2.60  | 2.3     | 0.0214*      | 64.96 ± 4.61 | 7.9     | 0.0001*      |
| Guatemalan male            | 35.18 ± 3.14 | 16.3    | 32.12 ± 2.61 | 10.8    | 97.41 ± 6.53 | 4.9     | 0.0001*       |         | 33.30 ± 2.67  | 7.2     | 0.0001*      | 61.97 ± 4.31 | 9.5     | 0.0001*      |
| Guatemalan female          | 31.60 ± 3.50 | 4.2     | 28.73 ± 2.24 | 3.5     | 91.50 ± 5.91 | 2.7     | 0.0069*       |         | 110.92 ± 7.80 | 3       | 0.0027*      | 28.14 ± 1.35 | -1.8    | 0.0718       |
| Cambodian male             | 32.38 ± 3.09 | 3.2     | 30.09 ± 2.42 | 3.75    | 95.8 ± 5.2   | 8.8     | 0.0001*       |         | 32.93 ± 2.56  | 5.7     | 0.0001*      | 62.66 ± 4.26 | 11.1    | 0.0001*      |
| Cambodian female           | 30.50 ± 2.93 | 2.8     | 27.69 ± 1.89 | 3.2     | 92.78 ± 3.99 | 5.6     | 0.0001*       |         | 31.25 ± 2.32  | 3.5     | 0.00465*     | 57.15 ± 4.22 | 6.3     | 0.0001*      |
| Chinese male               | 35.36 ± 2.75 | 7.9     | 32.73 ± 2.66 | 6.2     | 98.74 ± 6.19 | 2.6     | 0.000318*     |         | 33.82 ± 2.61  | 4.3     | 0.0001*      | 62.73 ± 4.59 | 5.5     | 0.0001*      |
| Vietnamese male            | 33.41 ± 3.18 | 3.14    | 31.44 ± 2.49 | 3.9     | 98.33 ± 4.19 | 2.2     | 0.0278*       |         | 115.57 ± 9.48 | 1.8     | 0.0119       | 34.14 ± 3.36 | 4.9     | 0.0001*      |
| Arikara male               | 36.00 ± 2.27 | 8.9     | 35.59 ± 2.63 | 11.9    | 101.38 ± 6.82| 5.4     | 0.0001*       |         | 36.77 ± 2.22  | 9.6     | 0.0001*      | 66.37 ± 5.34 | 9.5     | 0.0001*      |
| Arikara female             | 34.26 ± 2.38 | 11.8    | 32.72 ± 2.70 | 12.2    | 94.29 ± 4.07 | 6.7     | 0.0001*       |         | 34.76 ± 2.42  | 20.3    | 0.0001*      | 58.80 ± 4.33 | 8.33    | 0.0001*      |

Note: All the bold figures are statistically non significant. P > 0.05
Table 8. Comparison of mandibular variables with other Indian population

| Population name | Mean ± SD | Z-score | P-value |
|-----------------|-----------|---------|---------|
| MsHt            |           |         |         |
| Present study male | 30.30 ± 3.28 | NA    | NA    |
| Present study female | 26.93 ± 3.26 | NA | NA |
| Gujarati male | 29.14 ± 3.09 | -4.5 | 0.00001* |
| Gujarati female | 27.18 ± 2.93 | 0.8 | 0.424 |
| Andhrapradesh male (Sikka and Jain, 2016) | 29.98 ± 3.132 | -0.8 | 0.424 |
| Andhrapradesh female (Sikka and Jain, 2016) | 28.32 ± 2.784 | 2.17 | 0.03* |
| Punjab male (Sikka and Jain, 2016) | 25.4 ± 4.5 | -13.6 | 0.00001* |
| Punjab female (Sikka and Jain, 2016) | 23.2 ± 3.7 | -5.5 | 0.00001* |
| BGmBr           |           |         |         |
| Present study male | 94.31 ± 6.24 | NA    | NA    |
| Present study female | 86.96 ± 5.45 | NA | NA |
| Gujarati male (Kallalli et al., 2016) | 79.6 ± 7 | -7.8 | 0.00001* |
| Gujarati female (Kallalli et al., 2016) | 74.8 ± 12 | -6.43 | 0.00001* |
| Gujarati male (Mehta et al., 2014) | 97.57 ± 6.25 | 6.52 | 0.00001* |
| Gujarati female (Mehta et al., 2014) | 89.65 ± 4.86 | 5.3 | 0.00001* |
| Punjab male (Sikka and Jain, 2016) | 96.4 ± 6.4 | 3.3 | 0.00001* |
| Punjab female (Sikka and Jain, 2016) | 89.3 ± 5.8 | 2.1 | 0.03572* |
| Andhrapradesh male (Sikka and Jain, 2016) | 89.38 ± 6.9 | 6.4 | 0.00001* |
| Andhrapradesh female (Sikka and Jain, 2016) | 89.38 ± 6.9 | 6.4 | 0.00001* |
| Maharasthra male (Kallalli et al., 2016) | 60.0 ± 7.8 | -16.1 | 0.00001* |
| Maharasthra female (Kallalli et al., 2016) | 47.0 ± 6.0 | -27 | 0.00001* |
| Maharasthra male (Mehta et al., 2014) | 83.98 ± 5.46 | 6.9 | 0.00001* |
| Maharasthra female (Mehta et al., 2014) | 76.47 ± 4.12 | 2.68 | 0.0074* |
| MinHt           |           |         |         |
| Present study male | 31.22 ± 2.96 | NA    | NA    |
| Present study female | 29.48 ± 2.58 | NA | NA |
| Gujarati male (Kallalli et al., 2016) | 24 ± 7 | -8 | 0.00001* |
| Gujarati female (Kallalli et al., 2016) | 22 ± 1.8 | -10 | 0.00001* |
| Maharasthra male (Bhagwatkar et al., 2016) | 33.02 ± 2.80 | 3.91 | 0.000092* |
| Maharasthra female (Bhagwatkar et al., 2016) | 31.57 ± 2.43 | 4 | 0.000063* |
| MaxHt           |           |         |         |
| Present study male | 42.58 ± 3.50 | NA    | NA    |
| Present study female | 39.52 ± 6.67 | NA | NA |
| Maharasthra male (Bhagwatkar et al., 2016) | 42.01 ± 3.05 | -1.1 | 0.271 |
| Maharasthra female (Bhagwatkar et al., 2016) | 37.53 ± 2.48 | -2.9 | 0.003732* |
| Punjab male (Sikka and Jain, 2016) | 37.1 ± 6.2 | -12.7 | 0.00001* |
| Punjab female (Sikka and Jain, 2016) | 34.7 ± 5.5 | -5.7 | 0.00001* |
| GoGnLt          |           |         |         |
| Present study male | 81.28 ± 4.10 | NA    | NA    |
| Present study female | 75.35 ± 3.08 | NA | NA |
| Gujarati male (Kallalli et al., 2016) | 60.0 ± 7.8 | -16.1 | 0.00001* |
| Gujarati female (Kallalli et al., 2016) | 47.0 ± 6.0 | -27 | 0.00001* |
| Maharasthra male (Mehta et al., 2014) | 83.98 ± 5.46 | 6.9 | 0.00001* |
| Maharasthra female (Mehta et al., 2014) | 76.47 ± 4.12 | 2.68 | 0.0074* |
| CoHt            |           |         |         |
| Present study male | 61.69 ± 5.33 | NA    | NA    |
| Present study female | 55.73 ± 3.80 | NA | NA |
| Maharasthra male (Bhagwatkar et al., 2016) | 66.02 ± 4.39 | 5.21 | 0.00001* |
| Maharasthra female (Bhagwatkar et al., 2016) | 63.39 ± 2.40 | 10.9 | 0.00001* |
| CoHt            |           |         |         |
| Present study male | 57.68 ± 4.62 | NA    | NA    |
| Present study female | 52.63 ± 3.51 | NA | NA |
| Maharasthra male (Bhagwatkar et al., 2016) | 76.83 ± 4.22 | 20.8 | 0.00001* |
| Maharasthra female (Bhagwatkar et al., 2016) | 73.80 ± 1.94 | 33.1 | 0.00001* |
| PrRrHt          |           |         |         |
| Present study male | 53.42 ± 6.53 | NA    | NA    |
| Present study female | 48.33 ± 4.94 | NA | NA |
| Maharasthra male (Bhagwatkar et al., 2016) | 74.46 ± 4.04 | 17 | 0.00001* |
| Maharasthra female (Bhagwatkar et al., 2016) | 72.36 ± 4.20 | 27.9 | 0.00001* |
| MBHt            |           |         |         |
| Present study male | 28.29 ± 3.17 | NA    | NA    |
| Present study female | 25.66 ± 2.98 | NA | NA |
| Punjab male (Sikka and Jain, 2016) | 24.9 ± 4.6 | -11.1 | 0.00001* |
| Punjab female (Sikka and Jain, 2016) | 22.8 ± 4.2 | -4.3 | 0.000017* |
ramus size, reduced bicondylar breadth, posteriorly rotated mandible, more posteriorly directed growth of the condyle, and a shorter and inward-directed coronoid process (Martin and Denforth, 2009; Anderson et al., 2014; Gamba et al., 2016; Kono et al., 2017). Recently, Bosman et al. (2017) investigated the morphological difference in the mandible to examine alterations in the past 500 years and found that diet and food processing has a significant effect on mandibular size. The above studies explicate the association between masticatory muscle function and mandibular growth pattern and morphology. Moreover, comparatively feeble muscle forces during chewing may also cause smaller mandibles in females. In this way, the relative growth (size, strength, and angulation) of masticatory muscles additionally impacts the physiognomy of mandibular sexual dimorphism (Franklin et al., 2008). Humphrey et al (1999) demonstrated in their study on great ape and human populations that “patterns of sexual dimorphism are not under tight genetic control or conserved over long periods.” Studies indicated that throughout growth, the largest morphological changes are observed in the size of the mandibular ramus, condyle, and mental region due to bone deposition, resorption, and remodeling, which are consequently highly dimorphic (Ursi et al., 1993; Humphrey et al., 1999; Coquerelle et al., 2011; Saini, 2014). Nicholson and Harvati (2006) documented considerable geographical patterning in contemporary human mandibles and observed that some features of its morphology reflected climatic inclination along with functional specialization. Bosman et al. (2017) further added that mandibular shape and size are influenced by an amalgamation of several factors. These factors include transforming demography, fluctuating mortality patterns, improved dental and medical care, a more processed diet, and interaction with overall facial shape (Bosman et al., 2017).

**Sample size and error measurement in anthropometric studies**

In anthropometric studies, the sample size is crucial. The calculation of sample size is part of the initial stage of conducting an anthropological study. It has been observed that two studies conducted on the same population, with the same methodology, and by the same observer but on different sample sizes, may result in different conclusions. The variable which was found to be the most sexually dimorphic in a small sample may not prove so dimorphic in a large sample. Franklin et al. (2006), in a preliminary study on South African Blacks (40 samples), achieved up to 95% sexing accuracy, but this decreased to 84% in a subsequent study on a larger sample (Franklin et al., 2008). We also observed that classification accuracy might significantly increase or decrease with sample size, as shown in a previous study on the same population (Saini et al., 2011).

The difference in sexing accuracy may also be the result of an unequal number of males and females in samples, the selection of different variables for individual researches, measuring techniques (metric, CT scan, geometric morphometric), sample collection (recent, historic, or archaeological) as well as due to the expression of sexual dimorphism in populations. The classification accuracy and the most discriminating variables may vary even in regional groups. Such differences in sexing accuracy undoubtedly illustrate that the same variables may provide a changed sex classification rate depending on the magnitude of dimorphism in a population under consideration. Therefore, those particular variables must be tested on a larger sample of the same population before its use on a forensic sample. Furthermore, it is imperative to estimate the measurement errors in an anthropometric study. A decrease in measurement error increases the reliability of measurements (Bertsatos et al., 2019). In the present study, all measurements showed an acceptable measurement error between the first and second occasions, indicating high reproducibility and precision.

**Population specificity and variation**

Due to global shrinkage, population mixing has increased to its highest point. Nowadays, the term ‘race’ does not serve to describe any given person, or a person from a specific geographical location. Gradually, the term has started to be replaced by the term ‘ancestry.’ In recent times, it has been replaced by the term ‘population.’ In the next 10 years or may be even sooner, the given anthropometric standards may be different. From Table 7 and Table 8, it is evident that the mandibular parameters are population specific, and for a country such as India, the data should be developed not only...
according to regions but according to the states at least. The mandibular parameters showed a highly significant difference in the respective mean values compared with the non-Indian population (Table 7) and regional Indian population groups (Table 8).

The main scientific reason is the diversity in the external environmental factors such as culture, climatic conditions, geographical conditions, food habits, and occupations affecting bone development and bone appearance, and genetic factors, which ultimately lead to variation in the population. Hence, the higher the diversity, the greater the significant difference in the respective mean values, i.e. the population of other countries show a higher significant difference than the Indian population. In addition to this, in the case of different Indian populations nearer the state/region to the studied area, the difference in the respective values might have a lesser significant difference.

Unavailability of skeletal assemblage and databank

The crisis of skeletal assemblage is a long-standing problem in India and has been discussed in detail by Saini et al. (2017). We suggest the use of high-tech imaging techniques (cone beam CT, MRI, etc.) to create a databank for contemporary regional populations because the morphology, size, position, and diversity in the anatomical structure of the craniofacial regions can be easily captured by these techniques with high accuracy (Naikmasur et al., 2010; Mehta et al., 2014). In a country such as India, having highly diversified features in terms of climates, geographical conditions, cultures, food habits, etc., population-wise or state-wise study and data establishment with the maximum possible numbers is highly recommended. In large samples, we can identify and remove outliers (which may skew the data) which leads to a smaller margin of error and reliable results with better precision and power (https://sciencing.com/advantages-large-sample-size-7210190.html; https://select-statistics.co.uk/blog/importance-effect-sample-size/).

Conclusion

The mandible is an excellent discriminator for sex. The result of the present study may prove to be very useful in anthropological, archaeological, forensic, anatomic, and clinical domains, particularly in maxillofacial surgeries. The population specificity of the mandibular variables is also established, which makes it useful for identification purposes.

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