Sexual Dimorphism of North Indian Crania and its Forensic Application

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Abstract

Sex determination is a major challenge for forensic anthropologist in the medicolegal context. It constitutes initial step in personal identification from skeletal remains and is indispensable further to define age and stature of the deceased. There have been several studies on sex determination from different skeletal parts using osteometric and morphological approaches. Degree of sexual dimorphism and osteological standards vary across time and space. This requires need for valid population specific standards for sex determination. Skull is considered as the most discriminating after pelvis among skeletal parts.

As in India, the population varies to a large extent, assortment of skeleton cannot be made representing the whole country in general; therefore, regional studies must be promoted. Each population group thus needs its own sex specific osteometric standards. No large scale study on North Indian skull was conducted. The aim of the present study is to provide the population specific sex discriminating osteometric standards to aid identification.

A total of 483 crania (316 male and 167 females) with age range of 18-70 years of North Indian origin were studied using traditional osteometric methods. Twenty one traditional variables were measured. The p-value shows that all parameters were statistically significant and higher in males. The best parameters are bizygomatic breadth (BZBr) and mastoid bregma height (MBRH) which were reflected by highest t values and highest classification accuracies i.e. 82.2 and 80.5% respectively. In stepwise analysis accuracy reached up to 84.75% with the selection of five variables named Bizygomatic Breadth (BZBr), Mastoid Bregma Height (MBRH), Maximum Cranial Length (MaxClt), Biauricular Breadth (BAUBr) and Maximum Cranial Breadth (MaxCBr). On the other hand, bizygomatic breadth (BZBr) alone provided a sex classification accuracy of 82.2 % in direct analysis.

Keywords: Forensic Anthropology; Sex Determination; Cranium; North Indian; Discriminant Function Analysis

Introduction

Forensic anthropologists have uphill task to keep themselves abreast with the changing pattern of rapid metamorphosis in criminal behavior and acts, so that they can serve the society better with their expertise as and when required. In recent years crime behavior in India is globalizing with very heinous approaches to commit and hide the crime, such as dismembering body in 300 pieces by a celebrity and her fiancee in Mumbai [1], the Nithari Murder case [2]. Other modes of concealing the body beyond identification are also practiced by criminal for example burning. Other than homicidal cases, mass disasters and natural calamities, has brought up a big role of forensic anthropologists in establishment of identity of unidentified victims. One of the newest calamities, has brought up a big role of forensic anthropologists in burning. Other than homicidal cases, mass disasters and natural calamities are also practiced by criminal for example the Nithari Murder case [2]. Other modes of concealing the body beyond identification are also practiced by criminal for example burning. Other than homicidal cases, mass disasters and natural calamities, has brought up a big role of forensic anthropologists in establishment of identity of unidentified victims.

Previous studies on bones have shown that the performance of sex determination outside the reference population group for which the discriminant function has been developed is poor [3]. Therefore, anthropometric standards should be developed for each population group that needs to be updated time to time.

As evident from the past studies, skull is the most dimorphic and easily sexed portion of skeleton after pelvis, providing accuracy up to 94% [4-7]. Nevertheless, the two important parts, pelvis (95%) and skull (94%), are regarded as best indicators of sex identification in most situations owing to prominent dimorphic features in their architecture [4,7]. Commonly employed considerations in sex determination of skull are size differences and robusticity [8]. But Garvin, et al. [7], found that neither age nor body size plays a major role in trait expression, and thus does not need to be incorporated into sex estimation methods.

The presence of population variation in skeletal morphology necessitates the development of population-specific osteometric standards. Further, no data bank for sex discrimination from cranial measurements was provided for North Indians using large data set and variables. The main aims of the study were to verify the existence of sexual dimorphism in cranium and to develop sex discriminant formulae for the North Indian population to aid in identification process when unidentified human remains are recovered.

Materials and Methods

In the present study a total of 21 variables (out of 54) were selected on the basis of most commonly used variables in anthropometric studies. The data was adapted from the unpublished thesis of first author [9]. The study sample comprised of 483 modern human crania from Uttar Pradesh. Sample was collected from two medical colleges namely; Department of Forensic Medicine, Institute of Medical Sciences, Banaras Hindu University, Varanasi, India and Anthropology Museum of Anatomy Department, Ganesh Shankar Vidyarthi Medical College (GSVM), Kanpur, India. Distribution of sex and age in studying samples were shown in table 1.

Statistical Analysis

The measurements (table 2 and figures 1 to 3) were entered in the MS excel software and then data was transferred to the SPSS 16.0 for statistical analysis.

Descriptive statistics including the mean, standard deviation, range (minimum-maximum) were determined. The student-t-test, at 5 % level of significance was used to determine whether significant differences between male and female mean values existed.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Crania</th>
<th>Age ranges (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>316</td>
<td>23-65 (38.58 yrs)</td>
</tr>
<tr>
<td>Females</td>
<td>167</td>
<td>18-70 (31.75 yrs)</td>
</tr>
<tr>
<td>All total</td>
<td>483</td>
<td>18-70</td>
</tr>
</tbody>
</table>

Table 1: Distribution of sex and age in crania of Uttar Pradesh
Discriminant Function Analysis (DFA) is a statistical method that was developed in 1936 by Ronald A. Fisher, and since then it has been widely used in forensic science for the purpose of sex determination [10,11]. Comparisons of percentage classification accuracy indicate which variables or combination of variables produce a greater separation among groups and, in this particular case, the sexual dimorphism [12]. Discriminant function statistics is used to select the optimal combination of variables in order to classify cases in preexisting groups according to the similarities between each case and other cases belonging to the same group [13]. It therefore, requires a suite of measurements be taken on a bone in order to ascertain which measurements or combination of measurements is the best predictor of sex. Usually, more than one measurement is needed to obtain the best results.
required in order to obtain a high degree of accuracy for the discriminant function equation [11].

In addition, discriminant function equations are population specific and, as such, equations derived for one population cannot be used blindly on other, unrelated groups. These equations are also affected by temporal change and therefore require revision from time to time.

The discriminant function is constructed by assigning a discriminant score to each case. Depending on the variable and combination of variables for a function, the score changes from case to case. A sectioning point (SP) is created by using the mean male and female discriminant scores, which are also known as the group centroids [11,12]. Therefore, each function has a different sectioning point, which is based on the variables entered in the function. Unstandardized discriminant coefficients are used for constructing the formula. The standardized (Fisher’s) coefficients are used to compare the relative importance of the independent variables [11,12].

A discriminant function is built as follows:

\[ P = a_1 \times x_1 + a_2 \times x_2 + \ldots + a_n \times x_n + b \]

Where \( a_1 \) to \( a_n \) are the discriminant coefficients, \( x_1 \) to \( x_n \) are the discriminating variables and \( b \) is the constant. To assign the case to either male or female sex, the product \( P \) is compared to the sectioning point derived by the discriminant function [11,12]. A value higher than the sectioning point was deemed to be male and a value below it deemed to be female [11,12].

**Results**

Table 3 shows the descriptive statistics and classification accuracies for all parameters. The \( p \) value shows that all the parameters are statistically significant and higher in males. The t-values indicate that the differences between the sexes in all of these measurements are highly significant (\( p < 0.000 \)). The best parameters are BZBr and MBrHt, which is reflected by highest t values and highest classification accuracies i.e. 82.2 and 80.5 %. Lowest sex classification is provided by OHt and FMLt.

Table 4 shows the results of stepwise analysis, in which highest Wilk’s Lambda is shown by BZBr. In stepwise analysis, five variables were selected. BZBr provided the highest contribution followed by MBrHt.

Table 5 provides the results of stepwise and direct analysis with classification accuracies. In stepwise analysis classification accuracy reached up to 84.75 with the selection of five variables.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Male (n=316)</th>
<th>Female (n=167)</th>
<th>T-test</th>
<th>( p )-value</th>
<th>Classification accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>MaxCLt</td>
<td>180.61 ± 6.68</td>
<td>171.42 ± 5.91</td>
<td>14.955</td>
<td>0.000</td>
<td>78.7</td>
</tr>
<tr>
<td>MaxBr</td>
<td>126.76 ± 4.95</td>
<td>124.29 ± 5.02</td>
<td>5.191</td>
<td>0.000</td>
<td>63.1</td>
</tr>
<tr>
<td>CBLt</td>
<td>100.57 ± 4.29</td>
<td>95.35 ± 4.08</td>
<td>12.943</td>
<td>0.000</td>
<td>71.6</td>
</tr>
<tr>
<td>BBHt</td>
<td>132.49 ± 5.14</td>
<td>126.95 ± 4.92</td>
<td>11.444</td>
<td>0.000</td>
<td>70.8</td>
</tr>
<tr>
<td>BZBr</td>
<td>125.07 ± 4.65</td>
<td>116.86 ± 4.53</td>
<td>18.617</td>
<td>0.000</td>
<td>82.2</td>
</tr>
<tr>
<td>MaxFBt</td>
<td>112.03 ± 4.85</td>
<td>107.08 ± 3.95</td>
<td>11.347</td>
<td>0.000</td>
<td>71.8</td>
</tr>
<tr>
<td>MinFBt</td>
<td>92.25 ± 4.40</td>
<td>88.74 ± 3.77</td>
<td>8.751</td>
<td>0.000</td>
<td>64.2</td>
</tr>
<tr>
<td>FLt</td>
<td>94.49 ± 5.00</td>
<td>90.23 ± 4.68</td>
<td>9.100</td>
<td>0.000</td>
<td>67.7</td>
</tr>
<tr>
<td>UFHt</td>
<td>65.89 ± 4.40</td>
<td>61.47 ± 4.18</td>
<td>10.671</td>
<td>0.000</td>
<td>71.0</td>
</tr>
<tr>
<td>NHT</td>
<td>49.10 ± 3.17</td>
<td>45.86 ± 2.89</td>
<td>11.019</td>
<td>0.000</td>
<td>69.6</td>
</tr>
<tr>
<td>NBr</td>
<td>24.92 ± 1.96</td>
<td>23.30 ± 1.75</td>
<td>8.947</td>
<td>0.000</td>
<td>66.5</td>
</tr>
<tr>
<td>OHt</td>
<td>32.66 ± 1.89</td>
<td>31.95 ± 1.97</td>
<td>3.845</td>
<td>0.000</td>
<td>54.7</td>
</tr>
<tr>
<td>Br</td>
<td>38.59 ± 1.87</td>
<td>37.18 ± 1.86</td>
<td>7.981</td>
<td>0.000</td>
<td>64.2</td>
</tr>
<tr>
<td>BOBr</td>
<td>95.12 ± 3.56</td>
<td>90.79 ± 3.46</td>
<td>12.841</td>
<td>0.000</td>
<td>72.0</td>
</tr>
<tr>
<td>FMBr</td>
<td>28.63 ± 1.97</td>
<td>27.32 ± 2.08</td>
<td>6.776</td>
<td>0.000</td>
<td>66.7</td>
</tr>
<tr>
<td>FMLt</td>
<td>34.28 ± 2.45</td>
<td>32.93 ± 2.19</td>
<td>5.976</td>
<td>0.000</td>
<td>60.9</td>
</tr>
<tr>
<td>BAUBr</td>
<td>115.31 ± 4.38</td>
<td>109.24 ± 4.66</td>
<td>14.173</td>
<td>0.000</td>
<td>77.0</td>
</tr>
<tr>
<td>NOLt</td>
<td>178.11 ± 6.38</td>
<td>169.75 ± 5.65</td>
<td>14.238</td>
<td>0.000</td>
<td>75.2</td>
</tr>
<tr>
<td>BMTr</td>
<td>98.85 ± 4.56</td>
<td>93.76 ± 4.88</td>
<td>11.395</td>
<td>0.000</td>
<td>73.5</td>
</tr>
<tr>
<td>MBrHt</td>
<td>150.98 ± 5.37</td>
<td>142.54 ± 4.97</td>
<td>16.856</td>
<td>0.000</td>
<td>80.5</td>
</tr>
<tr>
<td>ABHt</td>
<td>125.13 ± 4.19</td>
<td>119.75 ± 3.90</td>
<td>13.715</td>
<td>0.000</td>
<td>74.5</td>
</tr>
</tbody>
</table>

Table 3: Descriptive statistics showing mean (mm), standard deviation, t-test with classification accuracies (*\( p < 0.05 \) Significant, **\( p < 0.01 \) Moderate Significant, ***\( p < 0.001 \) Highly Significant).
Discussion

The present study includes the identification of sexual dimorphism of 21 craniofacial measurements for adult male and female samples from North India. The presence or absence of sexual dimorphism for craniofacial measurements, along with the sex classification accuracies of individual variables are shown in Table 3. Bizygomatic breadth (BZBr) showed the highest accuracy of 82.2 followed by Mastoid bregma height (MBrHt) 80.5%. The result is in support with the antecedent studies exhibiting a consistent sexual dimorphism in bizygomatic breadth in the populations of different geographical regions utilizing traditional osteometric methods, cephalometrics and geometric morphometrics [13-15]. Gupta, et al. [16], also found bizygomatic breadth to be a highly dimorphic variable in Indian population with classification accuracy of 86.3% using cephalometry. Mehta and colleagues [17], also found bizygomatic breadth and cranial length to be most dimorphic for Gujrati population with an accuracy of 78.2%. Franklin and associates [13], investigated the crania of indigenous South African blacks utilizing eight cranial quantifications; average accuracies of correct sex relegation ranged from 77% to 80%, and bizygomatic breadth alone provided 77% precision employing geometric morphometrics. Their results were corroborated by further study investigating dimorphism in cranial shape of the same population group where the best sex discriminator was found to be the maximum lateral projection of the zygomatic arches, which is metrically bizygomatic breadth [14]. Dayal, et al. [15], examined same population using traditional osteometric method, which provided homogenous results; bizygomatic breadth was selected as best discriminator as it provided an average predictive precision of 75.8%. The highest precision (80.8%) was achieved by a discriminant function of four facial parameters, i.e., cranial length, basion-bregma, bizygomatic breadth, and nasal height. In 2008, Kranioti, et al. [18], investigated the discriminant function for modern Cretans and again bizygomatic breadth was found to be the maximum lateral projection of the zygomatic arches, which is metrically bizygomatic breadth [14]. Dayal, et al. [15], examined same population using traditional osteometric method, which provided homogenous results; bizygomatic breadth was selected as best discriminator as it provided an average predictive precision of 75.8%. The highest precision (80.8%) was achieved by a discriminant function of four facial parameters, i.e., cranial length, basion-bregma, bizygomatic breadth, and nasal height. In 2008, Kranioti, et al. [18], investigated the discriminant function for modern Cretans and again bizygomatic breadth was found to be the maximum lateral projection of the zygomatic arches, which is metrically bizygomatic breadth [14]. Dayal, et al. [15], examined same population using traditional osteometric method, which provided homogenous results; bizygomatic breadth was selected as best discriminator as it provided an average predictive precision of 75.8%. The highest precision (80.8%) was achieved by a discriminant function of four facial parameters, i.e., cranial length, basion-bregma, bizygomatic breadth, and nasal height. In 2008, Kranioti, et al. [18], investigated the discriminant function for modern Cretans and again bizygomatic breadth was found to be the maximum lateral projection of the zygomatic arches, which is metrically bizygomatic breadth [14]. Dayal, et al. [15], examined same population using traditional osteometric method, which provided homogenous results; bizygomatic breadth was selected as best discriminator as it provided an average predictive precision of 75.8%. The highest precision (80.8%) was achieved by a discriminant function of four facial parameters, i.e., cranial length, basion-bregma, bizygomatic breadth, and nasal height. In 2008, Kranioti, et al. [18], investigated the discriminant function for modern Cretans and again bizygomatic breadth was found to be the maximum lateral projection of the zygomatic arches, which is metrically bizygomatic breadth [14]. Dayal, et al. [15], examined same population using traditional osteometric method, which provided homogenous results; bizygomatic breadth was selected as best discriminator as it provided an average predictive precision of 75.8%.
which may be due to population variation or alternatively the result of different sample size. Kranović, et al [18], used a sample size of 90 males and 88 females (178 total) while in present study comparatively large sample is used. Sample size also contributes to the classification accuracy. Generally reliability of results increases with increasing sample size [19].

Rogers [20], stated that the elongated magnification in males causes the zygomatic arches to be larger and displaced these arches to be more laterally than the corresponding structures in females. It has been stated that the extra curving of the zygomatic arch is a reflection of more preponderant male robusticity [20]. Further, Franklin and colleagues [14], mentioned that the greater height and lateral projection of zygomatic bone are probably associated with increased development of masseter muscle, which is similarly associated with the development of the mandible. Saini and associates [21], concluded that more preponderant convexity of zygomatic arch in males may be associated with the outward push exerted by the hypertrophied belly of temporalis muscle which passes beneath the zygomatic arch. Habit of masticating tobacco and / or betel leaf (Paan) in this region is one of the factors which may responsible for considerably more hyper trophy in males [21].

Up to a large extent, variation has been observed in the degree, distribution, range, and extent of overlapping of sexual dimorphism among the different populations [13]. The least sexual dimorphism is shown by orbital region and cranial base though these were also sexually dimorphic. It has been stated that sexual dimorphism will be more in a population having enough nutritional resources to sustain the later adolescent male growth spurt [20,22]. The growth of facial bones is not a uniform process of overall surface accretion but it involves an interrelationship between all component parts. Kemkes and Gobel [23], affirmed that diversity in size and shape of facial skeleton arises through ontogenic, environmental, epigenetic influences as well as masticatory function. Sexual dimorphism in facial size is generally appears at 14 years of age and develops with the commencement of puberty in association with the skeletal adolescent growth spurt. A female face experiences significant decline in growth rate at 13 years of age and stops growing at around 15 years of age [21]. In males however, development of facial features starts at puberty and continue throughout the adolescent period and into early adulthood [21]. The process remains genetic, and in turn, hormonal control produces extreme differences in later growing regions (mandible, maxilla, upper face, cranial base, and head height) that experience greater relative growth [20]. During growth, the upper facial region (the orbital region) attains its final size first, thus making this region less dimorphic in comparison to nasal and maxillary areas which continue their growth for a longer time. These later growing regions of the face are subjected to increased opportunities for sexual dimorphism to develop [20].

A cross-sectional study on African-American populations using geometric morphometrics, Vidasdottir [24], revealed that sex differences in facial features are present at all stages of growth, and the final shape is achieved by the extension of the male size and shape vector.

It is concluded that estimating sex from crania using metric method, appear suitable to all population groups, but the most dimorphic variables can vary relative to the regional population concerned, even within the same population of different time frame.

Possible reasons for such craniofacial alteration over time are climatic adaptation [25,26], migrations [27], changed socio-economic environment [28], improved health and nutrition as well as biomechanical responses to a more processed diet which have been put forward as ultimate causes of craniofacial alterations over time [26,29,30]. Tomljanovic and coworkers [26], studied the effect of climatic condition on craniofacial features of Croatian young adults and concluded that the Mediterranean climate, characterized by higher average sunshine duration, higher average precipitation and higher average air temperatures, was associated with longer, higher and narrower skulls, higher head circumference, lower cephalic index, and higher and narrower faces (lower facial index) and these effects were more pronounced in the female sex. Bharai, et al. [25], concluded that the scheduled tribes who represent the original stock of India (suggesting adaptation to the region) and little migration showed a higher average cephalic index in colder regions than in non-humid regions.

Studies suggest that diet is an important factor affecting the expression of sexual dimorphism in a population [30,31]. An acute environmental stress, e.g., malnutrition, usually leads to a reduction of sexual dimorphism. Evidence suggests that populations that have an either very low or very high protein intake demonstrate the least amount of sexually dimorphic variation. A long-term protein deficiency reduces the growth rate of the skeleton, and it does so to a greater degree in males than females. Therefore, males cannot reach their maximum potential for stature and sexual dimorphism is reduced [31,32].

Food habits affect craniofacial morphology to a great extent. Hard, tough and/or unprocessed diets generally lead to an increase in the overall robusticity or size of the skull, an increase in facial size, temporal muscle area, temporo-mandibular joint size and cranial vault thickness, wider and taller faces, thicker mandibles, and taller palates [33,34]. Lierberman, et al. [35], found that animals faded on soft food had smaller faces, serious malocclusions and mandibles with smaller vertical height and condyle size.

Genetic causes like migration changes the demographics of the giving and receiving populations, as well as transferring genes from one locality to another, increasing the genetic variability for both populations, unless the migration is one way [36]. Relethford [27], has elaborated the main effects of migration to cranio metric distances in response to climatic stress, natural selection and gene flow.

Conclusions

Even within a restricted geographical region and in a short time span/historical period (up to four to five decades), patterns of sexual dimorphism sometimes vary significantly. Therefore, osteometric standards should be updated regularly. The osteometric method developed here provides updated standards for sex estimation from crania of Uttar Pradesh of North India, a population that has not been represented so far to the known databases and will be highly useful in forensic investigation of an unknown skull. Similar investigations covering diverse geographic regions and groups of the country, attaining greater balance of sex in samples are warranted. Creative rational novel measurements and use of more sophisticated measuring approaches may boost the outcome and inferences to critically establish the worth of suggestions made by present study.

Ethical Approval

The above work is being carried out after the approval from the Institutional Ethical Committee of Institute of Medical Sciences, Banaras Hindu University, Varanasi, India.

References


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**Received Date:** May 12, 2016, **Accepted Date:** June 21, 2016, **Published Date:** July 01, 2016.

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