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TECHNICAL NOTE

ANTHROPOLOGY

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An Osteometric Study of Northern Indian Populations for Sexual Dimorphism in Craniofacial Region

ABSTRACT: Sex identification is an initial crucial objective in the revelation of the complete identity of the human skeleton as it also renders significantly clearer guidance towards age and stature estimation. Population specific standards are of great practical relevance in the present era of increasing population intermixing. Size differences and robusticity are the two well-elaborated pillars holding most of the dimorphic burdens of the skull. This study is designed to explore dimorphic characteristics of the craniofacial region to establish anthropometric standards for contemporary North Indian populations, which have not been available so far. One hundred and twelve adult crania of known age (23–65 years) and sex (M:F; 82:30) were collected in the Department of Forensic Medicine, Institute of Medical Sciences, Banaras Hindu University, Varanasi, India. Ten standard metric parameters of craniofacial region were measured and subjected to stepwise and direct discriminant function analysis employing SPSS 16.00. Bizygomatic breadth emerged as the single best parameter in stepwise analysis, providing an average accuracy of 85.5%.

KEYWORDS: forensic science, craniometric osteology, sex determination, metric parameters, Indian population, discriminant function analysis

The challenging sphere of skeletal sex identification is of crucial merit to both physical and forensic anthropologists in medico-legal situations such as criminal cases, mass disasters (natural calamities, airplane crashes, bomb blasts, etc.) and human rights violation investigations. It is an imperative element in identification of human skeletal remains, as this information can reduce search out population by nearly half at once. Moreover, the subsequent methods of age and stature estimation are largely sex dependent (1,2).

Reliability of sex differentiation of skeletal material depends on the available parts, its completeness and degree of sexual dimorphism prevalent in the particular population (1,3). One hundred percent of accountability towards sex identification can be restored precisely with a complete skeleton, which is unfortunately not the common scenario in forensic instances. The human, skeleton is often recovered incomplete, damaged or fragmented, depending on its taphonomic history, as a result of scavengers' activity, preservation status, or recovery proficiency (4). Furthermore, fragmentation and/or decapitation of the victim's body are often resorted to in an attempt to subvert identity (5). Nevertheless, the two important parts, pelvis (95%) and skull (92%), serve best in most situations owing to prominent dimorphic features in their architecture (1,6–8). Commonly employed considerations in sex determination of skull are size differences and robusticity (2,6,9). These differences are unique to each population and thought to be influenced by genetic, environmental, and socio-economic factors such as dietary, occupational and living habits, indeed, in a time-dependent manner (10–13). Even within a restricted geographical region and historical period, patterns of sexual dimorphism sometimes vary significantly. Joy et al. (14) stated that local populations also show sexually dimorphic changes in skeleton, including cranial size and shape over time spans as short as a few decades. So the standards must be constantly updated to account for temporal changes in the community (15).

Numerous anthropological traits and parameters have been investigated on different parts of the skull, in an effort to make the sex determination more easy, reliable, and consistent, e.g., cranium (16–22), mandible (7,23–27), glabella (28), mastoid process (9,29–31), occipital bone (32–35).

Gonzalez et al. (36) recommended repeated measurement procedures for reproducibility by the same observer at different times or by different observers at a single instance. This ensures greater precision to indices employed for skeletal sex determination. Such an anthropometric approach would be objective, reproducible with low level of inter- and intra-observer errors. Despite the blemish of variability of populations, objective measures based on standard bony landmarks make the method more superior to gross morphological verdict on sex (6,22,37).

The need for an authentic data bank of population specific osteometric standards covering all the population type and subtypes, on a global basis has been felt for a long time. It is of more practical relevance now with increasing immigration and population intermixing. Previously, appreciable effort has been made at the University of Tennessee to construct the Forensic Anthropology Data Bank (FDB) in 1986 which contains extensive demographic

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and skeletal information (38). Also in Northern India, attempts were made to analyze the long bones for sexual dimorphism successfully (39–42); however, studies are inadequate concerning the skull. To look into the above lacunae, here we have conducted a discriminant function analysis of metric parameters of the craniofacial region for sexual dimorphism in contemporary Northern Indian populations.

Materials and Methods

A total of 112 dry adult crania, 82 males (25–65 years, mean age 38.58 years), and 30 females (23–50 years, mean age 31.75 years) of documented age and sex were collected, in the Department of Forensic Medicine, Institute of Medical Sciences, Banaras Hindu University, Varanasi, India, during the period of January 2007 to September 2009. Skulls were cleaned by water maceration and dried in natural process. Any pathological, fractured, or deformed crania were excluded from the study. All the measurements were taken with sliding calipers (0.05 mm precision) except bizygomatic breadth (taken with spreading calipers to the nearest millimeter) by the same observer thrice and average value was taken for the analysis (36). The following measurements were taken according to standards provided previously (43,44) (Figs 1 and 2):

Bizygomatic breadth (BZB): The straight distance between two zygia (zy) i.e., the most laterally placed points on the zygomatic bone.
Facial length (FL): The straight distance between basion (ba) to prosthion (pr).
Upper facial height (UFH): The straight distance from nasion (n) to prosthion (pr).
Orbital breadth (OB): The straight distance from dacrion (d) to ectoconchion (ect).
Orbital height (OH): Maximum height from the upper to lower orbital borders perpendicular to the d-ect line (orbital breadth).
Biorbital breadth (BOB): The straight distance between two ectoconchion (ect).
Interorbital breadth (IOB): The straight distance between dacrion (d) to dacrion (d).
Nasal height (NH): The straight distance from nasion (n) to nasospinale (ns).
Nasal breadth (NB): Maximum width of piriform aperture.
*Nasal bone length (*NH*):* Distance from nasion (n) to rhinion (rhi).

Statistical Analysis

The data were analyzed using the SPSS 16.0 program (SPSS Inc., Chicago, IL). Descriptive statistics, including means and standard deviations, were obtained for each of the measurements. Stepwise, univariate and multivariate direct discriminant function analyses were performed to calculate specific discriminant function formulae for all parameters, which can also be used on fragmentary remains. A "leave one out classification" procedure is applied to demonstrate the accuracy rate of the original sample and the one created by cross-validation.

Craniometric Indices

The craniometric indices offer the simplest and a fairly accurate way of judging the similarity or differences, when comparing the skulls of different population groups, so the craniometric indices were calculated using the appropriate formulae to get an idea of population affinity. The upper facial index is the ratio of the distance between the nasion (n) and prosthion (pr) to the bizygomatic breadth multiplied by 100 (6). Nasal index is ratio of the distance from nasion (n) to the lower margin of the nasal aperture to that of the maximum breadth of the nasal aperture and multiplied by 100 (6). The nasal indices have a marked relation to climatic conditions,

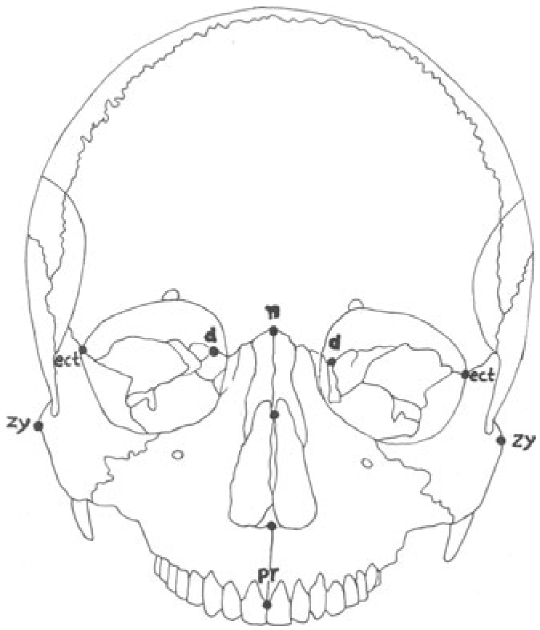

FIG. 1—*Frontal view of cranium showing landmarks used in the present study.*

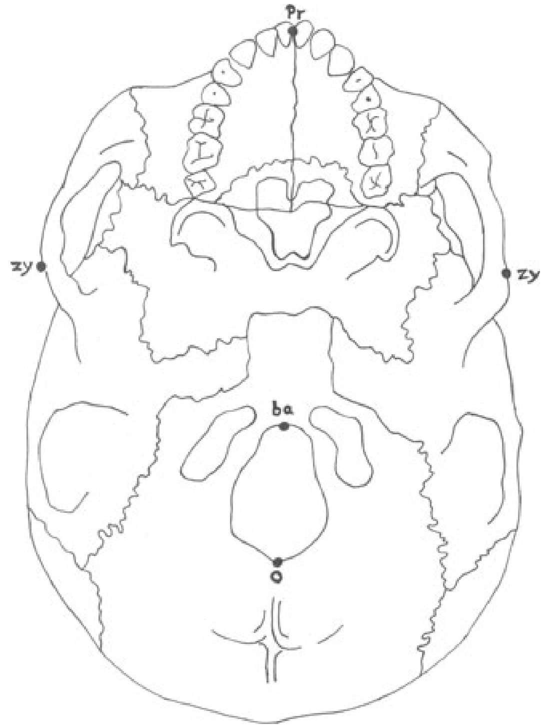

FIG. 2—*Basal view of cranium showing landmarks, used in the present study.*

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

	Male, N = 82		Female, N = 30						
Variables	Mean	SD	Mean	SD	F ratio	p-value	Identified Males (%)	Identified Females (%)	Average Accuracy (%)
BZB	127.18	3.676	120.52	4.679	61.333	0.000	87.5	80	85.5
FL	96.231	4.54	94.204	3.4	5.797	0.018	65.9	60	64.3
UFH	66.472	3.558	64.071	4.055	9.192	0.003	65	53.3	61.8
OH	32.670	1.468	32.211	1.741	1.94	0.167*	43.9	60	48.2
OB	39.083	1.848	37.836	1.179	11.835	0.001	56.1	80	62.5
BOB	96.187	3.345	93.158	2.580	20.154	0.000	68.3	66.7	67.9
IOB	20.395	1.907	19.793	1.677	2.321	0.131*	63.4	46.7	58.9
NH	49.598	2.628	47.134	3.758	15.139	0.000	65.9	66.7	66.1
NB	25.318	1.738	24.979	1.702	13.542	0.000	61	77.3	64.3
NBL	21.703	2.807	21.043	1.867	1.423	0.235*	58.5	53.3	57.1

*Nonsignificant.

BZB, bizygomatic breadth; FL, facial length; UFH, upper facial height; OH, orbital height; OB, orbital breadth; BOB, biorbital breadth; IOB, interorbital breadth; NH, nasal height; NB, nasal breadth; NBL, nasal bone length.

broad noses everywhere being associated with hot moist climates, and narrow noses with cool dry conditions. Orbital index is the ratio of the maximum breadth to the maximum height of the orbital cavity multiplied by 100 (6).

Results

Descriptive statistics with means, standard deviations, and univariate F-ratios for the 10 measurements are given in Table 1. The F ratio indicated that all measurements were significantly greater in males in comparison with females except OH, IOB, and NBL.

It was most marked in BZB, BOB, NH, and NB (all significant at <0.0001). Differences were also significant, though less so, in rest of the parameters. The average classification accuracy ranged from 48.2% to 85.5% by univariate discriminant analysis.

Table 2 shows the result of stepwise analysis using all variables. The best parameter selected in stepwise analysis is BZB by forward selection.

TABLE 2—*Stepwise discriminant analysis.*

Variables	Wilk's Lambda	Equiv. F-ratio	Degree of Freedom
BZB	0.638	61.333	1,108

BZB, bizygomatic breadth.

Table 3 shows the unstandardized coefficients constants, group centroids, sectioning points for the various functions, and average accuracies in cross-validation group (leave one out classification) for sex determination of an unknown cranium. The standardized coefficients indicate how much a given variable contributes to the overall classification. The structure coefficient measures the correlation between the variables and the function. The raw (unstandardized) coefficient is used to calculate discriminant scores for all functions. The discriminant score is obtained by multiplying each measurement by its raw coefficient, summing them and then adding the constant. For example: from function 1, the discriminant score is calculated as

$$D = (\text{BZB} \times 0.252) + (-31.572).$$

Sectioning point is the mean of male and female centroids. The discriminant function score smaller than the sectioning point, considered female, while a value greater than the sectioning point would indicate a male. The further the discriminant score is from the sectioning point, the higher the probability of correct identification.

In direct discriminant analysis, BZB with 85.5% accuracy was the most successful single variable for sex discrimination. After that, several combinations were tried using direct approach and no combination of variables provided higher accuracy than the BZB alone. However, a combination of three variables, BOB, NH, and

TABLE 3—*Standardized and unstandardized discriminant function coefficients, structure matrix, sectioning points in (direct discriminant analysis) original samples.*

Functions and Variables	Raw Coefficients	Standardized Coefficient	Structure Coefficient	Centroids	Sectioning Points	Average Accuracy O	Average Accuracy C
F1 BZB	0.252	1	1	M = 0.457	−0.381	85.5	85.5
(Constant)	−31.572			F = −1.219			
F2 BOB	0.166	0.534	0.728	M = 0.352	−0.305	78.6	73.2
NH	0.189	0.563	0.631	F = −0.963			
NB	0.274	0.428	0.597				
(Constant)	−31.941						
F3 BOB	0.229	0.724	0.803	M = 0.319		73.2	71.4
NH	0.202	0.601	0.696	F = −0.873	−0.277		
(Constant)	−31.749						
F4 BOB	0.316	1	1	M = 0.257	−0.222	67.9	67.9
(Constant)	−30.165			F = −0.701			
F5 NH	0.337	1	1	M = 0.222	−0.193	66.1	66.1
(Constant)	−16.488			F = −0.608			

O, original group correctly identified; C, cross-validated group cases correctly identified; BZB, bizygomatic breadth; BOB, biorbital breadth; NH, nasal height; NB, nasal breadth.

NB, provided 78.6% correct classification in the original group. These discriminant functions are constructed so that different preservation conditions can be considered to make identification.

Table 4 provides demarking points and sexual dimorphic indices for statistically significant variables. Demarking point is the average of male and female mean values.

In case of deformed or fragmentary crania, when only a single measurement is used for the analysis, the sex determination can be done according to the demarking point. The value of a measurement higher than the demarking point indicates male, while a measurement lower than or equal to the demarking point indicates female. In the present study, index of sexual dimorphism is calculated by the formula

$$\text{Index of sexual dimorphism} = \frac{\text{Male mean value}}{\text{Female mean value}} \times 100$$

This index shows the level of difference between sexes, values close to 100 indicate low level of sexual difference and the level of sexual difference increases with the increased deviation from 100 (25).

The craniometric indices are given in Table 5, to have a general idea of ethnic background. The upper facial index indicates that the population belongs to the group of medium upper face (Mesen, 52.27–53.16) (6). Nasal index shows that the North Indian population belongs to the group of wide nose type (Chamaerrhine, 51.05–52.99) (6). The orbital index shows that samples belong to the group of medium orbits (Mesoconch, 83.59–85.13) (6).

Discussion

Up to a great extent, variability is well observed in the degree, distribution, range, and extent of overlapping of sexual dimorphism among the populations (17,45). The growth of facial bones does not occur by a process of uniform, overall surface accretion but involves an interrelationship between all component parts. Kemkes and Gobel (30) 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 apparent around 14 years of age and develops with the onset of puberty in association with the skeletal adolescent growth spurt. A female face experiences significant decline in growth rate at *c.* 13 years of age and stops growing at about 15 years of age. While, in males, facial development begins to be manifested at puberty and continues throughout the adolescent period and into early adulthood (37,46,47). 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 (37). During growth, the upper facial region (the orbital region) is the first to gain its final size, making orbital region less dimorphic while nasal and maxillary areas continue their growth for a longer time. These later growing regions of the face are subjected to increased opportunities for sexual dimorphism to develop (37,46,48).

A cross-sectional study of size and shape of craniofacial features on African-American populations of known age and sex between age 9 months and adulthood using geometric morphometrics by Vidarsdottir (1999; cited in Bulygina et al.) revealed that sexual dimorphism in facial shape is present at all stages of growth, and the final shape is achieved by the extension of the male size and shape vector (47).

The results of the present study are very encouraging. Highly significant size dimorphism is found in the samples examined, providing an average accuracy of 61.8–85.5% that is comparable, and in some cases considerably better, than other studies conducted on different populations (16–18,21,22). This study shows bizygomatic breadth and orbital breadth as the best parameters for females, both providing same accuracy (80%). In males, bizygomatic breadth is the single best parameter (87.5%). Overall, the measurement expressing greatest sexual dimorphism is bizygomatic breadth (85.5%), followed by biorbital breadth (only 67.9%). Although some differences exist in other facial measurements of males and females, the degree of overlap is too large to identify sex with confidence in individual cases.

Our result is in support with the previous studies showing a consistent sexual dimorphism in bizygomatic breadth in the populations of different geographical regions using traditional osteometric methods and geometric morphometrics (16–18,21,22).

Franklin et al. (17) investigated the crania of indigenous South African blacks using eight cranial measurements; average accuracies of correct sex classification ranged from 77% to 80%, and bizygomatic breadth alone provided 77% accuracy employing geometric morphometrics. This was corroborated by their subsequent study investigating shape dimorphic features where best sex discriminator was the maximum lateral projection of the zygomatic arches, metrically bizygomatic breadth (18). The traditional osteometric method by Dayal et al. (21) on the same population produced similar results; bizygomatic breadth was again selected as best discriminator providing an average predictive accuracy of 75.8%, and highest accuracy (80.8%) was achieved by a function of four facial parameters, i.e., cranial length, basion-bregma, bizygomatic breadth, and nasal height.

More recently, Kranioti et al. (22) have investigated the discriminant function for modern Cretans and found bizygomatic breadth as the single best parameter providing an accuracy of 83% in the original group. In their study, the biorbital breadth and nasal height were the next best parameters and provided an overall accuracy of 75.3% and 74.3%, respectively; in contrast our study shows only 67.9% and 66.1%, respectively, which may be the effect of diverse

TABLE 4—*Demarking points and indices of sexual dimorphism.*

Variables	Demarking Points	Index of Sexual Dimorphism
BZB	Female ≤ 123.85 < Male	105.526
FL	Female ≤ 95.22 < Male	102.152
UFH	Female ≤ 65.27 < Male	103.747
OB	Female ≤ 38.46 < Male	103.295
BOB	Female ≤ 94.67 < Male	103.251
NH	Female ≤ 48.36 < Male	105.227
NB	Female ≤ 25.15 < Male	101.357

BZB, bizygomatic breadth; FL, facial length; UFH, upper facial height; OB, orbital breadth; BOB, biorbital breadth; NH, nasal height; NB, nasal breadth.

TABLE 5—*Facial, orbital and nasal indices for Northern Indians.*

Indices	Formula	Male	Female	Type
Upper facial index	(n−pr/zy−zy) × 100	52.27	53.16	Mesen or medium upper face
Orbital index	(h/d−ect) × 100	83.59	85.13	Mesoconch or medium orbit
Nasal index	(b/n−ns) × 100	51.05	52.99	Chamaerrhine or wide nose

climatic conditions, genetic factors, and different geographical location.

Rogers (37) stated that the extended growth in males causes the malars to be larger and the zygomatic arches to be displaced more laterally than the corresponding structures in females. Hoyme and Iscan (1999; cited in Rogers) indicated that extra curving of the zygomatic arch is a reflection of greater male robusticity (37). Franklin et al. (18) also 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.

We here suggest that greater convexity of zygomatic arch in males may also be associated with the outward push exerted by the hypertrophied belly of temporalis muscle which passes beneath it. Habit of chewing tobacco and/or betel leaf (Paan) in this region is one of the factors may responsible for considerably more hypertrophy in males.

Conclusion

India is a religious country having a wide range of variation in culture, customs, rituals, and food habits. In addition, the larger geographical area contains diverse climatic conditions, occupations, etc. which influences the development and the appearance of bones. As 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. In conclusion, this study provides new population specific craniometric standards for identification of sex in Northern India and will also help in the process of sex identification where fragmentary skulls are found. In applying these discriminant functions, some difficulties may come owing to the small sample size and unequal ratio of males and females. Although these results may provide new standards for this population, precaution is necessary for applying it to a forensic sample, as the true nature of sexual variation in a population may not be fully revealed in a relatively small sample (49).

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