Original Article

Discriminant Function Analysis of Craniometric Traits for Sexual Dimorphism and its Implication in Forensic Anthropology

Abstract

Introduction: Determination of sex from bony elements is the fundamental step to human virtue. Scholars agree highly accurate sex identification can be done from adult skulls. Direct assessment of the bones is not always the most appropriate or practical. Medical advances have provided cross-sectional slices of scanned individuals in the form of computed tomography (CT). The aim of the present study was to examine the reliability of cranial measurements for sex differences in CT head scan records of adult live subjects to the highest possible percentage in South Indians and to develop discriminant function equations. **Material and Methods:** Seventy head CT records were taken and 16 parameters were measured using RadiAnt DICOM viewer software. Statistical analysis was performed using descriptive statistics, Student's *t*-test, and discriminant function analysis. **Results:** The classification accuracy obtained by multivariate analysis of all 16 variables was 97.1%, multivariate analysis of nine most significant variables was 91.4% and by stepwise was 92.9% and that by univariate analysis for bizygomatic breadth, orbital breadth, basion-bregma height, and inter-orbital breadth was 81.4%, 74.3%, 72.9%, and 70%, respectively. **Discussion and Conclusion:** Multivariate analysis gave the highest classification accuracy and bizygomatic breadth, orbital breadth, basion-bregma height, and inter-orbital breadth were the most dimorphic variables in the study population and several other populations, and thereby should always be considered in the sex determination of humans. The study derived specific discriminant functions for sex determination in the South Indian population, providing a population-specific data for sex determination using craniometric parameters in the South Indian population and for future studies on skeletalized remains.

Keywords: *Computed tomography, craniometry, discriminant function analysis, forensic anthropology, sexual dimorphism*

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Introduction

The determination of sex from bony elements is the fundamental step to human virtue. The complete development of secondary sexual features is a prerequisite for precise sex determination from the human skeleton. Scholars agree highly accurate sex identification can be done from adult skulls.[1,2] Computed tomography (CT) records overcomes the potential obstacles in direct assessment of bones. Discriminant function analysis, an advanced analytical method, gives maximum discriminatory effectiveness with the least number of morphometric traits and overcomes the drawbacks of subjective and visual inaccuracies in morphological traits.[2,3] The uniqueness of skeletal characteristics of various populations necessitates population-specific analysis for sex determination.[4]

Material and Methods

The aim of the present study was to analyze the precise nature of cranial measurements for sex determination in CT head scan records of adult live subjects to the highest possible percentage in South Indian population by multivariate, stepwise and univariate discriminant function analysis and to develop discriminant function equations that can be used on skeletalized remains.

Seventy head CT records of patients (retrospective study) were collected from the Department of Radiology, complying with the inclusion and exclusion criteria. Institute ethics committee clearance was obtained. The study was done on

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randomly selected head CT records among a group of adult patients aged 20–60 years, who had taken it for various reasons in the Radiology department. Head CT records having evidence of head trauma, congenital abnormality, and chronic illness causing probable cranial deformities were excluded from the study.

The CT records were taken with patients in the supine position and a total of 16 parameters were studied.[5-8] The parameters studied in CT skulls were taken from retrospective routine head scans, which were obtained with the following settings:

- CT scanner (GE-Bright speed machine) with 16 slices
- Axial scanogram settings-kVp 120, mA 20, slice thickness-five mm with retro-reconstruction at 0.625 mm
- All the readings were taken from head CT scans using different views on DICOM images using electronic caliper inbuilt in RadiAnt DICOM viewer 2.0.9 software (Medixant, Poznan, Poland). The parameters were measured directly on primary cross-sectional images.

The parameters studied were maximum cranial length, maximum cranial breadth, bizygomatic breadth, basion-bregma height, cranial base length, basion–prosthion length, orbital breadth, orbital height, biorbital breadth, interorbital breadth, frontal chord, parietal chord, occipital chord, foramina magnum length, foramina magnum breadth, and mastoid length [Figure 1-5].[5-8]

Statistical analysis

The measurements were statistically analyzed using the windows statistical package for social sciences software IBM SPSS 20.0 (Chicago, IL, USA). The general descriptive statistics were done for both male and female skulls separately for all parameters. Student's *t*-test was used to determine the parameters exhibiting sexual dimorphism significantly ($P \leq 0.05$).

Multivariate, stepwise, and univariate methods were applied to perform direct discriminant function analysis and sectioning points were calculated. All the 16 parameters and the nine most significant variables were assessed using multivariate analysis separately, the relative contribution of the individual variable was analyzed by the stepwise method and the highly significant dimorphic variables were subjected to single-variable analysis. The outcome of the above was cross-checked by applying "leave one out classification" analysis.

Discriminant functional scores of male (Zm) and female (Zf) skulls were determined by applying the mean values of both the sexes using the equation, Discriminant functional score (Z) = b0 + b1 X1 + b2 X2+ - - - - - - - - + b16 X16 (b0 - constant, b1 – b16 are coefficients, X1 – X16 are variable of parameters). The average values of the mean of both the male and female parameters were used to calculate the sectioning point (Z0) which was set at zero. The averages of the two means were used to calculate the sectioning point when the two group centroids are different. The skulls were classified as male when the discriminant functional score was greater than the sectioning point and as female when it was less.[4]

Results

Descriptive statistics

Among the 70 CT skulls, 45 (64.3%) were males and 25 (35.7%) were females. The mean values were statistically significant ($P \leq 0.05$, Independent sample Student's *t*-test) between sexes for many of the craniometric measurements, as shown in Table 1. Mean values were higher in males in

Table 1: Gender-wise distribution of mean and standard deviations

Parameters	Mean (cm)		SD		*P* (Student's *t*-test)
	Male	Female	Male	Female	
Maximum cranial length	17.95	17.42	0.573	0.520	0.000*
Maximum cranial breadth	13.42	13.08	0.745	0.706	0.067
Bizygomatic breadth	12.74	12.19	0.437	0.356	0.000*
Basion-Bregma height	13.89	13.14	0.486	0.564	0.000*
Cranial base length	10.09	9.48	0.690	0.384	0.000*
Basion-Prosthion length	9.62	9.21	0.367	0.332	0.000*
Orbital breadth	4.21	3.96	0.195	0.189	0.000*
Orbital height	3.58	3.47	0.324	0.210	0.133
Biorbital breadth	9.76	9.14	0.427	0.320	0.000*
Interorbital breadth	1.50	1.20	0.284	0.254	0.000*
Frontal chord	11.79	11.16	0.440	0.844	0.000*
Parietal chord	11.49	11.45	0.831	0.872	0.850
Occipital chord	9.47	9.24	1.021	0.540	0.300
Foramina magnum length	3.81	3.65	0.360	0.455	0.125
Foramina magnum breadth	3.32	3.16	0.406	0.358	0.119
Mastoid length	2.81	2.77	0.316	0.365	0.621

*Significant at 5% level of significance. SD: Standard deviation all parameters. The variability was more in male sex in all measurements on comparison of standard deviation except basion-bregma height, frontal chord, parietal chord, foramina magnum length, and mastoid length, as shown in Table 1.

Multivariate discriminant analysis (Function 1)

Sectioning point was calculated by the analysis of all the 16 variables [Table 2]. This method classified 97.1% of the skulls (97.8% of males and 96% of females) and showed fair reliability and correctly classified 90% of skulls by the cross-validation "(Leave one out method)." Results of the multivariate direct discriminant analysis for the skulls are shown in Table 3.

Multivariate discriminant analysis (Function 2)

Nine variables with $P = 0.000$ were subjected to multivariate analysis and sectioning point was obtained [Table 4]. About 91.4% of the skulls were classified accurately,

Table 2: Discriminant equations, centroids, and sectioning points (Function 1)

Variables	Unstandardized coefficients	Standardized coefficients	Structure point	Centroids (male,female)	Sectioning point
Maximum cranial length	0.507	0.281	0.268	1.282, −2.307	−0.5125
Maximum cranial breadth	−0.079	−0.058	0.129		
Bizygomatic breadth	0.882	0.362	0.372		
Basion-Bregma height	0.892	0.459	0.407		
Cranial base length	0.182	0.109	0.283		
Basion-Prosthion length	0.424	0.151	0.322		
Orbital breadth	4.032	0.778	0.366		
Orbital height	0.225	0.065	0.106		
Biorbital breadth	−0.160	−0.063	0.439		
Interorbital breadth	2.187	0.599	0.303		
Frontal chord	0.350	0.215	0.283		
Parietal chord	0.039	0.033	0.013		
Occipital chord	−0.192	−0.170	0.073		
Foramina magnum length	0.761	0.301	0.108		
Foramina magnum breadth	−0.200	−0.078	0.110		
Mastoid length	1.085	0.362	0.034		
Constant	−63.865				

Wilks' Lambda: 0.247, Eigen value: 3.043, Canonical correlation: 0.868

Table 3: Classification results of craniometric traits in South Indians

Craniofacial parameters and functions	Predicted group membership		Total (%)
	Male, *n* (%)	Female, *n* (%)	
Function 1: Multivariate analysis (16 variables)			
Original	44/45 (97.8)	24/25 (96.0)	97.1
Cross-validated	39/45 (86.7)	24/25 (96.0)	90.0
Function 2: Multivariate analysis (9 variables)			
Original	41/45 (91.1)	23/25 (92.0)	91.4
Cross-validated	40/45 (88.9)	23/25 (92.0)	90.0
Function 3: Stepwise analysis			
Original	42/45 (93.3)	23/25 (92.0)	92.9
Cross-validated	41/45 (91.1)	23/25 (92.0)	91.4
Function 4: Univariate analysis - Bizygomatic breadth			
Original	37/45 (82.2)	20/25 (80.0)	81.4
Cross-validated	37/45 (82.2)	20/25 (80.0)	81.4
Function 5: Univariate analysis - Orbital breadth			
Original	36/45 (80.0)	16/25 (64.0)	74.3
Cross-validated	36/45 (80.0)	16/25 (64.0)	74.3
Function 6: Univariate analysis - Basion-Bregma height			
Original	32/45 (71.1)	19/25 (76.0)	72.9
Cross-validated	32/45 (71.1)	18/25 (72.0)	71.4
Function 7: Univariate analysis - Interorbital breadth			
Original	31/45 (68.9)	18 (72.0)	70.0
Cross-validated	31/45 (68.9)	18 (72.0)	70.0

of which 91.1% were male and 92% were female. On cross-validation, 90% classification accuracy was obtained [Table 3].

Stepwise discriminant analysis (Function 3)

Five parameters were taken in stepwise analysis of which four variables were determined as the most reliable discriminators between males and females [Table 5]. Bizygomatic breadth was the best single predictor, the next being orbital breadth, basion-bregma height followed by inter-orbital breadth. Discriminant function equation was established and sectioning point was obtained as below [Table 6].

Discriminant score (Z) = −48.700 (constant) + (1.108 × bizygomatic breadth) + (3.935 × orbital breadth) + (1.143 × basion-bregma height) + (2.151 × inter-orbital breadth)

92.9% of the skulls (93.3% males and 92% of females) were classified by stepwise analysis. The percentage accuracy was reduced to 91.4% on cross-validation of the above using "Leave one out method" and high reliability was obtained with 91.4% of skulls being correctly classified. Stepwise discriminant analysis results are depicted in Table 3.

Univariate discriminant analysis (Function 4, 5, 6, 7)

The best dimorphic variables bizygomatic breadth, orbital breadth, basion-bregma height, and inter-orbital breadth were analyzed by single variable discriminant analysis. Univariate discriminant analysis of bizygomatic breadth, orbital breadth, basion-bregma height, and inter-orbital breadth (Function 4, 5, 6, 7) was done and sectioning point was obtained discriminating male and female skulls [Table 7]. The classification accuracy along with cross-validated results of single-variable analysis is shown in Table 3.

Discussion

Determining the sexual dimorphism of an adult skeleton lays the pavement for its identification as well as helps in other sex-dependent techniques. Male and female skeletons are the two forms of sexual dimorphism.

Table 4: Discriminant equations, centroids and sectioning points (Function 2)

Variables	Unstandardized coefficients	Standardized coefficients	Structure point	Centroids (male, female)	Sectioning point
Maximum cranial length	0.189	0.105	0.293	1.169, −2.105	−0.468
Bizygomatic breadth	0.977	0.401	0.408		
Basion-Bregma height	0.799	0.411	0.446		
Cranial base length	0.326	0.195	0.310		
Basion-Prosthion length	0.192	0.068	0.353		
Orbital breadth	4.175	0.806	0.401		
Biorbital breadth	−0.319	−0.125	0.481		
Interorbital breadth	2.384	0.653	0.333		
Frontal chord	0.303	0.186	0.310		
Constant	−52.518				

Wilks' Lambda: 0.283, Eigen value: 2.533, Canonical correlation: 0.847

Table 5: Stepwise discriminant function analysis (Function 3)

Step	Variables entered	Variables removed	Wilks' Lambda	Equivalent *F*-ratio	Degree of freedom
1	Biorbital breadth	-	0.631	39.828	1, 68
2	Basion-Bregma height	-	0.459	39.478	2, 67
3	Bizygomatic breadth	-	0.373	37.016	3, 66
4	Orbital breadth	-	0.342	31.329	4, 65
5	Interorbital breadth	-	0.302	29.597	5, 64
6	-	Biorbital breadth	0.305	37.044	4, 65

Table 6: Discriminant equations, centroids and sectioning points (Function 3)

Variables	Unstandardized coefficients	Standardized coefficients	Structure point	Centroids (male, female)	Sectioning point
Basion-Bregma height	1.143	0.589	0.471	1.109, −1.997	−0.444
Bizygomatic breadth	1.108	0.454	0.430		
Orbital breadth	3.935	0.759	0.423		
Interorbital breadth	2.151	0.589	0.351		
Constant	−48.700				

Wilks' Lambda: 0.305, Eigen value: 2.280, Canonical correlation: 0.834

Table 7: Discriminant equations, centroids and sectioning points (Functions 4, 5, 6, 7)

Variable	Unstandardized coefficient	Wilks' lambda	Eigen value	Canonical correlation	Centroids (male, female)	Sectioning point
Function 4: Bizygomatic breadth†	2.439 −30.587 (constant)	0.703	0.422	0.545	0.477, −0.859	−0.191
Function 5: Orbital breadth†	5.182 −21.366 (constant)	0.711	0.407	0.538	0.469, −0.844	−0.1875
Function 6: Basion-Bregma height†	1.942 −26.456 (constant)	0.665	0.505	0.579	0.522, −0.940	−0.209
Function 7: Interorbital breadth†	3.652 −5.097 (constant)	0.781	0.280	0.468	0.389, −0.700	−0.1555

†Standardized coefficient=1, Structure point=1

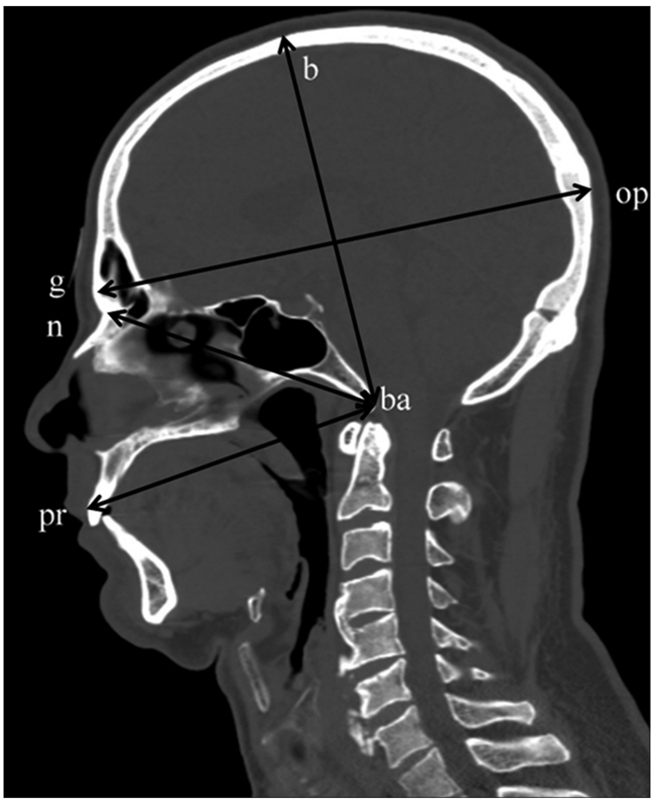

Figure 1: Maximum cranial length (g-op): glabella (g) to opisthocranion (op), Basion-bregma height (ba-b): basion (ba) to bregma (b), Cranial base length (ba-n): basion (ba) to nasion (n) and Basion-prosthion length (ba-pr): basion (ba) to prosthion (pr) measurements

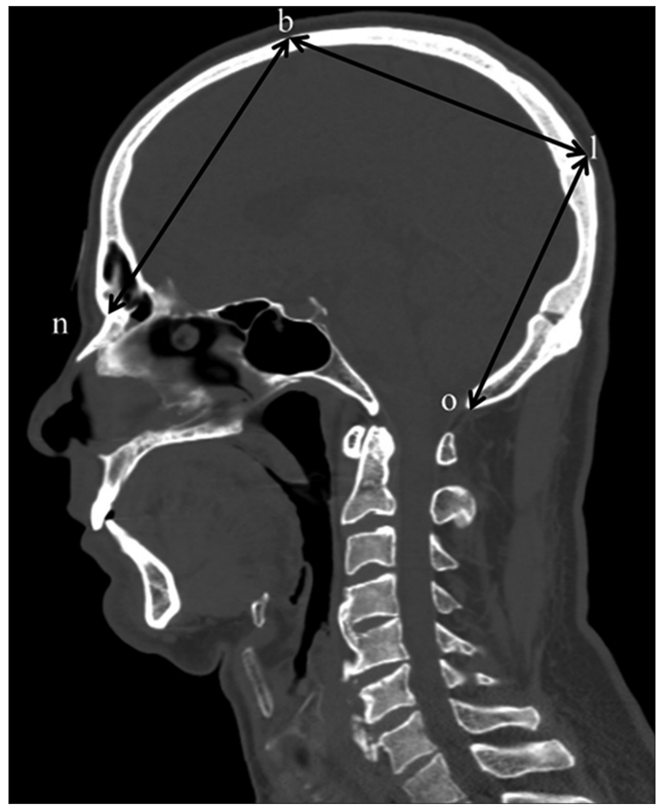

Figure 2: Frontal chord (n-b): nasion (n) to bregma (b), Parietal chord (b-l): bregma (b) to lambda (l) and Occipital chord (l-o): lambda (l) to opisthion (o) measurements

Pelvis and skull exhibit a high degree of sexual dimorphism.[9] The skull exhibits dimorphic features with greater stability due to its high resistance and determines individual sex with higher accuracy. Sexual traits are more precise only after the development of secondary sexual characteristics making adult skull preferred for sex determination.

Determination of the population source and applying data accordingly from the same or similar population is essential in sex determination. Sex determination techniques use cranial morphological features or craniometric values and ratios. Competent skill and expertise are required to obtain accuracy with observational technique. As suggested by Steyn and Işcan, objective method of sex determination was used in this study.[4]

Recently, computed tomographic images of skull were used by researchers to measure craniometric parameters for sex determination. The biggest advantage being, measurements are possible without directly handling the skulls; thereby, physical damage to the specimen because of handling can be prevented.

In addition, the radiological study provides easier measurements. In future, radiological studies can be accurately used in the determination of sex from any skeletal remnants without the need to travel. The use of CT scans to measure craniometric parameters for sexual dimorphism of

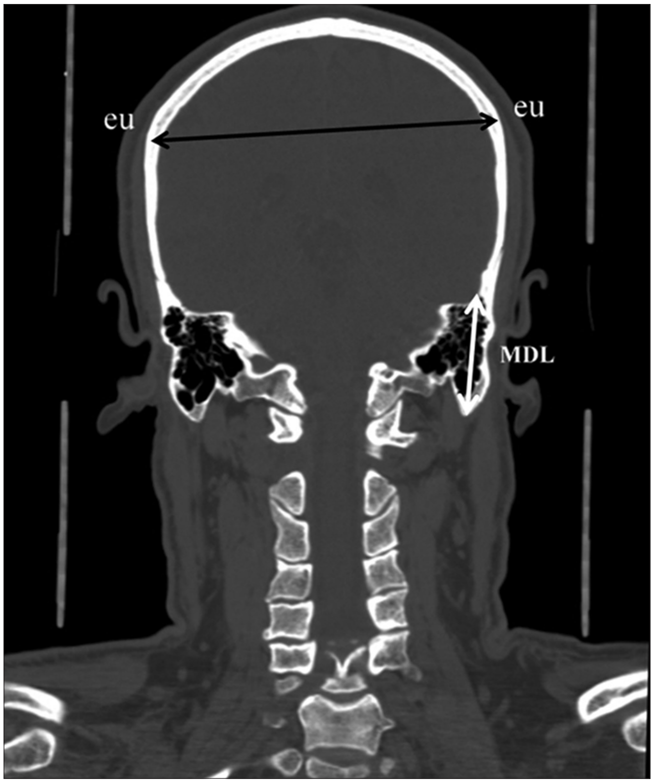

Figure 3: Maximum cranial breadth (eu-eu): Euryon (eu) to Euryon (eu) and Mastoid length (MDL) measurements

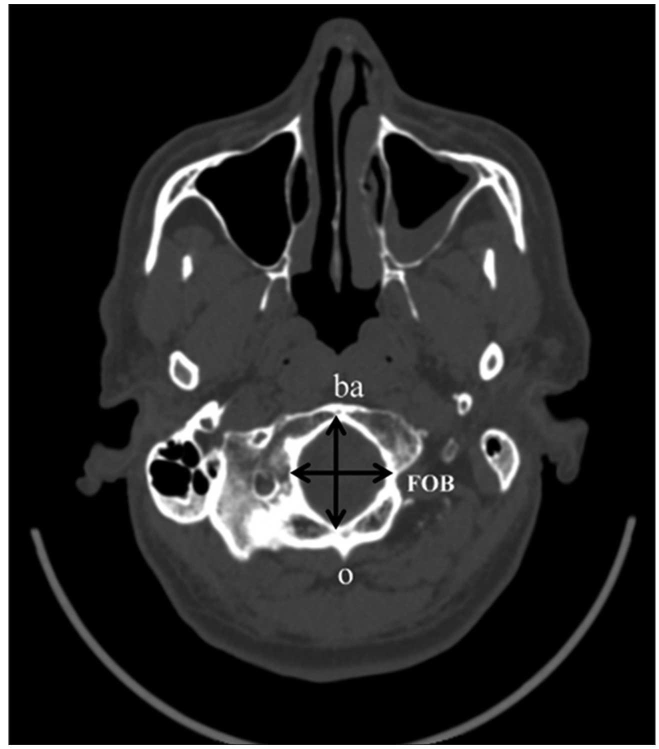

Figure 4: Foramina magnum length (ba-o): basion (ba) to opisthion (o) and Foramina magnum breadth (FOB) measurements

the skull was proved to provide comparable results similar to the usage of scientific calipers on dry skulls.[10]

Statistical methods used to play a role in determining the classification accuracies in sexual dimorphism. Thus multivariate, stepwise, and single variable direct discriminant function analysis techniques were used for sex determination. Comparisons of the above techniques were made; henceforth identifying the parameter with maximum information about sexual dimorphism in the study population.

As far as our knowledge, there are only sparse studies in the literature on the analysis of dimorphic features of the cranium in the South Indian population done with less number of variables. Hence, the present study was performed with 70 CT head records of adult live subjects to calculate the reliability of craniofacial parameters in sex determination, providing baseline value regarding the determination of sexual dimorphism in South Indians.

Measurements from head CT scans (live subjects) were included in the study as radiological methods are easier and help in overcoming the difficulties faced with nonradiological methods. Radiological methods also provide an added advantage of having digital data for future reference and research.

The mean values of craniofacial parameters were higher in male skulls than female skulls in this study. Different researchers obtained similar results on different population groups.[4-6,11-27] Of 16 parameters studied, a total of nine parameters showed statistically significant sexual dimorphism ($P \leq 0.05$).

Maximum cranial length, bizygomatic breadth, basion-bregma height, cranial base length, basion-prosthion length, orbital breadth, biorbital breadth, interorbital breadth, and frontal chord were found to be highly significant in discriminating male skulls from female skulls ($P < 0.001$).

These parameters were also significant in various studies.[4-6,12,15,18,20] It is important to note that bizygomatic breadth, maximum cranial length, and basion bregma height exhibit highly significant sexual dimorphism in the present study.

Naikmasur *et al*. studied 11 craniomandibular parameters in South Indian and immigrant Tibetans using Cephalogram. Bizygomatic width, ramus height, height, and depth of the face contributed most for sexual dimorphism in both populations. The accuracy in the South Indian population was 81.5% and in immigrant Tibetans, it was 88.2%.[11]

Craniometric study of Thai skull based on three-dimensional CT data was done on 91 cadaveric dry skulls. Maximum cranial length, basion-bregma height, and bizygomatic breadth were highly significant ($P < 0.001$)[13] and the present study has comparable results.

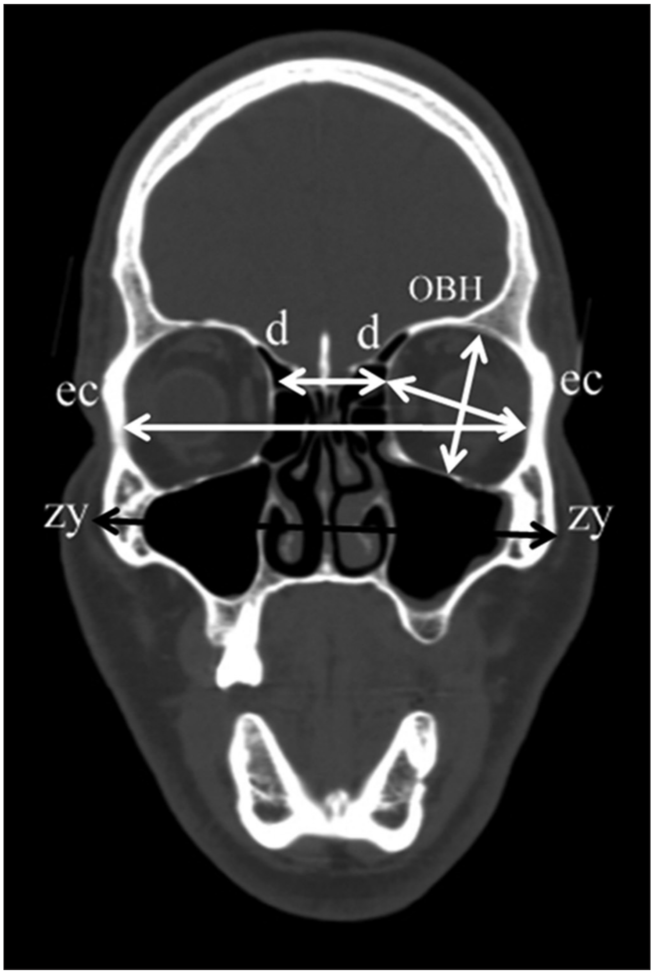

Figure 5: Orbital height (OBH), Orbital breadth (d-ec): dacryon (d) to ectoconchion (ec), Biorbital breadth (ec-ec): ectoconchion (ec) to ectoconchion (ec), Interorbital breadth (d-d): dacryon (d) to dacryon (d) and Bizygomatic breadth (zy-zy): zygion (zy) to zygion (zy) measurements

Northern Sudanese subjects were studied with seven radiological measurements done on 69 males and 41 females. Glabella-occipital length, basion-nasion length, basion-bregma height, basion-prosthion length, and frontal chord were statistically significant ($P < 0.001$).[17]

Another study by Franklin *et al*. using multi-detector CT in 400 Western Australian population found glabella-occipital length, basion-nasion length, basion-bregma height, basion-prosthion length, bizygomatic breadth, foramen magnum length, foramen magnum breadth, mastoid height, nasion-prosthion height, nasal height, nasal breadth, orbit breadth, bimaxillary breadth, palate breadth, bifrontal breadth, and biauricular breadth to be statistically significant ($P < 0.001$)[19] and many of the above parameters were found to be significant in the present study also.

Multivariate discriminant function analysis

The present study analyzed various measurements of South Indian skulls, thereby deriving sex discriminant functions. The percentage of accurate determination of sexual dimorphism was increased by multivariate analysis as this method assesses multiple variables in which the insignificant ones are potentiated by significant parameters. The classification accuracy of sex determination using multivariate analysis of all the 16 variables in the present study was 97.1% (97.8% male skulls, 96% female skulls). Multivariate analysis of the most significant variables (Function 2: nine variables) yielded 91.4% classification accuracy (91.1% male skulls, 92% female skulls). The classification accuracy was reduced to 90% on cross-validation by the “leave one out” method.

Studies on Northern Sudanese, Western Australians, Iraq, and Nepalese populations on CT skulls yielded an accuracy percentage of 83.6%, 82.6%, 81.8%, and 75%, respectively, which was less than that reported in the present study.[17,19,22,27] The percentage accuracy obtained in this study on CT skulls (97.1%) was higher than the other studies.[5,20,23,28]

In this study, the multivariate analysis yielded the highest classification percentages, in spite of cross-validation method showing a fall in the percentage of accuracy. This was due to cross-validation method ensuring the validity by verifying the dispersal of subjects allotted to the population groups. Studies on different population groups using this method yielded 70%–90% classification accuracy.[5,17,19,20,22,23,27,28]

Stepwise discriminant function analysis

Stepwise discriminant function analysis assesses the best dimorphic variable, giving higher accuracy percentages with few variables. In this regard, bizygomatic breadth was the most dimorphic variable of in this study followed by orbital breadth, basion-bregma height and inter-orbital breadth which was also reported as best dimorphic variables by Steyn and Işcan, Kranioti *et al*., Fortes de Oliveira *et al*., Ogawa *et al*., Saini *et al*.[4,6,18,20,29]

In the present study, stepwise analysis (bizygomatic breadth, orbital breadth, basion-bregma height, and inter-orbital breadth) gave an accuracy of 92.9% (93.3% male skulls, 92% female skulls) which was comparable to that studied by Franklin *et al*. (90%) and greater than that by Naikmasur *et al*. (South Indians 81.5%, Immigrant Tibetans 88.2%), and Ahmed *et al*. (81.8%).[19,11,17] The classification accuracy was 72%–90% by the stepwise analysis model studied by different researches in various population groups.[4,6,11,17-21,29]

Stepwise discriminant function analysis gave better classification accuracy using less number of variables with highly significant sexual dimorphism, thus proving it to be an effective method. The classification accuracy was reduced from 92.9% to 91.4% on applying cross-validation using “leave one out” method as the classification of every individual skull is done by the discriminant function based on the rest of the skulls.

Univariate discriminant function analysis

The accuracy of the parameters in the determination of sexual dimorphism is assessed separately by univariate analysis by analyzing single variables. Accuracy percentages obtained were 81.4% with bizygomatic breadth followed by 74.3% with orbital breadth, 72.9% with basion-bregma height and 70% with inter-orbital breadth.

The sex discriminating power of each parameter determines the predictive value of sexual dimorphism than the number of parameters. Except basion-bregma height, all the other variables yielded the same classification percentage on cross-validation using "leave one out" method.

Bizygomatic breadth gave an accuracy of 80.2%, 81.9%, 83.5%, and 85% in studies by Steyn and Işcan, Kranioti *et al*., Marinescu *et al*., and Franklin *et al*., respectively compared to the present study (81.4%).[4,6,21,19]

Marinescu *et al*. reported a classification accuracy of 75% with orbital breadth, which was comparable to the present study and Kaya *et al*. gave a classification accuracy of 61.6% which was less than the present study (74.3%).[21,30]

Basion-bregma height gave a classification accuracy of 72.9% which was comparable to that reported by Ahmed *et al*. (70%) and Kranioti *et al*. (75.3%) and greater than that reported by Fortes de Oliveira *et al*. (65%) and less than that reported by Marinescu *et al*. (77.5%).[17,6,18,21]

Inter-orbital breadth accurately classified 70% of the skulls correctly in the present study.

The multivariate analysis gave better classification accuracy in the evaluation of sexual dimorphism in the study population than stepwise and single variable analysis. Bizygomatic breadth, basion-bregma height, and orbital breadth were the most dimorphic variables in several populations similar to the present study, and thereby should always be considered in the sex determination of humans.[4-6,11-13,15,17-20]

The study stresses the necessity on the application of multiple variables for the analysis of sexual dimorphism. Comparable sex classification percentage can be obtained by choosing the best dimorphic variables alone for the specific population group. The study also provides essential data on the best dimorphic variables with reliable classification accuracy in the evaluation of sexual dimorphism of the skulls in the South Indian population.

Hence, we conclude that there was a significant sexual dimorphism in the skulls of South Indians and the discriminant function equations established from the study could be applied to populations from similar groups and that there is a necessity to derive similar equations for other population groups.

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Conflicts of interest

There are no conflicts of interest.

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