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Morphometric analysis of foramen magnum in human skull for sex determination

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ABSTRACT

Identification of human skeletal remains is the most important task for a forensic anthropologist during forensic examinations. The need for methods to estimate sex from cranial fragments becomes apparent when only a part of skull is brought for identification. In the present study, the morphometric measurements taken on foramen magnum in a documented Indian collection were analyzed for sex differences using standard osteometric techniques. Fifty adult skulls of known sex were included in the study. Morphometric analysis of foramen magnum was conducted using digital vernier calipers. Six standard parameters were measured and analyzed by discriminant function analysis using SPSS 16. Males displayed larger mean values than females for all measured variables but only one of the variables (maximum bicondylar breadth) exhibited statistically significant differences between the sexes. The results demonstrated a low level of sexual dimorphism in the cranial base of this sample. Based on sectioning point derived by the discriminant function, a value higher than the sectioning point was deemed to be male and value below it deemed to be female. The accuracy of sex prediction based on discriminant function analysis ranged from 66% to 70%. In stepwise analysis, maximum bicondylar breadth was found to be more discriminating variable providing an accuracy of 66%.

KEY WORDS: Forensic anthropology, sexual dimorphism, sex determination, foramen magnum, discriminant function analysis

INTRODUCTION

Sex determination is one of the first steps in the identification of any human skeletal remains discovered in a forensic or archaeological context (Krogman and Iscan, 1986). The most accurate results are obtained when the entire skeleton is available for study; however, skeletal material derived from forensic and archaeological contexts is rarely complete and undamaged. Therefore, it is important to establish methods for determining sex from skeletal elements likely to survive and be recovered (Macaluso Jr., 2011).

The most conspicuous feature of the occipital bone is the large foramen magnum through which the cranial cavity communicates with the vertebral canal. The anterior border of the foramen magnum is formed by basilar process of the occipital bone, the lateral border by the left and right ex-occipitals and posterior border is formed by the supraorbital part of the occipital bone (Scheuer and Black, 2004). A pair of large smooth protuberances, the occipital condyles lies lateral to each side of the foramen magnum. Each condyle articulates with the corresponding superior articular facet on the atlas vertebra to form an atlanto – occipital joint (Singh, 1999).A number of studies has investigated the utility of this anatomical region for sex assessment employing morphometric traits using discriminant function analysis. Teixeria (1982) published an initial study on estimation of sex based on the size of the foramen magnum. His findings based on a small sample of 40 adult (20 males, 20 females) Brazilian skulls indicated that if the area of the foramen magnum was 963 mm^2 or larger, it was a male skull and if it was 805 mm^2or less it was female skull. In another study, Routal *et al*. (1984) found the dimensions of foramen magnum in Indian sample to be sexually dimorphic and reported up to 100% accuracy of correctly identifying sex using simple demarking points .Many other studies have been conducted on different populations with respect to sexual dimorphism in foramen magnum and occipital condyles using different statistical considerations (Gunay and Altinkok.,2000; Wescott and Moore 2001; Selma *et al*., 2005; Deshmukh & Devershi., 2006; Suazo *et al*., 2009 ; Gruber *et al*., 2009; Macaluso Jr.,2011; Raghavendra Babu *et al*., 2012 and Radhakrishna *et al*., 2012).
Gapert *et al.,* (2009) used discriminant function analysis and regression analysis on an eighteenth and nineteenth century British sample. The discriminant functions developed in the study predicted correct sex in 70.3% of all cases. Gruber *et al*., (2009) did not find any sexual dimorphism in the diameters of the foramen magnum in central European dry specimen dating from Pleistocene to modern times. The foramen magnum had low discriminatory power in sexual dimorphism in UNIFESP sample and accurately classified 66.5% skulls (Suazo *et al*., 2009). In French sample, Macaluso Jr., (2011) found a low level of sexual dimorphism in the cranial base and in this study maximum length of left occipital condyle and minimum distance from occipital condyles gave the best results with accuracy rate of 67.7%. A study on sexual dimorphism based on antero-posterior diameter, transverse diameter and area of foramen magnum in population of coastal Karnataka region (Raghavendra Babu *et al*., 2012) revealed predictability of foramen magnum measurements in sexing the crania as 64.5% for transverse diameter and 86.5% for the antero-posterior diameter.

A review of literature reveals scanty information in sexual dimorphism based on foramen magnum in Indian populations. Therefore, present study has been undertaken with a view to augment data in this direction and to assess the level of sexual dimorphism present in the basal region of the occipital bone in a documented Indian sample.

MATERIAL AND METHODS

The data were collected on a sample of 50 skulls (26 males and 24 females) from Department of Anatomy, Government Medical College and Hospital Chandigarh, for which prior permission was sought from Head of Anatomy department. The skulls were free from any fracture or other deformities. Morphometric measurements of the foramen magnum were taken with Digital vernier calipers graduated to the last 0.01mm and recorded according to the definitions provided by Gapert *et al*., (2009).

1. Maximum length of the foramen magnum (LFM) - Maximum distance between anterior and posterior margins measured along the principle axis of the foramen magnum (Fig. 1)
2. Maximum width of the foramen magnum (WFM) - Maximum distance between the lateral margins measured approximately perpendicular to principle axis of the foramen (Fig.1)
3. Maximum bicondylar breadth (BCB) - Maximum distance between the lateral margins of the left and right condylar articular facets (Fig.2)
4. Minimum distance between occipital condyles (MnD) - Minimum distance between the medial borders of the left and right condylar articular facets (Fig. 2)
5. Maximum interior distance between occipital condyles (MXID) - Maximum distance between the medial borders of the left and right condylar articular facets (Fig. 2).
6. External Hypoglossal Canal distance (EHC) - Distance between external hypoglossal canal openings measured at the most medial walls of the both left and right openings (Fig. 3).
7. Area of the foramen was calculated from length and width of foramen magnum utilizing different formulae given by Teixeria(1982) and Routal et al (1984).

Formula given by Teixeria (1982): Area = $\pi\ ([LFM+WFM]/4)^2$

Formula given by Routal et al (1984): Area = $LFM \times WFM \times \pi / 4$.

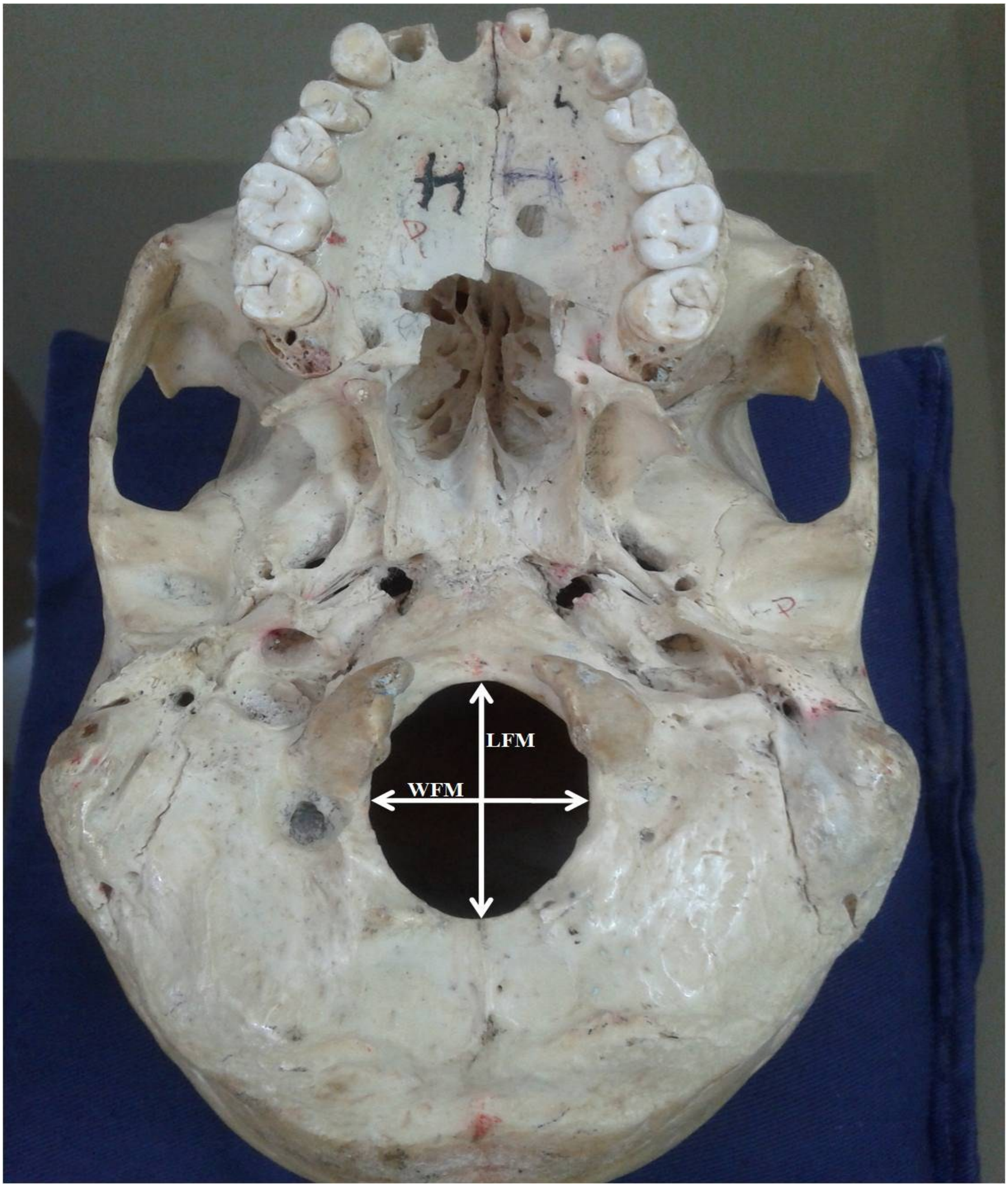

Fig.1 Foramen magnum measurements: (LFM) maximum Length, (WFM) maximum width

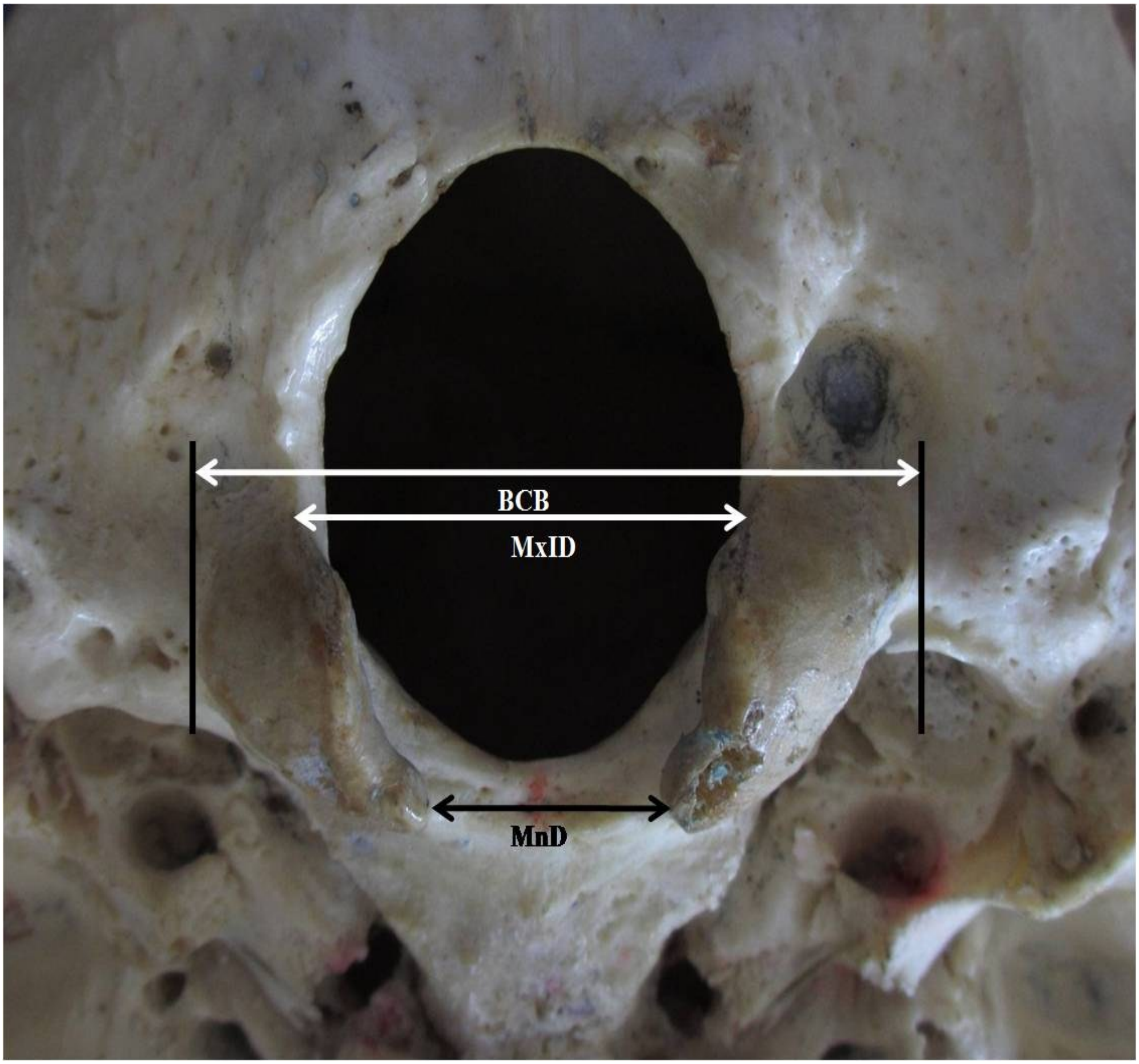

Fig. 2 Bicondylar measurements: (BCB) maximum bicondylar Breadth, (MxID) maximum interior Distance between occipital Condyles, and (MnD) minimum distance between occipital condyles.

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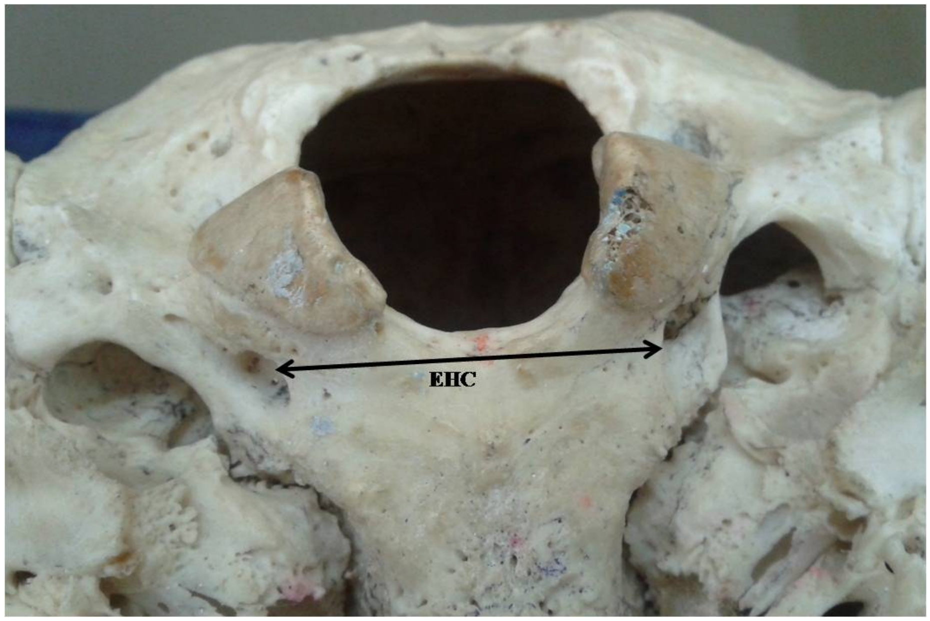

Fig. 3 External hypoglossal canal distance

Statistical Analysis

Intra-observer error in measurement was calculated by randomly selecting ten crania from the original sample. These skulls were measured for second time without reference to the original measurements taken for the first time on the same skull. Intra observer error was estimated using paired t – test. Descriptive statistics, including means, standard deviations and coefficients of variation, were obtained for both sexes for each of measurements. To assess the level of significance in the mean values between the sexes student's t-test was applied. The only dimension which was found to be statistically significant (maximum bicondylar breadth) was entered into stepwise discriminant function analysis. In addition, all other measurements individually were subjected to direct discriminant function analysis to derive formulae to be applied on skulls and fragmentary remains. The data was analyzed using SPSS (Statistical package for social sciences, version 16.0) statistical software package.

Table -1 Intra-observer variations assessment using paired t-test.

Variable	First observed mean	Second observed mean	SD	t- value	Correlation Coefficient
LFM	31.50	31.77	1.04	-0.82	.95
WFM	27.20	26.90	0.82	1.15	.94
BCB	46.40	45.90	1.84	0.86	.86
MnD	15.30	15.40	1.29	-0.25	.86
MxID	25.10	24.80	1.49	0.63	.87
EHC	33.60	32.50	2.88	1.21	.91

*LFM, maximum length of the foramen magnum; WFM, maximum width of the foramen magnum; BCB, maximum bicondylar breadth; MnD, minimum distance between occipital condyles; MxID, maximum interior distance between occipital condyles; EHC, external hypoglossal canal distance

†All measurements are in millimeters

RESULTS

The results for intra-observer variations are depicted in Table 1. The differences seen between the measurements recorded at two different occasions were found to be non significant as is clear from the t- value. This observation also gets conformation from the highly correlated values of correlation co-efficient. Table 2 presents the descriptive statistics and t values for all the measured variables of the occipital bone. The results clearly indicate that males displayed larger mean values than females for all measured variables of the cranial base. However, statistically significant differences between the sexes ($p<0.05$) were observed only for a single measurement of maximum bicondylar breadth (BCB). When values of coefficient of variations between sexes were compared it was found that females exhibited more variability than males for measurements like length of foramen magnum, width of foramen magnum, minimum distance between occipital condyles, maximum interior distance between occipital condyles and area of foramen magnum while, males were more variable for maximum bicondylar breadth and external hypoglossal canal distance**.** Discriminant function analysis for cranial base has been presented in table 3. It also shows the unstandardized coefficients, constants, and sectioning points that were used to formulate the discriminant function score equation. Only significantly dimorphic value (BCB) was entered into the stepwise discriminant function analysis and rest of the variables were subjected to direct analysis.

Sex of the skull and fragmentary cranial remains can be determined from both equations which were derived from the stepwise and direct discriminant function analysis. Each dimension was multiplied with its associated unstandardized coefficient and adding the products together along with the constant, a score was calculated, If the discriminant score is more than the sectioning point which we determined from the discriminant score equation, then it indicates a male skull, whereas, a value lower than sectioning point indicates a female skull. The tested accuracy of sex determination of the skull by stepwise discriminant function analysis was 66% and by direct discriminant function analysis was 70%. In the present study the percentage of correctly classified skulls was quite low, with direct discriminant function providing slightly better results than stepwise discriminant score equations.

Table - 2 Descriptive statistics and t-value for the measured variables of the occipital bone

	Males				**Females**				
Variable	**N**	**Mean**	**S.D**	**CV**	**N**	**Mean**	**S.D**	**CV**	**t-value**
LFM	26	33.54	2.80	8.36	24	32.31	3.24	10.07	1.555
WFM	26	27.77	2.10	7.57	24	27.21	2.99	11.00	0.722
BCB	26	46.73	2.79	5.98	24	44.29	2.34	5.30	3.326*
MnD	26	14.88	2.26	15.25	24	14.33	2.56	17.90	0.806
MxID	26	26.15	3.31	12.69	24	24.71	4.57	18.51	1.286
EHC	26	32.31	4.45	13.78	24	30.75	1.67	5.45	1.611
FMA - Routal	26	733.32	9.40	12.93	24	692.64	13.20	19.07	1.262
FMA - Teixeria	26	741.40	9.56	12.90	24	699.17	13.36	19.45	1.292

For abbreviation see table 1

† FMA – Foramen magnum area *Statistically significant at $p<0.05$

Table - 3 Discriminant functions analysis for cranial base dimensions.

Variable	N	Unstandardized coefficient	Group centroid		Sectioning point (a)	Correctly classified (%)			% sex bias (b)
Stepwise analysis	50		**Male**	**Female**		**Male**	**Female**	**Overall**	
BCB		3.860	0.452	-0.490	-0.38	65.4	66.7	66	-1.3
Constant		-17.588							
Direct analysis	50								
LFM		1.249	0.485	-0.525	-0.04	69.2	70.8	70	-1.6
WFM		-0.353							
BCB		3.482							
MnD		-0.253							
MxID		-0.238							
EHC		-0.399							
Constant		-19.291							

For abbreviation see table 1.

(a) As sample size for males and females are unequal for all functions, sectioning points are not calibrated to zero, but rather calculated by averaging the two group centroids.
(b) % Sex bias = % males correctly classify - % of females correctly classified.

DISCUSSION

It is evident from the results that males displayed larger mean values than females for all measured variables of the foramen magnum. Of all the variables only one variable i.e. Maximum Bicondylar Breadth (BCB) exhibited statistically significant difference between the sexes. Although length and width of foramen magnum was found to be slightly larger in males than females in the present sample, these dimensions did not yield statistically significant differences. However, in French sample (Macaluso Jr., 2011) the length of foramen magnum did not reveal significant differences but width showed the significant results. In African – American group (Wescott & Morre Jansen, 2000) found length of foramen magnum as one of the most reliable measurement for sex determination. Our findings are in contrast with the results reported on British sample (Gapert *et al*., 2009), UNIFESP sample (Suazo *et al*., 2009) as well as on Indian populations(Raghavendra Babu *et al*., 2012, Radhakrishna *et al*.,2012) which show statistically significant differences between males and females for length and breadth. In our study the mean of foramen magnum area in females was found to be smaller than in males. This result is in consensus with the findings reported by Teixeria (1982); Gunay & Altinkok (2002), Gapert et al., (2009) and Macaluso Jr. (2011). Our study did not reveal significant differences for mean of foramen magnum area. This finding is in contrast with those reported by Gunay & Altinkok (2000), Gapert *et al*., (2009) and Raghavendra Babu *et al*., (2012).

Maximum Bicondylar Breadth (BCB) exhibited significant differences between skull of males and females in the present sample. Similar findings have been reported from other studies where intercondylar dimension i.e. Maximum Bicondylar Breadth (BCB) displayed significant difference in diverse populations including the historic British samples from St. Bride's church. In the present study, the values of maximum bicondylar breadth (BCB) as observed in both sexes (males 46.73mm; females 44.29mm) were comparatively smaller than French skulls (males 51.32mm; females 48.73mm) British samples (males 51.29mm; females 48.67mm) and African – American group (Black males 49.6mm; females 47.3mm;white males 51.9mm; females 49.8mm). Besides BCB, Gapert *et al.* (2009) in the British sample, found MxID and EHC to be significantly dimorphic, which was not the case in the present study. In our study maximum bicondylar breadth was found to be the most reliable variable for sex estimation.

There are sexual differences in foramen magnum of varying magnitude across different Populations. To ascertain these differences the results of the present study were have been compared with the existing studies as shown in Table 4.

Table - 4 Comparison of measurements of foramen magnum (mean) of the present study with various studies

Variables	Routal *et al.* India	Sayee *et al.* India	Deshmukh *et al.* India	Gapert *et al.* Britain	Suazo *et al.* Brazil	Present study
FML Males (mean)	35.5	34.2	34.0	35.91	36.5	33.54
FML Females (mean)	32.0	33.5	34.0	34.71	35.6	32.31
FMW Males (mean)	29.6	28.5	29.0	30.51	30.6	27.77
FMW Females (mean)	27.1	28.0	28.0	29.36	29.5	27.21

The mean values for all the variables in present study were comparatively lower than that of other studies except for Routal *et al*., (1984) where, females exhibited almost similar values as that of the present study. Area of the foramen magnum of the present study when compared with other studies also revealed minimum value in both sexes (table 5).

Table - 5 Comparison of measurements of area of foramen magnum (mean) of the present study with various studies

Area	Raghavendra Babu et al India (2012)		Gapert et al British (2009)		Macaluso jr French sample (2010)		Texieria Brazilian (1982)		Present study (2012)	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
FMA Routal	811.	722	862	801	854	807			733	692
FMA Texieria	821	727	868	808	860	815	963	805	741	699

†Area in mm^2

It is widely recognized however, that size related levels of sexual dimorphism are generally population specific, due to a combination of genetic, environmental and socio-cultural factors and thus metric standards developed for sexing cranial remains may not be accurately applied to other skeletal samples (Kajanoja 1966; Birkby 1966; Calcagno 1981; Steyn & Iscan 1988; Hoyme &Iscan, 1989;Kranioti, Dayal *et al*., 2008 Gapert *et al*., 2009; Macaluso Jr.,2011). It can be concluded from the present study that of, all the variables considered in the present study, maximum bicondylar breadth was found to be the most reliable variable for sex estimation. In stepwise, analysis it was found to be more discriminating variable providing an accuracy of 66%. The accuracy of sex prediction base on discriminant function analysis ranged from 66% to 70%. Looking at the overall accuracy rates in the present study it can be inferred that morphometric analysis of foramen magnum dimensions cannot be regarded as a very reliable method for determining sex in the present collection on complete skulls. However, in case of highly fragmentary remains, where no other skeletal remains are preserved, metric analysis of the basal region of the occipital bone may provide a statistically useful indication as to the sex of an unknown skull.(Gapert *et al*.,2009 Macaluso Jr., 2011).Similar findings have been reported by present study. Since the present study was based on a limited sample, it is suggested that further research based on larger samples of documented Indian skulls should be undertaken to check the reliability of morphometric measurements of foramen magnum in sex determination.

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