ABSTRACT

Background and Objectives: (1) To evaluate dimensions of the foramen magnum (FM) among males and females and to establish its role in sexual dimorphism using cone beam computed tomography (CBCT). (2) To evaluate sagittal diameter, transverse diameter, area, and circumference of FM among males and females.

Materials and Methods: Two hundred and eighty CBCT scans (140 males and 140 females; age range, 20–80 years) were selected for this study. The sagittal diameter, transverse diameter, area, and circumference of FM were measured, and data were subjected to discriminant analysis for the evaluation of sexual dimorphism.

Results: The area of FM was the best discriminant parameter which is used to study the sexual dimorphism with an overall accuracy of 72%.

Interpretation and Conclusions: It can be concluded that the reconstructed CBCT image provides valuable measurements for the FM and could be used for sexing even when other methods are inconclusive.

Key words: Cone beam computed tomography, foramen magnum, forensic dentistry, radiography

A man is born with an identity and deserves to die with the same. This is the fundamental right of being born a human. However, due to natural calamities, mass disasters, intentional/unintentional acts of fellow human beings, a number of instances of “unidentified bodies” come to fore. Establishing the identity of the unknown dead bodies always poses a challenge to the investigating team and to the forensic experts.[1]

Thus, there should be appropriate methods for proper identification so that as soon as possible the victims can be identified from their remains. In the construction of a biological profile from unidentified human remains, sexual dimorphism of the skeletal system has its own magnitude. The most accurate results are obtained when the entire skeleton (100%) is available; however, skeletal material derived from forensic and archaeological contexts is rarely complete or undamaged. Therefore, it is important to establish methods for determining sex from skeletal elements which are likely to survive and be recovered.[2]

Several studies of skull base showed a substantial significance due to the resistant nature of its parts such as the mastoid, foramen magnum (FM), the occipital condyles in explosions, fire trauma, and aircraft accidents. In the base of the skull, FM also has a favorable anatomical position as it is covered by soft tissue and the skeleton of the head that protects it from direct impact, thus preserving this area for forensic examination.[3]

The need for methods to predict sex from cranial fragments becomes apparent even when only a part of the skull is brought for identification like FM. This structure has
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The importance of radiographic techniques in clinical forensic medicine is also widely recognized. It is a common practice to obtain radiographs as a part of postmortem examinations to locate foreign bodies or document fractures or other injuries.[5]

In general, Towne’s view, lateral skull radiographs and submentovertex view are used for viewing FM.[6] As these views are two-dimensional and problem like superimposition of structures is experienced, computed tomography (CT) is generally the preferred choice.[5] Cone beam CT (CBCT) is now a newer modality which came into existence in present scenario and is better than CT in terms of less exposure, less scan time required, and also cost effectiveness.

Hence, it can be used as a better modality to study sexual dimorphism by using different dimensions of FM or their combinations.

In view of these observations, and with the aim of expanding the body of evidence on this matter, the proposed study was carried out with the objective to measure the relevant parameters of FM for sexual dimorphism using CBCT. Full-volume CBCT scans were used for this purpose.

MATERIALS AND METHODS

This retrospective study was carried out in the Department of Oral Medicine and Radiology at Sri Aurobindo College of Dentistry, Indore. The study was designed to measure the dimensions of FM for sexual dimorphism using CBCT. The study population comprised 280 participants who were divided into two main groups, which comprised 140 males and 140 females. They were previously referred to the Radiology Department for several other reasons. The study protocol was approved by the Local Ethical Committee of Sri Aurobindo College of Dentistry, Indore. FM measurements (sagittal, transverse, circumference, and area) were obtained from reformatted axial sections using CBCT scans. A pilot study was conducted and based on the findings of the pilot study. The sample size was calculated using statistical software N Master 2 (Copyright @ Department of Biostatistics; CMC Vellore; India). The minimum required sample size in each group was found to be 134. (Standard deviation in Group 1 and 2 = 0.6, mean difference = 0.3, effect size = 0.5, alpha error = 0.5, and power = 90%). Hence, the study was carried out on CBCT scans of 140 males and 140 females.

The CBCT images were examined on the computer monitor in dim light. To predict the gender based on the value of selected skull measurements, discriminant analysis was used. The measurements were carried out by two trained and calibrated oral radiologists. A total of 25 CBCT images were examined and measured by two radiologists until the desired inter- and intra-examiner reliability[7] was obtained (Cohen’s kappa value = 0.92).

Individuals above 20 years of age were included in the study as the stabilization of size of FM occurs between 18 and 20 years. (The occipital and sphenoid become united, forming a single bone).

Patients <20 years of age, patients having any developmental anomaly/syndromes related to vertebral column or associated with cranial malformation were excluded from the study. The age and gender of all patients were recorded. Consent was taken from all the participants at the time of taking the scan that required data from their CBCT scans can be used for further retrospective studies. Scans were imported in the OnDemand3D App, Medical Imaging Software (CyberMed, Seoul, Korea). All sections selected were aligned parallel to the plane of the FM to select the best image of the foramen [Figure 1].

FM measurements (sagittal, transverse, circumference, and area) were obtained from reformatted axial sections using CBCT scans. For standardization in the sagittal section, we have taken a line joining basion and opisthion known as Macrey’s line. In three-dimension (3D), sagittal plane is passing through the intermaxillary suture and symphysial region. In the coronal section, we have standardized by taking a bisector from the body/base of C1 vertebrae which is passing through the body of C2 vertebrae. In the 3D coronal section, it is passing through C1 and C2 vertebrae, and it is behind the styloid process and external auditory meatus [Figure 1].

Figure 1: Standardization with coronal, sagittal, and axial sections

Four parameters of FM were evaluated in this study. FM transverse diameter (FMTD) was recorded as the greatest width of the FM. FM sagittal diameter (FMSD) was recorded as the greatest anteroposterior dimension of the FM (basion – opisthion). FM area (FMA) was automatically given after tracing the bony margin of the FM by using area tool [Figure 2]. FM circumference (FMC) was automatically...
given after tracing the bony margin of the FM by using parameter tool [Figure 3].

Statistical analysis
The raw data of 280 responses were entered into the computer database, and the responses of frequencies were calculated and analyzed. The prevalence of an outcome variable along with 95% confidence limits was calculated. The statistical software MINITAB version 17.0 (Minitab, Ltd. Coventry CV3 2TE, United Kingdom) was used for analysis. Regression analysis was performed for each variable.

RESULTS

The mean FMA values calculated for males and females were 916 ± 145 and 812.22 ± 95.9 mm², respectively. When the mean values of FMA in males and females were compared, highly significant \((P = 0.000)\) results were found. Range recorded for females was 620–1208 mm² and the range recorded for males was 679–1307 mm². Hence, the overall accuracy of this parameter to assess gender by using the given regression equation was found to be 72.1% [Table 1].

Regression equation: Gender = 2.619 – 0.001303 × FMA (mm²)

If the equation value is near to 2 and then the individual is male, and if the equation value is near to 1 then the individual is female.

The mean FMTD calculated for males was 31.34 ± 2.19 mm, while for females, it was 28.98 ± 2.23 mm. When the mean values of FMTD in males and females were compared, highly significant \((P = 0.000)\) results were found. Range recorded for females was 24.5–38.44 mm and that for males was 26.55–43.2 mm. Hence the overall accuracy of this parameter to assess gender came out to be 65.4% [Table 1].

Regression equation: Gender = 1.6034 – 0.00319 × FMTD (mm)

The mean FMSD calculated for males was 37.30 ± 2.61 mm, while for females it was 35.95 ± 2.38 mm. When males and females were compared, moderately significant \((P = 0.014)\) results were found. Range recorded for females was 30.2–39.66 mm, and the range recorded for males was 31.77–42.4 mm. Hence, the overall accuracy of this parameter to assess gender came out to be 53.9% [Table 1].

Regression equation: Gender = 2.522 – 0.0280 × FMSD (mm)

The mean FMC calculated for males was 115 ± 11.6 mm and for females was 109.23 ± 9.68 mm, respectively. When the mean values of FMC in males and females were compared, moderately significant \((P = 0.014)\) results were found. Range recorded for females was 96.78–138.6 mm and the range recorded for males was 90–128.13 mm. Hence, the overall accuracy of this parameter to assess gender came out to be 68.6% [Table 1].

Cohen’s kappa value (inter- and intra-examiner reliability=0.92), Oral health surveys=Basic methods. 4th edition. FMA=Foramen magnum area, FMTD=Foramen magnum transverse diameter, FMSD=Foramen magnum sagittal diameter, FMC=Foramen magnum circumference

Table 1: Comparison of mean values of various parameters of foramen magnum among males and females

| Parameters     | Males          | Females        | P  | Significance     |
|----------------|----------------|----------------|----|-----------------|
|                | Mean ± Range   | Mean ± Range   |    |                 |
| FMA (mm²)      | 916±145        | 812.22±95.9    | 0.000 | Highly significant |
| FMTD (mm)      | 37.1±36.1      | 29.51±2.77     | 0.000 | Highly significant |
| FMSD (mm)      | 37.3±2.61      | 35.95±2.38     | 0.014 | Moderately significant |
| FMC (mm)       | 115±11.6       | 109.23±9.68    | 0.014 | Moderately significant |

Figure 2: Foramen magnum sagittal diameter, foramen magnum transverse diameter, and foramen magnum area

Figure 3: Foramen magnum circumference
Regression equation: Gender = 3.222 − 0.01550 × FMC (mm)

When regression analysis was performed using 140 males and 140 females with the regression equation given below using all the parameters (FMSD, FMTD, FMC, and FMA), the overall accuracy was 71.9%.

Regression equation: Gender = 2.636 + 0.0134 FMSD (mm) − 0.00214 FMTD (mm) − 0.001099 FMA (mm²) − 0.00551 FMC (mm)

Using all the parameters, correlations were calculated by using Pearson’s correlation test. It was found that significant correlation was observed between FMA and FMSD (P < 0.05), FMA and FMTD (P < 0.05), FMC and FMSD (P < 0.05), and FMC and FMA (P < 0.05). Other correlations were found to be nonsignificant. The strongest correlation was between FMC and FMA for males and females and between FMSD and FMC, respectively. The weakest correlations were between FMTD and FMSD (r = 0.449 and 0.776 for males and females, respectively).

DISCUSSION

In explosions, warfare, and other mass disasters like aircraft crashes, recognition and sex determination is not very simple. The study of anthropometric characteristics is of primary importance when solving troubles related to identification. Craniofacial features are included among these characteristics, which are closely connected to forensic medicine since they can be used to aid in identifying an individual from a skull found detached from its skeleton.[3]

Next to the pelvis, the skull is the most easily sexed portion of the skeleton, but the determination of the sex from the skull is not reliable until well after puberty. The craniofacial structures have the advantage of being composed largely of hard tissue, which is relatively everlasting.[7]

Sex estimation can be accomplished using either morphological or metric methodologies. Statistical methods using metric traits are becoming more accepted, with most of the bones having been subjected to linear discriminant classification.[2]

In the skull samples analyzed, a significant sexual dimorphism in the FM dimensions was observed. However, classification of the skulls through the discriminant function described from these dimensions was found to be useful. These results are consistent with most of the literature analyzed.

In the vein of our study, Catalina-Herrera et al (1987)⁶, Uysal et al (2005)⁸, and Uthman et al (2012)² used helical CT for evaluating the foramen diameters, area, and circumference concluded that the circumference and area were the best discriminant parameters for sex determination with an overall accuracy of 67% and 69.3%, respectively.² In case of transverse diameter, the predictability of gender in our study was 65.4% as compared to 66.4% in their study. In the case of the predictability of gender using sagittal diameter as a parameter, it was 53.9% in our study as compared to 69.6% in their study.²

It can be concluded from the present study that among all the variables considered in the present study, FMA was found to be the most reliable variable for sex estimation.

The study conducted by Uthman et al. (2012) using helical CT for evaluating the foramen diameters, area, and circumference concluded that the circumference and area were the best discriminant parameters for sex determination with an overall accuracy of 67% and 69.3%, respectively.² This was close to our study, having an overall accuracy of 68.2% and 72.1%, respectively.

Considering the high sex predictability of FM dimensions in the present study and the studies preceding it, the foramen
measurements can be used to supplement other sexing evidence available, so as to precisely ascertain the sex of the skeleton. It can be concluded from the present study that among all the variables considered in the present study, FMA was found to be the most reliable variable for sex estimation. Hence, either with a combination of other parameters or individually, FMA can be used as a reliable parameter to estimate the gender.

It is more accurate when we look at the qualitative features of the occipital bone, such as the roughness of the nuchal lines, the shape of the occipital condyles, and the characteristics of the external occipital protuberance. Hence, according to our study, the tables of the expected range of FM dimensions in skulls of men and women should be used only as a first ballpark figure to the diagnosis of sex.

CONCLUSIONS

It was revealed that significantly higher mean values of length, breadth, circumference, and area of FM were present in males than in females. It was also found that the most reliable indicator to predict the gender is FMA.

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Conflicts of interest
There are no conflicts of interest.

REFERENCES

1. Soames RW. Grays Textbook of Anatomy. International Edition. New York: Churchill Livingstone; 1995.

2. Uthman AT, Al-Rawi NH, Al-Timimi JF. Evaluation of foramen magnum in gender determination using helical CT scanning. Dentomaxillofac Radiol 2012;41:197-202.

3. Krogman WM, Iscan MY. The Human Skeleton in Forensic Medicine. Springfield, Illinois: Charles C Thomas Publisher Ltd.; 1986.

4. Macaluso PJ Jr. Metric sex determination from basal region of the occipital bone in a documented French sample. Bull Mem Soc Anthropol Paris 2011;23:19-26.

5. Kamath VG, Asif M, Shetty R, Avadhani R. Binary logistic regression analysis of foramen magnum dimensions for sex determination. Anat Res Int 2015;2015:459428.

6. Catalina-Herrera CJ. Study of the anatomic metric values of the foramen magnum and its relation to sex. Acta Anat (Basel) 1987;130:344-7.

7. World Health Organization. Oral Health Surveys: Basic Methods. 4th ed. England: World Health Organization; 1997.

8. Uysal S, Gokharman D, Kacar M, Tuncbilek I, Kosa U. Estimation of sex by 3D CT measurements of the foramen magnum. J Forensic Sci 2005;50:1310-4.

9. Radhakrishna SK, Shivarama CH, Ramakrishna A, Bhagya B. Morphometric analysis of foramen magnum for sex determination in South Indian population. Nitte Univ J Health Sci 2012;2:20-2.

10. Jain SK, Choudhary AK, Mishra P. Morphometric evaluation of foramen magnum for sex determination in a documented North Indian sample. J Evol Med Dent Sci 2013;2:8093-8.

11. Patel R, Mehta CD. Morphometric study of foramen magnum at the base of human skull in South Gujrat. IOSRJDMs 2014;13:23-5.

12. Kanchan T, Gupta A, Krishan K. Cranio metric analysis of foramen magnum for estimation of sex. Int J Med Health Biomed Pharm Eng 2013;7:111-3.

13. Shepur MP, Magi M, Nanjundappa B, Havaladar PP, Gopi P, Saheb SH. Morphometric analysis of foramen magnum. Int J Anat Res 2014;2:249-55.

14. Gapert R, Black S, Last J. Sex determination from the foramen magnum: Discriminant function analysis in an eighteenth and nineteenth century British sample. Int J Legal Med 2009;123:25-33.

15. Raghavendra Babu YP, Kanchan T, Attiku Y, Dixit PN, Kotian MS. Sex estimation from foramen magnum dimensions in an Italian population. J Forensic Leg Med 2012;19:162-7.

16. Deshmukh AG, Devershi DB. Comparison of cranial sex determination by univariate and multivariate analysis. J Anat Soc India 2006;55:48-51.