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FORAMEN MAGNUM AS DIMORPHIC TOOL FOR SEX DETERMINATION IN THE EGYPTIAN POPULATION USING CONE BEAM COMPUTED TOMOGRAPHY: A RETROSPECTIVE STUDY

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ABSTRACT

Objective: To evaluate the differences in the measurements of the Foramen magnum (FM) in relation to sex in an Egyptian population using cone beam computed tomography (CBCT).

Material and Methods: One hundred and twenty retrospective CBCT scans of adult Egyptian individuals were included in this study (sixty males and sixty females). The maximum length (sagittal diameter) and the maximum width (transverse diameter) of the FM were measured on axial CBCT images, then the foramen magnum index (FMI) and foreman magnum area (using two different equations) were calculated. All the measurements were statistically analyzed.

Results: It was found that all the FM measurements performed in this study were higher in males than that in females with statistical significance difference, except for the FMI which was higher in males, but the difference didn't reach the statistical significance level. Moreover, discriminant function analysis showed that FM length and FM area are the best sex discriminant measurements with overall accuracy of 65% and 64% respectively.

Conclusion: FM measurements assessed on CBCT scans can be used as a reliable indicator of sexual dimorphism in the Egyptian population.

Keywords: Cone beam computed tomography, Foramen magnum, Sexual dimorphism, Forensic dentistry

INTRODUCTION

Forensic dentistry is a subdivision of forensic medicine, where dental evidence is processed, reviewed, evaluated, then presented to contribute scientific and objective data that aids in the legal processes. Human identification is one of the main interests of dental forensic science, as the dental forensic experts apply their knowledge and skills to achieve high level of accuracy during the identification process.[1,2]

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In mass disasters and catastrophes such as war zones, plane crashes, terrorist attacks or explosions, where skeletons are incomplete and only remnants are left, the identification of the victims becomes really challenging. Sex determination is the first step in the complex process of human identification, when achieved successfully, a certain percentage of possibilities are immediately ruled out. Forensic odontologists use teeth and skull traits for the sex identification depending on the proved differences in the skull patterns and skull traits between the two sexes. [3,4]

Foramen magnum is an important structure of the skull base located inferior to the sagittal suture and surrounded by the basilar, squamous and lateral parts of the occipital bone. It is considered an ideal structure for forensic purposes, as it is situated in the deepest part of the posterior cranial fossa and covered by a large volume of soft tissue which make it well preserved and much less damaged.[5]

Different studies were performed to assess the FM dimensions as indicators for sexual dimorphism in different populations. Some studies were performed on dried skulls by direct bony measurements and others were radiographic studies using different imaging techniques either conventional or three dimensional such as computed tomography. Radiographic studies are easier to perform as the scans can be studied retrospectively, which allows for greater sample collection and wider research.[5,6,7]

Among the available advanced imaging techniques, CBCT offers several advantages including, good image resolution, accurate measurement, simple technique and at low cost, which made it a widely used modality for forensic studies.[8]

CBCT studies were performed on many populations to examine FM as a sexing tool which was found to be reliable but it is highly influenced by environmental, socioeconomic, and genetic factors specific to different populations. The fact that each population has distinct morphologic and morphometric manifestations of sexual dimorphism, made it essential to study the specific characteristics of a population and then comparing these morphometric patterns with other populations from different parts of the world. This is what encouraged the authors of the current study to expand the research on a sample of the Egyptian population. [5,6,7,9,10,11]

MATERIALS AND METHODS

All 120 retrospective CBCT scans (60 males and 60 females) of adult (above 18-year-old) Egyptian individuals were retrieved from the database of the Oral and Maxillofacial Radiology department of the faculty of Dentistry, Cairo University, Egypt. The scans were acquired by Promax 3D Planmeca® system (Helsinki, Finland). The scanning parameters were 90 kV, 6 mA, and a voxel size of 0.2 mm. The field of view (FOV) of the retrieved scans included the area from the bottom of the cranial base to the hard palate and anterior nasal spine (ANS) superiorly with the entire extent of the foramen magnum (FM). Scans showing motion artifacts, metallic object artifacts or blurring were excluded from the study. Besides, scans of subjects with history of trauma, surgery or any other pathological lesion (congenital/acquired) in the region of cranial base were excluded. The CBCT images were imported to Planmeca Romexis viewer 4.2.6.R software.

Two independent experienced observers (both are consultants of oral and maxillofacial radiology with more than 10 years of experience), blind to the sex of the subjects, independently analyzed the CBCT scans. After importing the DICOM file for each case, the dataset was adjusted such that the sagittal plane was aligned with the ANS, and the axial plane was tilted until it was aligned with the McRae line (the line connecting the basion and the opisthion of FM) (Fig. 1). Observers were permitted to use the magnification tool and modify screen brightness and contrast of the software for optimal visualization as well as scroll through the axial cross section images.

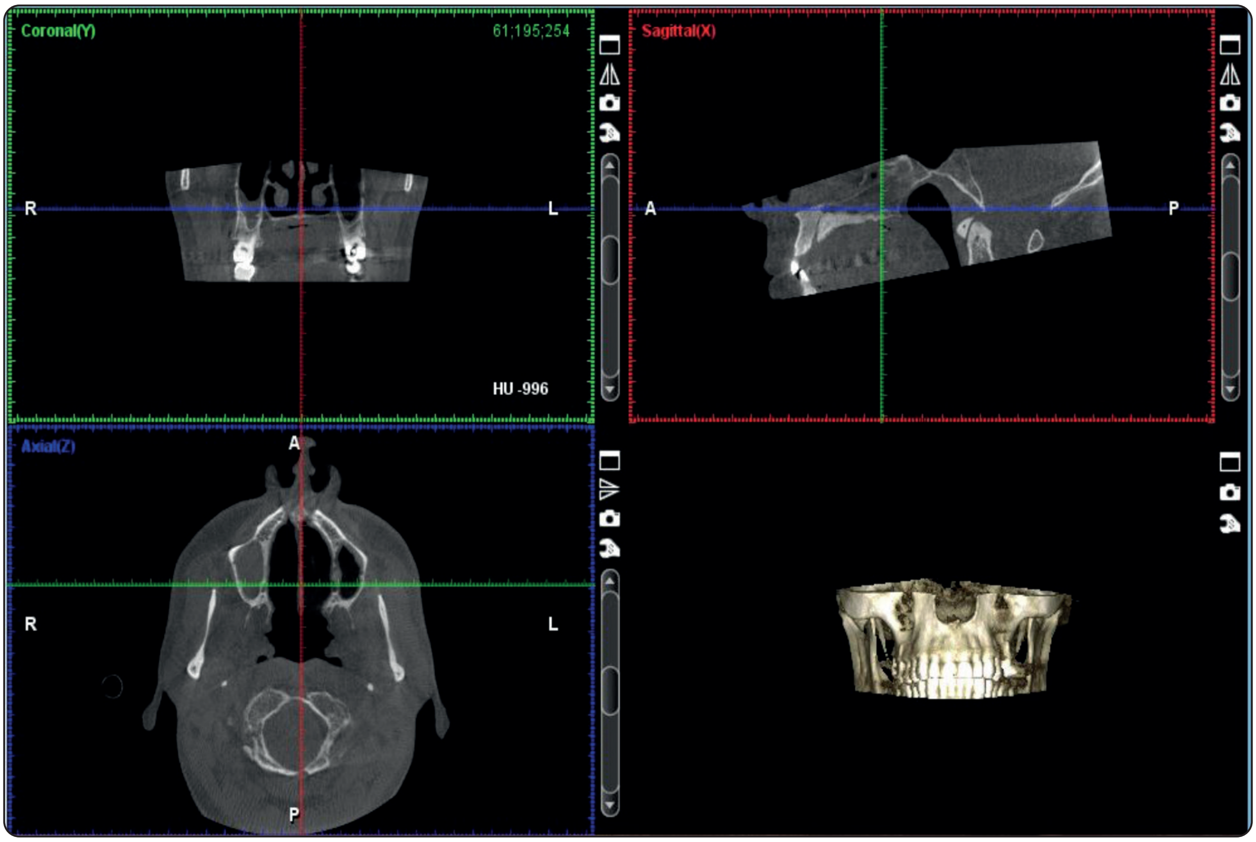

Fig. (1) The orientation of the sagittal plane with the ANS and the orientation of the axial plane with the basion and the opisthion of foramen magnum

The parameters of the FM measured in this study were the maximum length (sagittal diameter), and FM maximum width (transverse diameter). Maximum length of the FM was measured in an Anteroposterior direction along the principal axis of the foramen (Fig. 2). Maximum width of the (FM) was measured perpendicular to the maximum length and recorded at the widest transverse diameter of the foramen (Fig. 2).[9,10,12].

Length and width measurements were measured on three successive axial cross section images parallel to the plane of the foramen in order to select the image of the foramen where the widest distances could be obtained (Fig. 3).

Fig. (2) The maximum length and width measurements of the foramen magnum on axial CBCT cross-sectional image

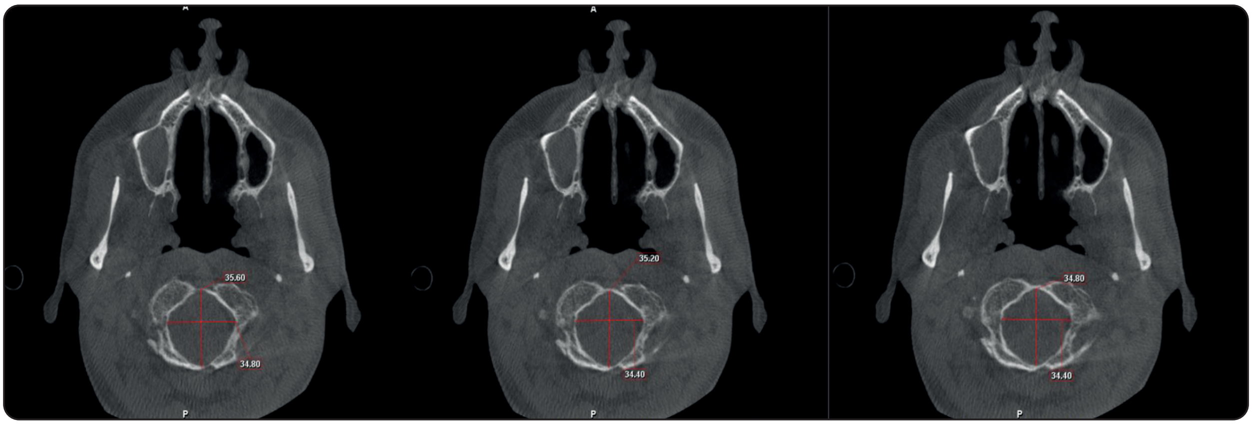

Fig. (3) The measurement of the length and width of the foramen magnum on three successive axial CBCT cross-sectional images

Then, the FM area and the foramen magnum index (FMI) were calculated through mathematical equations. To calculate the area of the FM, the pre-measured length and width were inserted into two different equations. The first equation used a formula proposed by Routal et al.[13] (Area = ¼ x π x length x width) and referred to as "Area 1". The second equation used a formula derived by Teixeira.[14] (Area = π x [(length + width)/4]^2) and referred to as "Area 2".[5,15]

However, for performing the FMI, this equation was used as follows: FM width / FM length x 100.[16]

Statistical analysis

Data management and statistical analysis were performed using the Statistical Package for Social Sciences (SPSS) version 18. Numerical data were summarized using mean, standard deviation and confidence intervals. Data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Comparisons between both groups with respect to normally distributed numeric variables were compared using independent t test. Comparison of both equations for FM area was performed by Paired t test. The receiver operating characteristic curve (ROC curve) and area under the curve (AUC) were plotted to determine whether the measured parameters exhibited a statistically significant differences in the sex discrimination accuracy. Moreover, a discriminant functional analysis was performed for sex prediction based on the value of the measurements of the FM.

All p-values are two-sided. P-values ≤0.05 were considered significant.

RESULTS

Inter-rater reliability

The interobserver analysis demonstrated an excellent correlation (0.995, with Confidence interval 0.993 to 0.996) (Table 1). Therefore, average of both examiners was used for statistical analysis.

TABLE (1) Interobserver analysis (Cronbach's Alpha)

	Correlation coefficient	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	P vlue
Average Measures	.995	.993	.996	193.796	119	119	.000*

Significance level p≤0.05, *significant

Comparison between males and females

The length (36.71±2.16) and width (31.83±2.70) in males were significantly higher than the length (35.11±3.14) and width (30.26±2.24) in females with (p=0.002) for the length measurements and (p=0.001) for the width measurements (Fig.4).

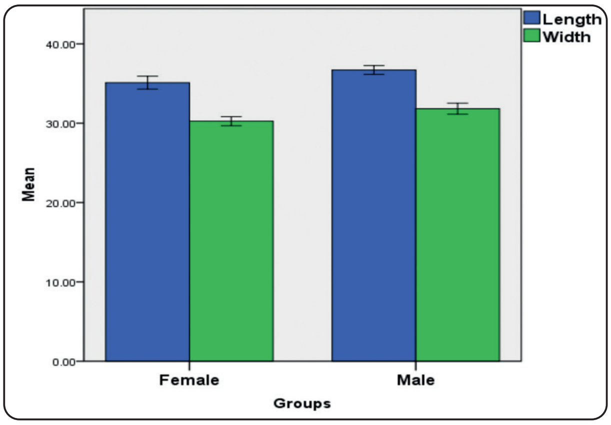

Fig. (4) Bar chart illustrating mean value of length and width in males and females

Area 1 in males (919.61±113.70) was significantly higher than females (836.66±111.45), (p=0.00). Also, Area 2 in males (925.43±112.65) was significantly higher than females (842.81±111.70), (p=0.00) (Fig.5).

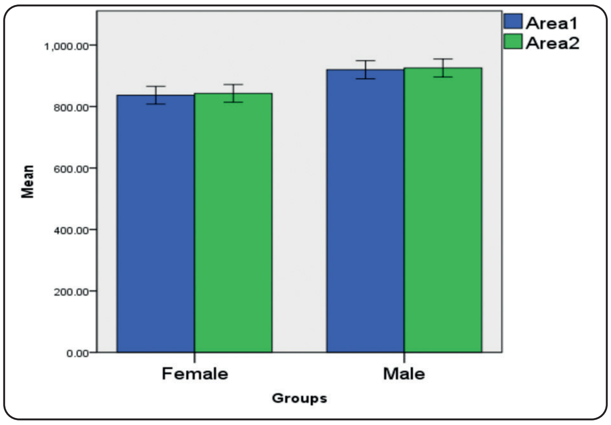

Fig. (5) Bar chart illustrating mean value of area (calculated by equations 1 & 2 in males and females)

The FMI in males (86.78±6.44) was higher than females (86.72±8.64). However, this difference didn't reach the level of statistical significance (p=0.969).

ROC curve

FM Area (1 or 2) had the highest value of area under the curve (AUC for Area1 = 0.709, Area 2=0.710), followed by the FM width (AUC=0.673), then the FM length (AUC=0.669). While the FM index had no value (AUC=0.527) (Fig. 6).

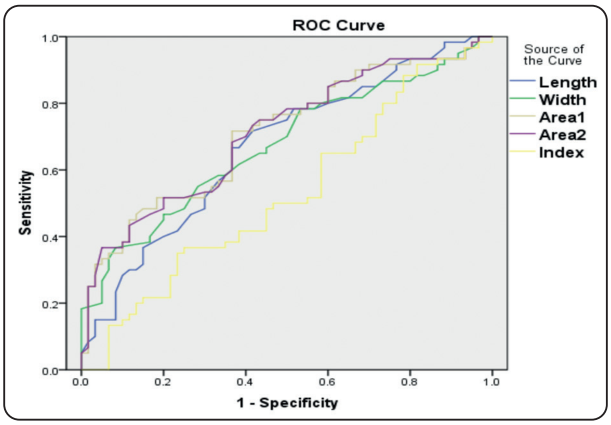

Fig. (6). ROC of different FM measurements

Discriminant Function Analysis

For univariate analysis (Table 2), the parameter with the highest male, female and overall accuracy with and without cross-validation was the FM length (Both area 1 and area 2 also had the same female predication rates as length). While the parameter with the lowest predication rates was the FMI.

TABLE (2): Discriminant analysis (Univariate)

Variable	Coefficient	Fisher's linear DF		Correct prediction rates (%)			Correct prediction rates after cross-validation (%)		
		Female	Male	Female	Male	Mean	Female	Male	Mean
Length	0.371	4.830	5.050	63.3%	66.7%	65.0%	63.3%	66.7%	65.0%
Constant	-13.319	-85.493	-93.385						
Width	0.403	4.916	5.172	61.7%	61.7%	61.7%	61.7%	61.7%	61.7%
Constant	-12.513	-75.054	-83.002						
Area 1	0.009	0.066	0.073	63.3%	61.7%	62.5%	63.3%	61.7%	62.5%
Constant	-7.800	-28.309	-34.057						
Area 2	0.009	0.067	0.074	63.3%	65.0%	64.2%	63.3%	65.0%	64.2%
Constant	-7.881	-28.917	-34.722						
Index	0.131	1.495	1.496	55.0%	45.0%	50.0%	16.7%	11.7%	14.2%
Constant	-11.391	-65.531	-65.612						

DISCUSSION

The differentiation of biological sex is an important phase of medico-legal investigations through the procedure of identifying unknown skeletal remains. Where the residues of human skeletons are incomplete or have been damaged or fragmented, this can disturb the precision of sex determination and demands the development of reliable methods using isolated bony parts.[5,11]

The skull is the second most simply sexed part of the skeleton after the pelvis. The craniofacial structures have the benefit of being composed mainly of hard tissues, which is comparatively indestructible.[12,17]

Additionally, compared to other skeletal parts, the FM reaches its adult dimensions relatively early in childhood and that's why it is doubtful to respond to significant secondary sexual changes. Also biomechanically, no musculature is acting upon the contour and dimensions of the FM, therefore its main function is to create a channel for vital structures into and out of the cranium, chiefly the medulla oblongata, which occupies the largest proportion of the foraminal space. As the nervous system grows and reaches maturity at young age in comparison to other systems of the body, it causes no change in the size of the FM. This is proved by the completion of union of the different parts of the occipital bone by 5-7 years of age.[9,18]

Morphometric analysis offers an objective method to study sex differentiation and permits comparisons to be performed with the results of other studies. This technique is way better to be done before performing destructive methods of testing such as DNA analysis. It may also be used in cases where DNA testing is not possible because of the damage of the sample remains, as in extensive heat damage.[11,19]

To evaluate effect of sex on FM morphometric variables, the sample size of this study was calculated based on (Lopez-Capp et al., 2018; Mustafi et al., 2019)[15,20], with an actual **power (1-β error) of 0.8 (80%)** and a significance level **(α error) 0.05 (5%)** for two-sided hypothesis test.

Although some recent studies by Darwish et al., 2014; Lashin et al., 2019; Abo El-Atta et al., 2020 and Slima & Abdou., 2020 performed FM analysis on the Egyptian population, these studies were done on CT images.[21,22,23,24] Therefore, as far we know that this current study was the first to perform FM measurements using CBCT on Egyptians.

The researchers of the current study utilized retrospective CBCT scans because CBCT is widely used in the dental and maxillofacial field and other medical fields.[25] Meanwhile, researches as Gapert et al., 2009; Jain et al., 2014 and Lopez-Capp et al., 2018, who performed FM analysis on human crania and skulls which is not readily available and has some ethical concerns.[5,15,16]

Moreover, this study utilized CBCT data because linear measurements obtained from CBCT scans are highly accurate and reproducible.[26] This came in agreement with Akay et al., 2017 who only measured the sagittal and transverse diameters on Turkish population. Besides to, Ilgüy et al., 2014 who measured the sagittal and transverse lengths on adults of European descent and Tambawala at al., 2016 who obtained both the linear measurements and areas of FM on Indian population.[9,10,12]

To the best of our knowledge, no other studies measured the length and width measurements on three successive axial cross section images. This step was performed to assure the accuracy of choosing the best CBCT axial image showing the clearest FM with the widest distances.

The assessed lenght, width and area measurements were found to be significantly higher in males than in females, this came in concordance with many previous studies performed on Egyptian, Indian, Swiss, Turkish, Iranian, Brazilian and Polish populations.[9,10,11,15,23,27,28,29]

The FM index was found to be higher in males than in females but with no significant difference, this came in agreement with Vinutha et al. in their study on the Indian population. However, in the studies performed by Hosseini et al., Slima et al. and Abo El-Atta et al. on Iranian and Egyptian populations the FM index had a significant difference between the two sexes.[23,24,27,30]

The current study revealed that the mean length and width of FM is males in (36.71, 31.83mm) and (35.11, 30.26mm) in females respectively. Nearly similar values were recorded by Abo Elatta et al on their study of the Egyptian population using CT scans, the mean of the length and the width were (36.8, 31.5mm) in males, and (35.7, 29.9mm) in females. However, Slima & Abdou found approximately similar values for FM length and width in an Egyptian male sample (36.74, 31.1) but lower values in Egyptian females (32.18, 27.20mm).[23,24]

The mean values for FM length & width in males and females were higher in our study compared to the same measurements in the Indian, English & Turkish populations. However, higher values were recorded by Edwards et al. in their study on Swiss population. The difference in the values in the different populations can be attributed to the distinct anatomical variation of each population based on genetics, habits and customs.[5,9,10,11,31,32]

Moreover, in the present study, the area of FM was significantly different in the males compared to the females, similar to the results in previous studies by Tambawala et al., Tellioglu et al., Edwards et al. and Thais et al. on Indian, Turkish, Swiss and Brazilian populations.[9, 10,11,15,32]

ROC curve analysis showed that FM area 2 is the best for sex differentiation with 0.710 AUC, followed by FM area 1 (AUC 0.709), while for the FM width and length, the AUC was 0.673, 0.669 respectively. However, the ROC curve analysis in Lopez et al study on the Brazilian population showed near but slightly lower values where the predictors for sex were arranged from the highest to the lowest as FM Area 1 (AUC=0.693), FM Area 2 (AUC=0.691), FM width (AUC=0.633) and FM length (AUC=0.627).[15]

By discriminant function analysis, we found that the FM length has the highest sex prediction value in males and females (66.7%, 63.3% respectively), with an overall accuracy of 65%. The second highest discriminator of sex is the FM area using Teixiera. formula (Area 2) that reached an overall accuracy of 64.2% (65% in males and 63.3% in females). However, the overall accuracy of sex prediction for FM area using Routal et al formula (Area 1), width and FMI were 62.5%, 61.7% & 14.2% respectively.

In previous studies on the Egyptian populations, Lashin et al. found that the highest sex discriminator was the FM Area 2 (using Teixeira. formula) that reached 65% followed by FM width (63.5%) and FM length (63%), while in Abo El-Atta et al.'s study, the accuracy of FM width and FM length were 64.5% and 59.5% respectively.[22, 23]

However, Lopez et al. values for discriminant function analysis were lower than the current study, prediction values were arranged from highest to the lowest as; Area2 (59.6%), Area1 (57.4%), FM length (51.1%) and the least was the FM width (44.7%). On the contrary, in Uthman et al. study on the Iraqi population, the prediction value of FM Area was 69.3% which is higher than our study.[15,33]

CONCLUSION

In our study on an Egyptian population, the FM width, length and area measurements exhibited a higher sex discrimination accuracy compared to the FMI. Additionally, this study shows that the FM length and Area calculated using Teixeira's formula are a reliable discriminant parameters that could be used for sex prediction. Therefore, the results of this study show that CBCT images can provide valuable information regarding FM and its measurements which may be reliably used for sexual dimorphism in forensic medicine.

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