DOI : 10.48165/jiafm.2023.45.3.1

ORIGINAL ARTICLE

Clinical Importance of Foramen Magnum Measurements for Determining Sex - CT Scan Based Study using Discriminant Function Analysis

Bhoi S,[1] Das S,[2] Subramania DB,[3] Mishra A,[4] Ganapathy S,[4] Ravi K.[5]

1. MBBS student, JIPMER, Puducherry.
2,5. Department of Forensic Medicine & Toxicology, JIPMER, Puducherry.
3. Department of Radiodiagnosis, JIPMER, Puducherry.
4. Department of Biostatistics, JIPMER, Puducherry.

Abstract:

Identification of an individual is one of the important objectives of an autopsy. In forensic practice, partial identification from the bones in the form of sex is possible from the bones or any part of it. Foramen magnum (FM) measurements from skull or Computer Tomography (CT) scan images are useful for determining sex in different populations. The present study was undertaken with an objective to assess the clinical importance of FM measurements for determining sex from CT scan images in a south Indian population.

The parameters studied were the length and breadth of foramen magnum, foramen magnum index (FMI) and area of foramen magnum (AFM). The sample size was 384 consisting of 245 males and 139 females of south Indian origin. Independent student t-test showed that all the studied parameters except FMI was significantly different between the two sexes. Discriminant function analysis was used to differentiate sex from the measured parameters by using the split data method. Foramen magnum length (FML) was the best sex differentiating predictor with an accuracy of 70.9%. When all the parameters were taken together the accuracy increased marginally to 71.5%. FM measurements can be used to determine sex from CT scan measurements in a south Indian population but it is better to use it as an adjunct to other methods to increase the precision.

Keywords: Foramen magnum measurements; Computer tomography scan; South Indian population; Sex determination; Discriminant function analysis.

Introduction:

Sex determination is an essential criterion for establishing the partial identity of an individual. In many cases sexing of the deceased is done with the help of their skeleton. This situation may arise during mass disasters or homicide where only some body parts of the deceased are recovered. Accuracy of sex determination from analysis of long bones, skull, pelvis, pelvis and skull, entire skeleton was found to be 80%, 90%, 95%, 98% and 100% respectively.[1] The skull bone and its parts have a significant role in establishing the sex of an individual. The FM of skull remains well preserved and intact even during conditions of tremendous trauma or natural calamities owing to its compact anatomical structure and concealed location, especially due to the occipital condyles which encompasses it bilaterally. This significantly increases the utility of FM in sex determination.

Studies that have been done to evaluate the utility of FM measurements in determining the sex have utilised dry skulls mainly. In general, morphometric details of FM on dry skulls has been inspected by employing vernier callipers and calibrated paper strips. Gapert et al. evaluated 18th and 19th century British dry skull specimens by manual craniometry. Their study consisted of 76 male skulls and 82 female skulls and they could establish sex from FM measurements with an overall accuracy of 68%.[2] One Brazilian study evaluated 211 skulls and estimated the accuracy of sexual dimorphism from FM measurements to be 66.5% by using discriminant function analysis.[3] Researchers from Turkey studied the AFM in 219 skulls and found the correlation coefficient with sex to be 0.27.[4] For calculating AFM, two formulae are available which are given by Radinsky and Teixeira.[5,6] A study calculated AFM from dry skulls of an Indian population from the above two formulae and the accuracy was found to be 81.6% and 82.2% respectively from binary logistic regression (BLR) analysis.[7] Lately, studies have taken FM measurements from CT scan images for determining the sex.[8-11] In medico-legal practice, at times soft tissues may be found adhered to the skull. In such a scenario it is desirable to go for a CT scan of the skull rather than wasting time for processing the skull for removal of the soft tissues and making it dry for use. The objective of this study was to assess the utility of FM measurements from CT scans for determining sex in a south Indian population.

Methods:

The study was conducted as a part of the ICMR-STS-2020 (Indian Council of Medical Research – Short Term Studentship-2020) project, in the Department of Forensic Medicine and Toxicology and Department of Radiology of our institute. The CT scan images of 384 South Indian adults were analysed, which comprised of 139 females and 245 males, who had undergone CT

Corresponding Author
Dr. Siddhartha Das (Professor)
Email : sendsids@gmail.com
Mobile No. : +91-9445803019

Article History
DOR : 07.03.2022 DOA : 29.03.2023

scan of head and neck in our institute for various medical and surgical necessities.

Data collection: The CT scan images were accessed retrospectively after obtaining the approval of the Institute Ethics Committee. The scans were done by Siemens Somatom CT scanner, and were accessed via institute PACS (Picture Archiving and Communication System), using Siemens Healthineers Syngo Via 2.0 software. The images were visualized under VRT (Volume Rendering Technique) or cinematic VRT. VRT allowed 3D photorealistic visualization of CT scans, for better anatomical and diagnostic understanding of the structures. The image obtained in VRT was then rotated so as to view the FM at the base of skull. In majority of the cases the vertebrae and occipital condyles obscured the view of margins of FM and hence had to be removed using Punch tool.

In all the studies employing CT scan, the transverse diameter is measured in transverse section passed through the base of skull. But, the disparity in the measurement of antero-posterior diameter is noteworthy. It is either measured at mid-sagittal plane or the transverse plane passing below the base of skull. The two measurements taken were namely FML and foramen magnum breadth (FMB). They were measured using the inbuilt measuring scale present in the Syngo Via software. The adult south Indian patients for whom CT scans covering the FM region of the skull that were performed and the scan records available in the department of Radiodiagnosis of our institute were included in the study. Patients having congenital developmental deformities of the skull which affected the FM measurements and patients with fracture of the FM region of the skull bone were excluded from the study.

FML is the distance between basion and opisthion. FMB is the distance between the lateral margins of FM at point of greatest lateral curvature. Basion and opisthion are defined as the point where the anterior margin of FM is intersected by mid sagittal plane and the point where the mid sagittal plane intersects the posterior margin of FM respectively.

AFM: It is the area under the FM and estimated by two formulae namely Radinsky and Teixeira.

AFM1 (by Radinsky's formula) = ¼ x π x FML x FMB

AFM2 (by Teixeira's formula) = π x {(FML + FMB)/ 4}2

FMI is the the ratio of FMB and FML multiplied to 100.

FMI = (FMB/FML) x100.

Statistical analysis: All the continuous FM measurements like FML, FMB, FMI, AFM1 and AFM2 were reported for their mean, standard deviation, minimum and maximum. The significance for the mean difference of all the continuous measurements between male and female group was tested using Independent Student t test after checking for the normalcy assumption for both the groups by using Kolmogorov-Smirnov test. The Pearson correlation coefficient was calculated between all the above continuous measurements for both males and females. The entire dataset was split as training (80%) and testing (20%) dataset for internal validation. The discriminant function was built for each FM parameter and the combination of FM

Table 1. Descriptive statistics for individual measurements.

Para meters	Males (n = 245)			Females (n = 139)			t-statistic	P value
	Min.	Max.	Mean (SD)	Min.	Max.	Mean (SD)		
FML	2.87	4.15	3.49 (0.22)	2.22	3.68	3.27 (0.22)	9.35	<0.001
FMB	2.19	3.57	2.94 (0.23)	2.14	3.63	2.71 (0.21)	10.32	<0.001
FMI	63.48	117.05	84.47 (6.84)	63.97	122.97	83.08 (7.67)	1.82	0.069
AFM1	5.74	10.53	8.07 (0.93)	4.72	9.44	6.95 (0.78)	12.51	<0.001
AFM2	5.96	10.58	8.14 (0.93)	4.81	9.46	7.03 (0.79)	12.45	<0.001

Table 2. Correlations between FM measurements in males (upper right corner of the table) and females (lower left corner of the table).

Variables	FML	FMB	FMI	AFM1	AFM2
FML	1	.352**	-.455**	.784**	.820**
FMB	.251**	1	.670**	.856**	.824**
FMI	-.574**	.637**	1	.191**	.134*
AFM1	.755**	.823**	.092	1	.998**
AFM2	.794**	.786**	.035	.998**	1

*, ** Correlation is significant at 0.01 and 0.05 level of significance (2-tailed).

Table 3. Discriminant function analysis and canonical discriminant coefficient for the variables.

Function	Variable Entered	Wilks' Lambda	Unstandardized Coefficient	Male and female centroids	Sectioning Point
Function 1	FML	0.842	4.387 Constant: -14.92	M: 0.325 F: -0.571	-0.246
Function 2	FMB	0.765	4.446 Constant: -12.755	M: 0.417 F: -0.732	-0.315
Function 3	FMI	0.978	0.130 Constant: -10.984	M: 0.113 F: -0.198	-0.085
Function 4	AFM1	0.717	1.137 Constant: -8.738	M: 0.472 F: -0.828	-0.356
Function 5	AFM2	0.723	1.137 Constant: -8.815	M: 0.465 F: -0.817	-0.361
Function 6	FML FMB FMI AFM1	0.715	-0.598 -2.901 0.048 1.806 Constant: -7.574	M: 0.474 F: -0.833	-0.359

Table 4. Percentage of correct group membership in training and testing dataset.

Function	Predicted group membership (%)			Correct classification (%)
		Males	Females	
Function 1	Training	68.8	62.2	66.4
	Testing	75.2	63.2	70.9
Function 2	Training	69.4	76.8	72.1
	Testing	71.3	64.9	69.0
Function 3	Training	59.0	61.0	59.7
	Testing	43.6	56.1	48.1
Function 4	Training	74.3	80.5	76.5
	Testing	67.3	70.2	68.3
Function 5	Training	73.6	79.3	75.7
	Testing	68.3	73.7	70.3
Function 6	Training	74.3	80.5	76.5
	Testing	70.3	73.7	71.5

parameters. The correct classification rate was estimated for training and testing dataset. The area under the curve (AUC) of receiver operating characteristic (ROC) was used as a measure of discrimination for all discriminant function built for the continuous measurements between males and females for each discriminant function. All the statistical analysis was carried at 5% level of significance and a P-value < 0.05 was considered to be statistically significant.

Results:

In our study cohort, we had a total of 245 (63.8%) males and 139 (36.2%) females.

Difference in FM measurements across gender: The descriptive measurements of the parameters were estimated for both males and females in the sample, as presented in Table 1. It was found that FML, FMB, AFM1 and AFM2 parameters differed significantly between the two genders as tested using Independent Student t-test. The mean values of all these parameters were significantly higher for males as compared to females (P value <0.001). However, it was found that FMI did not differ significantly between the groups (P value = 0.069).

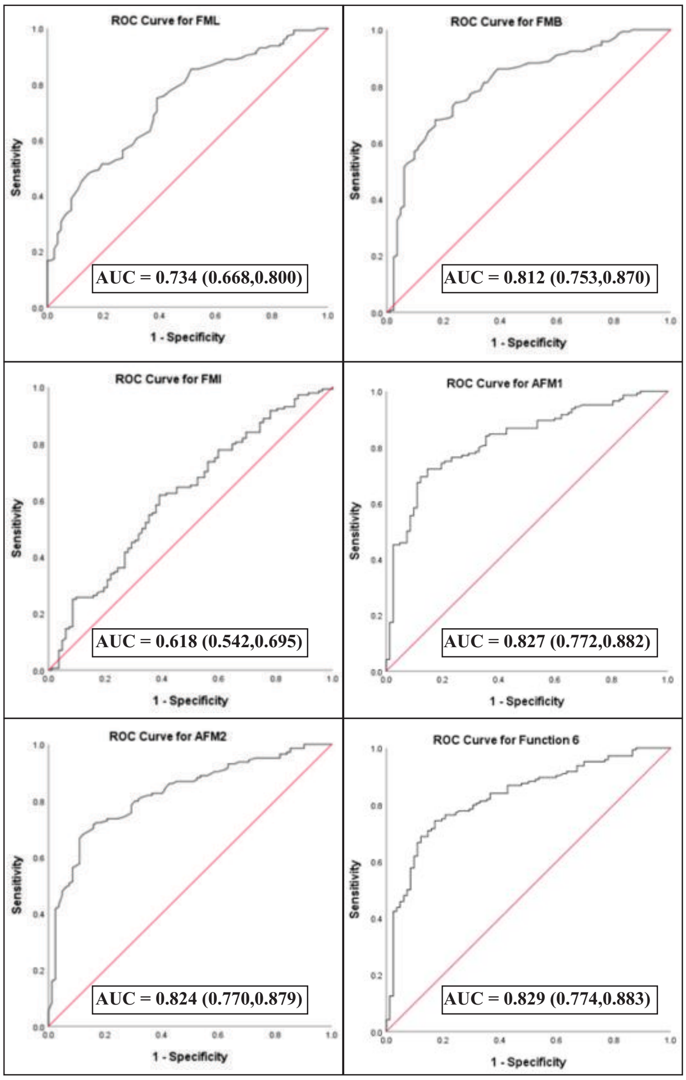

Figure 1. ROC curve of the different foramen magnum parameters.

Correlation between FM parameters: The correlation between FM parameters were estimated for both males and females using Pearson's correlation coefficient as presented in Table 2. The correlation coefficient between the FM parameters for males are given in the upper right corner of the table and for females in lower left corner of the table. It was found that FML, FMB, AFM1 and AFM2 were significantly and positively correlated to each other in both males and females.

Discriminant function: The entire dataset was split into training (80%) and testing (20%) dataset for the purpose of internal validation of the models. Binary linear discriminant functions were built for each of the FM parameter separately as a function along with the combination of them as given in Table 3 in the training dataset. We observed that amongst all the discriminant function that was built, function 6 gave us the least Wilk's lambda value ($\lambda = 0.715$) which indicated the best discriminatory ability of the model amongst others. Function 3 gave the maximum Wilk's lambda value suggesting it to be the worst amongst all the discriminant function for the discriminatory ability. Subsequently, the group centroids determined by the discriminant function was calculated which tells us about the mean of the function in each group. The sectioning points were determined which is the cut-off value categorizing the subjects into groups based on the discriminant function. In the case of the combination of FM parameters, AFM2 was not been considered in the discriminant function as it did not pass the tolerance criterion cut off of 0.001. Tolerance is the proportion of a variable's variance not accounted for by other independent variables in the equation.

Internal validation and discriminant accuracy: The internal validation of the discriminant functions was carried out using the split-data method. The proportion of correct classification for each function in males, females and overall were calculated in both training and testing dataset. We observed that Function 6 and Function 4 gave the best overall classification rate (76.5%) amongst the functions in training dataset. When the same function was allocated for testing dataset, Function 6 gave the best classification rate (71.5%) which was consistent (Table 4). Similarly, AUC from ROC curve was plotted for each of the discriminant function (Fig. 1). Function 6 had the best AUC (0.829; 95% CI = 0.774, 0.883) whereas Function 3 had the least AUC (0.618; 95% CI = 0.542, 0.695). We also observed that in spite of having the combination of four parameters in Function 6, the discriminant function with AFM1 and AFM2 gave us a good AUC of (0.827; 95% CI = 0.772, 0.882) and (0.824; 95% CI = 0.770, 0.879) respectively.

Discussion:

Of late, population specific research has gained momentum owing to the reasonable degree of variability in the craniometric parameters of the skull. The same is also applicable for FM measurements. Studies have been done on different populations for determining sex from FM measurements.[2-4,7-11] Some of these researches have been done by using dry skull and some by CT scanning. India is a big country with lot of ethnic variation. Though research has been done to evaluate the sex from FM measurements but our study confined it to a defined population only. Thus, this study was conducted to assess the sexual dimorphism of FM measurements using CT scan images of the south Indian population.

The FM parameters in our study was found to be greater in males when compared to females. Hence the parameters derived from them i.e., AFM1, AFM2 and FMI also show a similar trend. FMI was found to be insignificant in assessing sexual dimorphism, and same was reported in other studies also.[10,11] The length and breadth of FM showed high degree of correlation with the AFM owing to the fact that AFM is derived from the FML and FMB itself. When individual parameters were analysed using discriminant function analysis, FML showed highest accuracy rate i.e., 70.9%. But when all the variables were used together namely, AFM1, FMI, FML and FMB, it resulted in an accuracy of 71.5%.

Researchers evaluated 18th and 19th century dry specimens (n= 158, male = 82 and female = 76), available at St. Bride Church, Fleet Street, London.[2] They took into consideration the parameters like maximum length of the foramen magnum, maximum width of the foramen magnum, circumference of the foramen magnum, AFM1 and AFM2. The overall accuracy for establishing sex was 68% in their study (univariate and multivariate functions had an accuracy of 65.8% and 70.3% respectively). Males were correctly classified at 70.7% and females at 69.7% using multivariate functions. 76% of the males and 70% of the females could be correctly predicted by using linear regression equations. Our study did not evaluate the circumference of the FM but instead used FMI which showed least significance. Babu et al. evaluated dry skulls of an Indian population for sexing, (n = 99, male = 50 and female = 40). They measured antero-posterior (FML) and transverse diameter (FMB) of the skull, and applied it to two available formulae, namely Radinsky and Teixeira. When individual parameters were analysed, AP diameter i.e., FML showed the highest accuracy of 86.5%, and when AFM was used it came out to be 81.6% and 82.2%, for Radinsky and Teixeira respectively using BLR analysis. When both antero-posterior and transverse diameter were used together for BLR analysis it resulted in an accuracy of 88%.[7]

In another Indian study using CT scan, the overall accuracy rate of all the FM parameters and AFM (Teixeira) was found to be 66.4%.[9] In the same study the best parameter for sex determination was AFM. One Iraqi study did helical CT scanning of 88 patients which included 43 males and 45 females and concluded that FM circumference and area were the best parameters for sex determination with an accuracy of 67 and 69.3% respectively. Multivariate analysis could correctly determine sex from FM measurements of males and females in 90.7% and 73.3% respectively.[8] Sexual dimorphism from FM of the Saudi population was studied retrospectively by analysing 200 CT scans. The study scrutinized seven measurements, oriented around the dimensions of occipital condyles. They are length of right occipital condyle (LROC), length of left occipital condyle (LLOC), width of right occipital condyle (WROC), width of left occipital condyle (WLOC), length of foramen magnum (LFM), width of foramen magnum (WFM) and maximum bi condylar distance (MBD). Then the AFM was calculated. When individual parameters were employed, they showed an accuracy varying from 62.5% to 65.5%, with the highest being LROC and lowest being LFM. When LROC, LLROC, WROC, WLOC, and MBD were considered it gave an accuracy of 71%.[10] We neither evaluated the length and width of the occipital condyles nor the bicondylar distance. One Bulgarian study evaluated the FML, FMB, AFM (digital, Radinsky and Teixeira), FM circumference and FMI from CT scans of 140 Bulgarian adults. Using discriminant function analysis and BLR, sexual dimorphism was noted in FM shape and size, but they concluded that FM does not offer enough accuracy for sex determination.[11]

The objective of our study was to find out whether the FM measurements taken from the CT scans is able to predict the sex in a south Indian population. We conclude that the measurements of different FM parameters taken from CT scans is helpful in predicting sex in a south Indian population by discriminant function analysis. Though statistically significant differences were observed but alone they should not be used to differentiate sex. Hence it is advisable that the FM parameters should be used in conjunction with other available methods to precisely estimate the sex of unknown skeletons of a defined population.

Funding: No funding was received from any source for this research

Conflict of interest: The authors declare that there is no conflict of interest.

Ethical approval: All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References:

1. Iscan MY, Steyn M, Sex. In: Iscan MY, Steyn M, editors. The human skeleton in forensic medicine. Springfield: Charles C Thomas publishers; 2013.p. 143–194.
2. Gapert R, Black S, Last J. Sex determination from foramen magnum: discriminant function analysis in an 18th and 19th century British sample. Int J Leg Med. 2009;123(1):25–33.
3. Galdames ICS, Russo PP, Matamala DAZ, Smith RL. Sexual dimorphism in the foramen magnum dimensions. Int J Morphol. 2009;27(1):21–23.
4. Gunay Y, Altinkok M. The value of the size of foramen magnum in sex determination. J Clin Forensic Med. 2000;7(3):147–149.
5. Radinsky L. Relative brain size – a new measure. Science. 1967;155:836–838.
6. Teixeira WRG. Sex identification utilizing the size of the foramen magnum. Am J Forensic Med Pathol. 1982;3 (3):203–206.
7. Babu YPR, Kanchan T, Attiku Y, Dixit PN, Kotian MS. Sex

 DOI : 10.48165/jiafm.2023.45.3.1

estimation from foramen magnum dimensions in an Indian population. J Forensic Leg Med. 2012;19:162–167.

8. 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.

9. Tambawala SS, Karjodkar FR, Sansare K, Prakash N, Dora AC. Sexual dimorphism of foramen magnum using Cone Beam Computed Tomography. J Forensic Leg Med. 2016; 44:29–34.

10. Madadin M, Menezes RG, Al Saif HS, Alola HA, Al Muhanna A, Gullenpet AH et al. Morphometric evaluation of the foramen magnum for sex determination: A study from Saudi Arabia. J Forensic Leg Med. 2017;46:66–71.

11. Toneva D, Nikolova S, Harizanov S, Georgiev I, Zlatareva D, Hadjidekov V et al. Sex estimation by size and shape of foramen magnum based on CT scanning. Leg Med. 2018;35: 50–60.