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Measurement of Foramen Magnum Dimensions in Computed Tomography of Head

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ABSTRACT

Introduction: Dimensions of the foramen magnum are clinically important because of the vital structures passing through it and for sex determination of the skull. The objective of this study was to measure various dimensions of the foramen magnum in Computed Tomography (CT) and correlate them with sex.

Methods: Descriptive cross-sectional study was done on 120 CT head images in the Department of Radiology and Imaging, from July to October 2019. The shape of the foramen magnum (FM), anteroposterior diameter (APD), transverse diameter (TD), FM area and FM index were calculated. Statistical analysis was done with SPSS 25 and Excel 2016. Discriminant function analysis and binary logistic regression analysis were used for gender verification.

RESULTS: The mean values of the APD, TD, area and FM index in males and females were 33.56 ± 4.30 mm, 29.76 ± 4.10 mm, 792.94 ± 191.60 mm^2, 85.01 ± 8.67 and 30.01 ± 2.04 mm, 25.33 ± 4.6 mm, 599.63± 128.13 mm^2, 83.17 ± 7.78 respectively. All dimensions were significantly greater in males ($r = 0.906$, $P<0.001$). The most common shape of the foramen magnum was oval (40.8%). The accuracy of sex identification was 68.3% using dimensions of the foramen magnum.

Conclusion: There was sexual dimorphism in the diameter and area of the foramen magnum which can be used for sex determination.

Keywords: *Foramen Magnum; Skull; Tomography, X-Ray Computed*

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INTRODUCTION

Foramen Magnum (FM) is a large opening in the occipital bone of the cranium. [1] It is clinically important because vital structures passing through it may suffer compression in conditions like achondroplasia and FM brain herniation.[2] The knowledge of FM dimensions is needed for the diagnosis of conditions like occipital dysplasia and Arnold Chiari malformations.[3] FM dimensions are important for surgeons who perform transcondylar surgeries for lesions ventral to the brainstem and cervical-medullary junction.[4]

FM dimensions are accurate for the sex determination of the human skull. Due to the thickness of bones in the base of the skull, FM is resistant to physical insults and inhumation activities.[5] Another advantage of FM is that its dimensions do not change after puberty. [6]

FM dimensions can be measured in CT scans and cadaver studies. Considering the advantages of FM dimensions, our study aimed to evaluate the radiologic metric values of FM and their variations in shape and variations by gender. This type of study is limited in our setup.

METHODS

This cross-sectional study was carried out in the Department of Radiology and Imaging, Tribhuvan University Teaching Hospital, Kathmandu Nepal from July to October 2019. After obtaining ethical approval, a Computed Tomography of the head was obtained in 120 adults between the age of 18 to 75 years who were referred to the radiology department for a CT scan of the head. Non-probability purposive sampling technique was used for sample selection. Computed tomography images were obtained using Siemens SOMATOM Definition AS^{+}128 slice MDCT. Measurements were performed in images with bony windows (window width: +2000 and window level: +400 HU) and shape was evaluated in volume-rendered images. Measurements were made in the Syngo.via Work Station (Siemens). The shape of FM, anteroposterior (AP) and transverse diameter (TD), and area of FM were measured and the FM index was calculated.

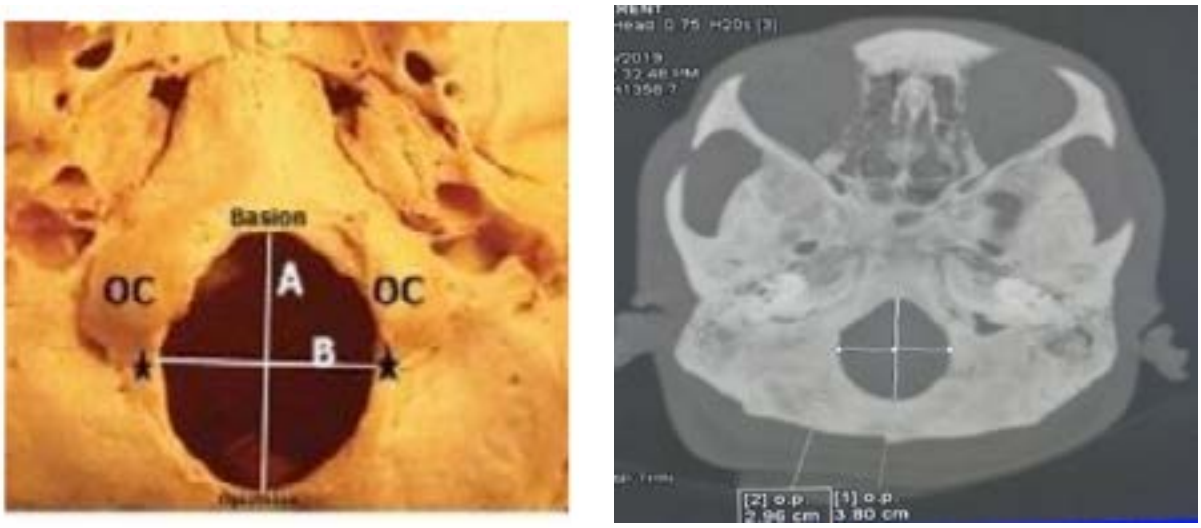
Images with cranial deformities and structural abnormalities which could affect the foramen magnum dimension and those with fractures or pathologies affecting FM were excluded from the study. The maximum anteroposterior diameter (APD) was measured from the basion (the midpoint of the anterior margin of the FM) to the opisthion (the midpoint of the posterior margin of the FM). (Figure1)

The maximum transverse diameter (TD) was measured between the lateral margins of the FM at the point of greatest lateral curvature. (Figure 1)

The area (A) of the foramen magnum was calculated using Radinsky's formula based on the available literature (7). Radinsky's formula: A = 3.14 x (APD x TD/4)

Foramen magnum index was calculated by dividing APD by TD. The shape of the foramen magnum was determined by visual assessment. Different shapes of foramen magnum were categorized as:

(a)Hexagonal
(b) Oval
(c) Egg
(d) Round
(e)Pentagonal
(f)Tetragonal (Figure 2)



(APD=A and TD=B) *APD=Anteroposterior Diameter, TD=Transverse Diameter

Figure 1: Measurement of APD and TD

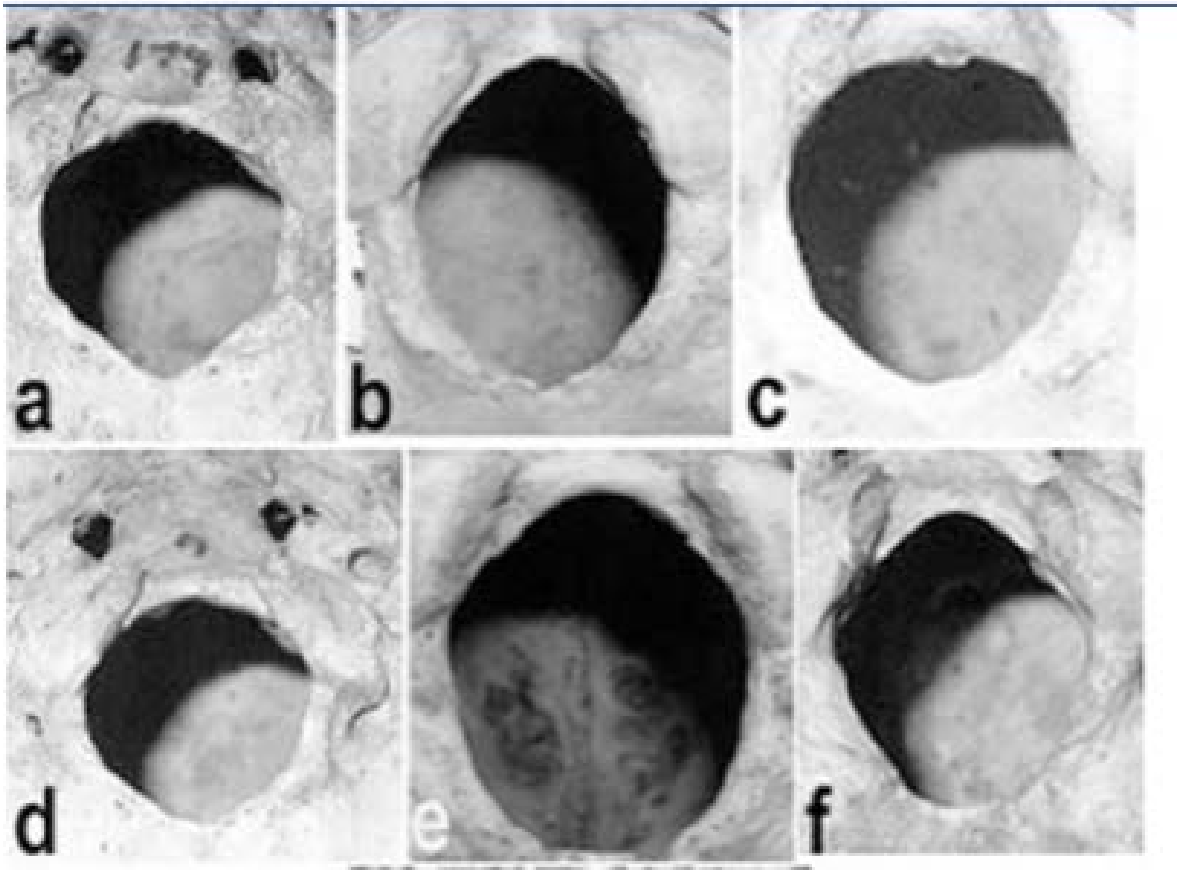


Figure 2: Shape of Foramen Magnum. (a)Hexagonal (b) Oval (c) Egg (d)Round (e)Pentagonal (f)Tetragonal

The data obtained were tabulated in Excel 2016 worksheet and analyzed statistically by using an IBM SPSS 25. Descriptive statistics like mean, standard deviation, maximum, minimum and percentages were calculated. Gender verification was done using the discriminant function and binary logistic regression analysis. The results were considered significant when $P<0.05$ and considered highly significant when $P<0.001$.

RESULTS

The data was collected from 120 normal CT scans of the head of which 66 (55%) were male and 54 (45%) were females with a mean age of 47.58±16.34 years (range 18 to 75 years).

Foramen Magnum Shape

The most common shape of FM was oval in 49 (40.8%) and the least common was pentagonal in 7 (5.8%) (Figure 3)

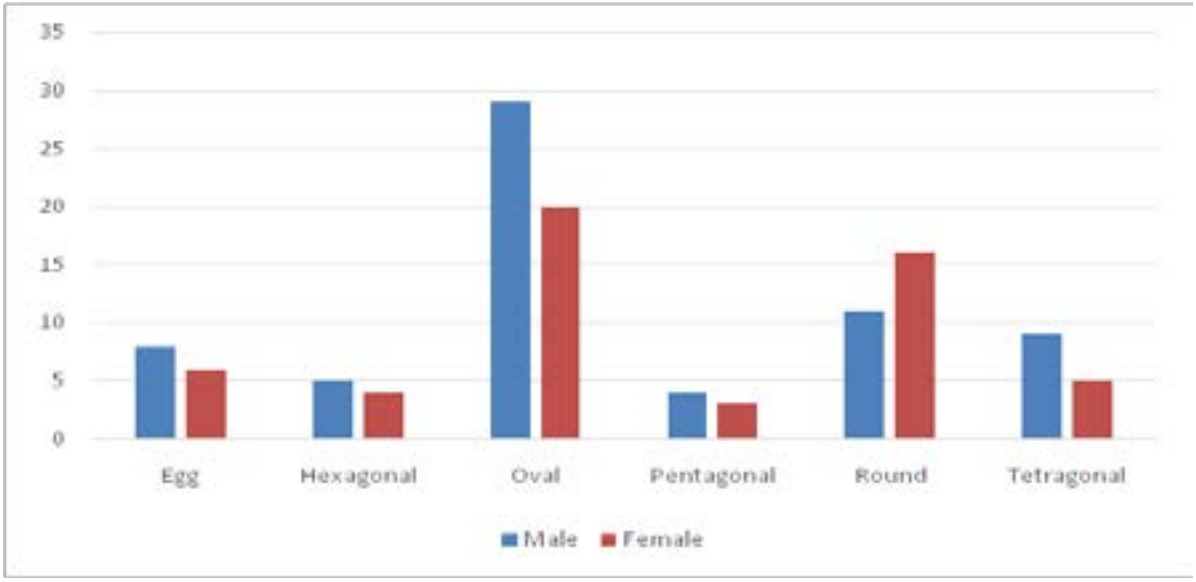


Figure 3: Distribution of the foramen magnum shape according to Gender

In males, the mean anteroposterior diameter was 33.55±4.30mm and the transverse diameter was 29.76±4.10 mm. In females, the mean anteroposterior and transverse diameters were 30.01±2.04 mm and 25.33±4.62 mm, respectively. The mean area of the foramen magnum was found to be 792.94±191.61 mm^2 in males and 599.63±128.13 mm^2 in females. The mean FM index was 1.13±0.14 in males and 1.21±0.211 in females. Foramen magnum APD, TD, and area were significantly greater in males than in females (P< 0.001) while the FM index was greater in females than in males (p<0.016). (Table 1)

Table 1: Foramen Magnum dimensions in both genders

	PARAMETERS	MAX.	MIN.	MEAN±SD	t	p
MALE	APD	40.50	20.90	33.55± 4.30	5.55	0.000
	TD	38.18	20.50	29.76± 4.10	5.56	0.000
	AREA	1207.24	337.97	792.94±191.61	6.34	0.000
	FM Index	1.51	0.99	1.13±0.14	2.45	0.016
FEMALE	PARAMETERS	MAX.	MIN.	MEAN ± SD	t	p
	APD	34.01	20.73	30.01±2.04	5.55	0.000
	TD	30.89	20.30	25.33± 4.62	5.56	0.000
	AREA	824.70	337.97	599.63±128.13	6.34	0.000
	FM Index	1.61	0.93	1.21±0.211	2.45	0.016

FM: Foramen magnum, APD: Anteroposterior Diameter, TD: Transverse Diameter

Table 2: Gender verification by binary logic regression

Observed Sex	Predicted Sex			Binary Logistic Classification		Function Centroid Value	
	Female	Male	Percentage Correct				
Female	30	24	55.6	Parameters	B Value		
Male	14	52	78.8	APD	0.34	Female	-0.549
				TD	0.13		
Overall Percentage			68.3	Constant	-14.12	Male	0.526

APD: Anteroposterior Diameter, TD: Transverse Diameter

A binary logistic regression equation was derived based on combined APD and TD for the determination of sex. The equation was (APDx0.342+TDx0.130-14.122). It classified sex as male if the value was positive and more than 0.5 and female if the value was negative and less than 0.5. The predictability of sex from foramen magnum was 55.6% accurate for females, 78.8% accurate for males and 68.3 % accurate for the overall population (Table 2).

Table 3: Gender verification by discriminant function analysis

OBSERVED SEX Female		Predicted sex			Canonical Discriminant		Function Centroid Value	
		Male	Total					
Count	Female	31	23	54	APD	0.16	Female	-0.643
	Male	15	51	66				
Percentage	Female	57.4	42.6	100	TD	0.13		
	Male	22.7	77.3	100	Constant	-8.94	Male	0.526

APD: Anteroposterior Diameter, TD: Transverse Diameter

The discriminant Function equation was derived based on combined APD and TD for the determination of sex. The equation was (APDx0.16+TDx0.13-8.94). It classified the sex as male if the value was positive and more than 0.5 and female if the value was negative and less than 0.5. The predictability for sex from foramen magnum dimensions was 57.4% accurate for females, 77.3% accurate for males and 67.3 % accurate for the overall population. (Table 3).

Sex estimation based on discriminant function analysis APD, TD, Area and FM Index: Sex estimation based on discriminant function analysis, an equation was derived as (Y= mx + C, where m denotes measurement, x is discriminant function coefficient and C is constant). It classified the sex as male if the value was positive and more than 0.5 and female if the value was negative less than 0.5 except in the case of the foramen magnum index where if the value was negative, it classified the sex as male and if the value was positive, it classified the sex as female. The sex prediction from foramen magnum dimensions was 67.5%, 67.5%, 68.3% and 60% by using APD, TD, AREA, and FM INDEX respectively. (Table 4)

DISCUSSION

In this study, we evaluated the shape and

measured various dimensions of the foramen magnum in 120 CT scans of the head. We categorized the shape of the foramen magnum on visual assessment. The area was calculated using the Radinsky formula. [7] Gender verification was done using the discriminant function and binary logistic regression analysis.

The foramen magnum was recognized as a longitudinally elongated aperture. However various studies at different times have suggested different shapes of the foramen magnum.

Variation in the shape of the foramen magnum may be caused due to ossification of primordial cranial residues, which join the endochondral ossification points in different locations, resulting in various shapes.[8] In our study, the commonest shape of the foramen magnum was oval, seen in 40.8%, and the least common shape was pentagonal seen in 7.5%. In study by Loyal et al. in 2013, in a Kenyan ethnic group involving two hundred and two adult skulls, it was observed that the commonest shape was pentagonal 63% followed by circular 24%.[9]

Table 4: Gender verification by discriminant function analysis

APD 67.5% Of Original Grouped Cases Correctly Classified	**Sex**	**Predicted Group**		**Total**	**Discriminant Function Coefficient**	**Centroid Function**
	Female	Female	Male		APD=0.288	Male=0.45
		96.3	3.7	100	Constant= -9.19	Female= -0.56
	Male	56.1	43.9	100		
TD 67.5% Of Original Grouped Cases Correctly Classified	**Sex**	**Predicted Group**		**Total**	**Discriminant Function Coefficient**	**Centroid Function**
	Female	Female	Male		TD=0.230	Male=0.45
		53.7	46.3	100	Constant= -6.39	Female= -0.56
	Male	21.2	78.8	100		
AREA 68.3% Of Original Grouped Cases Correctly Classified	**Sex**	**Predicted Group**		**Total**	**Discriminant Function Coefficient**	**Centroid Function**
	Female	Female	Male		Area=0.006	Male=0.64
		52	2	100	Constant= -4.25	Female= -0.52
	Male	37	29	100		
FM INDEX 60.5% Of Original Grouped Cases Correctly Classified	**Sex**	**Predicted Group**		**Total**	**Discriminant Function Coefficient**	**Centroid Function**
	Female	Female	Male		FMI=5.56	Male= -0.20
		52	2	100	Constant = -6.54	Female = 0.24
	Male	37	29	100		

The cut-off value is 0.50. APD: Anteroposterior Diameter. TD: Transverse Diameter, FMI: Foramen magnum index

Table 5: Comparison between the measurement of foramen magnum dimensions with our study and previous studies

Author name	Sample size	Target population	APD(M)	APD(F)	TD(M)	TD(F)
Routal et al. (1984)	152	India	35.5±2.8	32.0±2.8	29.6±1.9	27.1±1.6
Murshed et al. (2003)	110	Turkey	37.2±3.2	34.6±2.6	31.6±2.99	29.3±2.99
Gapert et al. (2009)	158	UK	35.91±2.41	34.71±1.91	30.51±2.60	29.6±1.53
Uysal et al. (2005)	100	Turkey	37.08±1.93	34.87±2.6	30.83±2.04	28.93 ± 2.43
Erdil et al. (2010)	54	Turkey	36.95 ± 4.01	34.41±3.89	30.75 ± 2.81	29.98 ± 2.78
Garcia et al. (2011)	110	South American	37.4 ± 3.3	31.9 ± 2.6	31.9 ± 2.6	30.1 ± 2.4
Uthman et al. (2012)	88	Iraq	34.9 ± 2	32.9 ± 2	29.5 ± 2.5	27.3 ± 2.2
Tanuj et al. (2013)	118	India	34.51±2.773	33.60±2.63	27.36±2.092	26.74±2.36
S.P.Vinutha et al. (2018)	200	INDIA	35.96 ± 3.75	33.83	30.38 ± 2.84	27.98
Present study	120	Nepal	33.55± 4.30	30.01± 2.04	29.76± 4.10	25.33± 4.62

APD: Anteroposterior Diameter, TD: Transverse Diameter, M: Male, F: Female

The difference in shape and its occurrence may be due to diversity and variation in the ethnic groups studied. Teixeira was probably one of the first researchers who published his research on the estimation of sex based on the size of the foramen magnum in the later part of the 20th century.[10] In past, studies on the estimation of sex from foramen magnum have been conducted on British, Turkish, and Indian populations using different methodologies and statistical considerations.[10-13] All the previous researchers have reported a larger size of the foramen magnum in males than in females which were similar to our study.

In our study, the mean anteroposterior diameter in males was 33.55±4.30 mm and the mean transverse diameter was 29.76±4.10 mm. In females, the means were 30.01±2.04 mm and 25.33±4.62 mm, respectively. The mean area was found to be 792.94±191.61 mm^2 and 599.63±128.13 mm^2 for males and females respectively. In our study, mean values of length, breadth, FM index and area of the foramen magnum were higher in males than in females. All the variables studied in our study showed greater measurements in males than in females ($p<0.001$). Our findings are similar to the studies conducted by Routal et al. and Sayee et al. in Western and Southern India respectively and also in the Turkish population study by Gunayet et al. [12,14,15] This was also observed by several authors such as Olivier, Gruber et al., and Raghavendra Babu et al., Catalina-Herrera, Holland TD, Uysal et al., and Uthman et al. [6, 16-21]

The measurement of FM dimensions found in our study was less than those found in earlier studies which may be because of the diverse ethnic groups involved in the study.[12,13,19,20] Small size of FM in our populations might be due to small physical builds, which are directly influenced by genetic, environmental and socio-economic factors. Hence, this study helped to have our reference ranges because the range used in other studies may not be suitable in our context.

In our study, APD, TD, Area and FM index was used for gender verification. The shape did not show sexual dimorphism. All the studied data were analyzed statistically using discriminant function and binary logistic regression, both methods showed a similar result. For gender verification, the cut-off value was kept at 0.50. A value larger than 0.5 and positive was determined as male whereas a value less than 0.50 and negative was determined as a female. APD and TD when combined showed an overall accuracy of 68.3 % and 67.3% in gender verification by binary logistic regression and discriminant function analysis respectively.

When area and FM index were used singularly for sex determination, it showed an overall accuracy of 68.3% and 60% respectively. APD and TD singularly showed overall sexual accuracy of 67.5% in both cases. In our study, all the parameters showed a nearly equal percentage of accuracy, and the result observed in this study was nearly similar to the study by Uthman et al.[21] In the study by Uthman et al, the circumference and area were the best discriminant parameters for sex determination with an overall accuracy of 67% and 69.3% respectively, but in a study by Gruber et al. on dry skulls sexual dimorphism was not seen in the central European population which may be due to variation of ethnic groups involved in the study.[6,21]

CONCLUSION

The dimensions of the foramen magnum measured in a CT scan of the head were greater in males than in females, which is mostly in agreement with other studies. Sexual dimorphism i.e differences in foramen magnum morphology between males and females was obtained in our setup. This would be very useful for radiologists, surgeons and forensic experts.

CONFLICT OF INTEREST

None

SOURCES OF FUNDING

None

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