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Original Research Article

MORPHOMETRY AND SEXUAL DIMORPHISM IN FORAMEN MAGNUM: A STUDY OF HUMAN SKULL BONES

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ABSTRACT

Background and Objectives: The foramen magnum is a fundamental component in the interaction of bony, ligamentous and muscular structures composing the craniovertebral junction. The measurements of the foramen magnum have a crucial importance in surgical resection and thereby reaching the lower clivus and premedullary region in transcondylar approach. The objectives of the present study are to find out the shape and dimensions of foramen magnum in human skull bones.

Materials and Methods: The study sample comprised of 200 skull bones (100 males and 100 females) of south Indian origin. Measurements were taken using sliding vernier calipers. The parameters were noted meticulously and the statistical analysis for sex comparison was made by student's t-test and was considered significant whenever $p \leq 0.05$.

Results: The Foramen magnums were classified into 8 types based on shape. Commonest being oval and pentagonal was the least common type. The mean APD of FM in male and female skull bones were found to be 33.37 mm ± 2.33 and 29.72 mm ± 1.89 respectively. The mean TD of FM in male and female skull bones were found to be 27.40 mm ± 2.44 and 24.73 mm ± 2.05 respectively. The mean circumference of FM in male and female skull bones was found to be 102.58 mm ± 4.68 and 92.65 mm ± 4.37 respectively. The area of the FM was calculated using three different formulas. The mean area 1 of FM in male and female skull bones was found to be 718.41 mm^2 ± 83.75 and 577.52 mm^2 ± 64.36 respectively. The mean area 2 of FM in male and female skull bones was found to be 727.50 mm^2 ± 83.12 and 583.71 mm^2 ± 63.58 respectively. The mean area 3 of FM in male and female skull bones was found to be 838.77 mm^2 ± 75.94 and 684.36 mm^2 ± 64.10 respectively. All parameters were significantly greater in males than in females ($P<0.001$).

Conclusion: The data obtained may be useful to the neurosurgeon in analyzing the morphological anatomy of the craniovertebral junction. The findings are of particular interest in anthropology, anatomy, forensic medicine and other medical fields.

KEY WORDS: Foramen magnum, Sexual dimorphism, Shape, Anteroposterior Diameter, Transverse Diameter.

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INTRODUCTION

Foramen magnum is the largest foramen in the skull. It lies in an anteromedian position and leads into the posterior cranial fossa. It is oval, wider behind, with its greatest diameter being anteroposterior. It contains the lower end of the medulla oblongata, meninges, vertebral arteries and spinal accessory nerve [1].

The shape of foramen magnum varies, commonest being oval. The importance of variations in shape is due to its effects on the vital structures passing through it and also plays an important role in various surgical approaches. Dimensions of the foramen magnum have clinical importance because the vital structures that pass through it may suffer compression. It has also been noted that longer anteroposterior dimension of foramen magnum permitted greater contralateral surgical exposure for condylar resection [2].

Measurements of various bones are often used during forensic and anthropological investigations of unknown individuals for estimation of age, gender, stature and ethnicity. Base of the skull is covered by large mass of soft tissue which helps to protect the foramen magnum. So in cases of severe trauma, fire and explosions etc. an intact foramen magnum morphometry helps in determining the gender and consequent identification of a person. Hence, morphometry of foramen magnum becomes important [3].

It is also noted that the foramen magnum dimensions are specific for a particular population and becomes low when applied to populations with a large ethnic mix. From qualitative and quantitative point of view, the features and morphometry of foramen magnum and occipital bone, when used in approximation are good indicators for the diagnosis of sex [4].

The objectives of the present study are to find out the shape, anteroposterior diameter, transverse diameter, circumference, area and index of foramen magnum in skull bones.

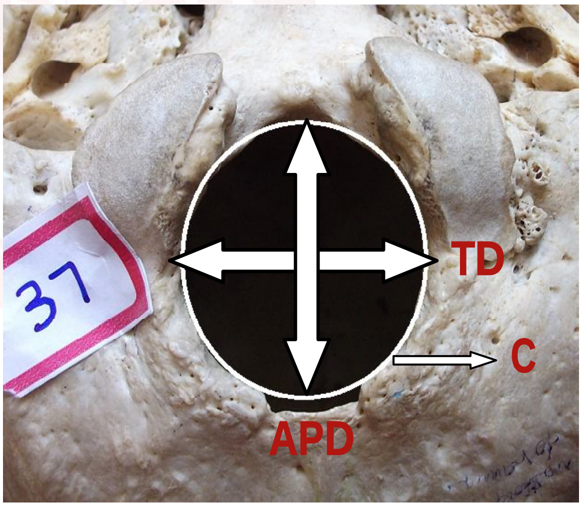
MATERIALS AND METHODS

The study sample comprised of 200 adult skull bones (100 males and 100 females) of known sex available in the Department of Anatomy, Kempegowda Institute of Medical Sciences, Bangalore. Adult skull bones with complete FM were included in the study, where as skull bones with damaged FM, when associated with pathological conditions and those skull bones whose sexing cannot be done were excluded from the study.

In case of skull bones, all 200 cranial bases were visually assessed for FM shape classification. Each FM shape was classified into one of the 8 types: oval, egg, round, tetragonal, pentagonal, hexagonal, combination of 2 different semicircles and irregular.

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). The maximum transverse diameter (TD) was measured between the lateral margins of the FM at the point of greatest lateral curvature. The APD and TD were measured with vernier sliding calipers. The circumference (C) was measured by pressing a narrow strip of paper along the inner margin of the FM; the paper strip was then unrolled and measured with sliding calipers [Fig 1]. All measurements were recorded to an accuracy of 0.1 mm.

Fig. 1: Cranial base demonstrating the foramen magnum measurements.



The area of the FM was calculated using 3 different formulas based on the study by Macaluso et al [5].

1) Routal et al. formula based on the height and width of the foramen magnum

$$A = \frac{1}{4} \times \pi \times w \times h$$

2) Teixeira et al. formula based on the height and width of the foramen magnum

$$A = \pi \times \{(h + w)/4\}^2$$

3) Gapert et al. formula uses the circumference to estimate the radius of the foramen magnum, assuming it to be circular. This radius is then applied to the formula of the area of the circle.

$$r = c/2\pi \text{ and } A = \pi r^2$$

Foramen magnum index was calculated using the formula:

Transverse diameter D Anteroposterior diameter × 100

The foramen magnum index was evaluated according to the Martin and Saller classification [6].

a) Narrow: x - ≤ 81.9

b) Medium: 82.0 - 85.9

c) Large: ≤ 86.0 - x.

Table 1: The no. and percentages of various shapes of the foramen magnum of both genders.

Types of shapes	Skull bones, No. & %	
	Male	Female
Oval	32	35
Egg	11	5
Round	10	13
Tetragonal	12	12
Pentagonal	5	5
Hexagonal	11	12
2 semicircles	9	10
Irregular	10	8

RESULTS

Oval shape was the most common type and pentagonal was the least common type in both skull bones of both genders. In addition, egg shape was also the least common type in female skull bones. Below is the tabular representation of no. and percentages of different types of FM shape [Table 1].

Fig. 2: Comparison of percentages of various shapes of FM in both male and female skull bones.

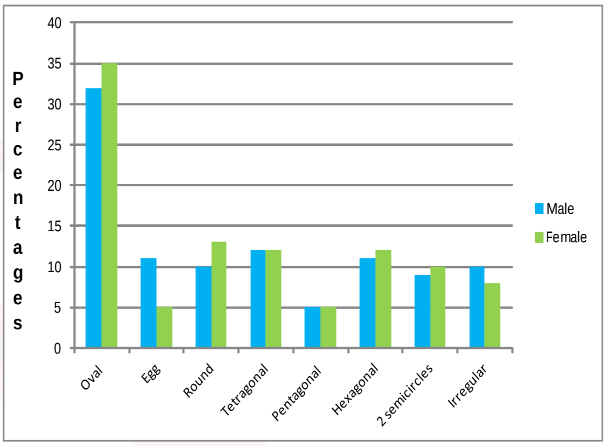
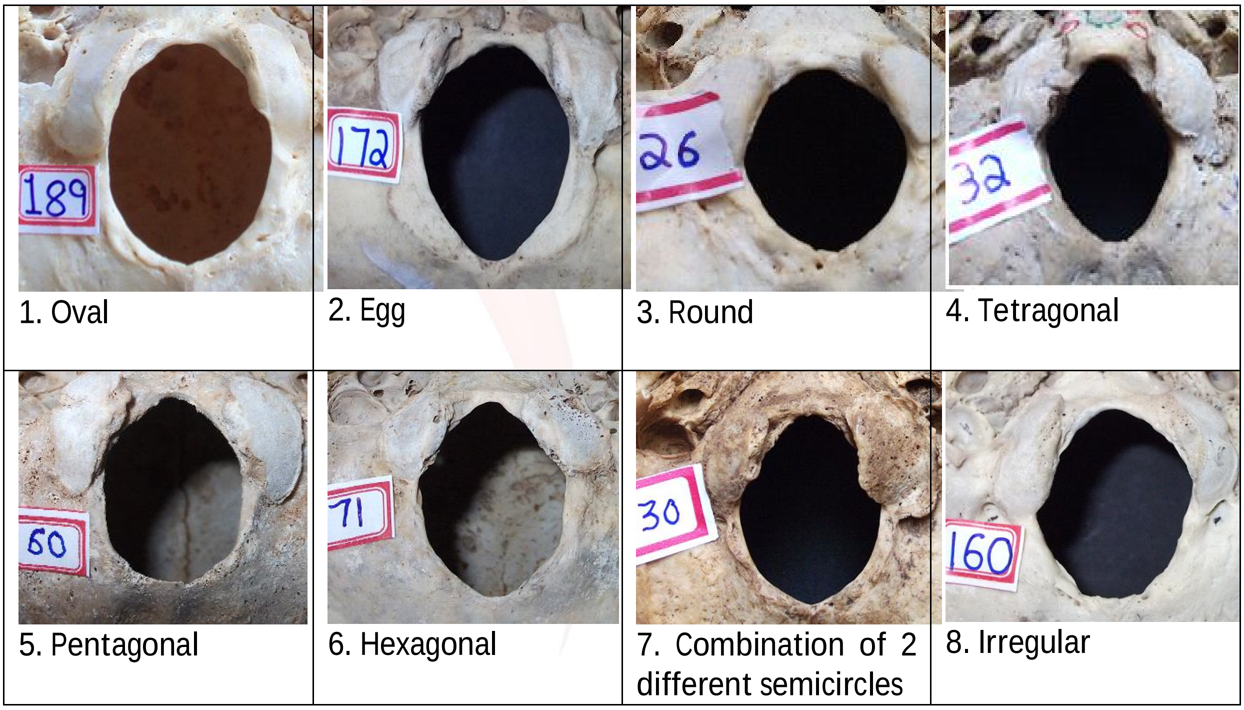


Fig. 3: Different shapes of foramen magnum as studied in skull bones.



In case of 2 skull bones (1%), a tubercle was found projecting posteriorly from the anterior margin of the FM. Both of them were female skull bones (2.11%). The same is shown in the photographs below. In one of them, the tubercle measured 5 mm anteroposteriorly and 3 mm transversely while in the other, it measured 3 mm anteroposteriorly and 2 mm transversely.

Table 2: Descriptive statistics of measured parameters of FM in both genders of skull bones.

Variable	Gender	Mean	S.D	SE of Mean	Min	Max	t	P-Value
APD (mm)	Male	33.37	2.33	0.23	25	38	12.097	<0.001*
	Female	29.72	1.89	0.19	23	33		
TD (mm)	Male	27.4	2.44	0.24	21	35	8.335	<0.001*
	Female	24.73	2.05	0.21	21	30		
Circumference (mm)	Male	102.58	4.68	0.46	90	115	15.467	<0.001*
	Female	92.65	4.37	0.45	83	103		
Area 1 (mm^2)	Male	718.41	83.75	8.17	494.8	955.04	13.235	<0.001*
	Female	577.52	64.36	6.6	431.97	728.85		
Area 2 (mm^2)	Male	727.5	83.12	8.11	510.71	962.11	13.814	<0.001*
	Female	583.71	63.58	6.52	433.74	730.62		
Area 3 (mm^2)	Male	838.77	75.94	7.41	644.32	1051.99	15.453	<0.001*
	Female	684.36	64.1	6.58	547.99	843.9		

Fig. 4: Tubercle at the anterior margin of FM in skull no. 95 and 166.

The results of the study in 200 skull bones showed that the APD, TD, Circumference, Area 1, Area 2 and Area 3 were significantly greater in males than in females (P<0.001).

Foramen magnum index: The results showed the **medium** type of **FM index** according to Martin and Saller classification. The mean FM index of male skull bones was 82.54 ± 10.49, where as in case of female skull bones, it was 83.52 ± 8.93. Even though the FM index was higher in female skull bones when compared to male skull bones, the difference was not statistically significant (P>0.05).

Table 3: Comparison of FM index in both sexes in skull bones.

	Gender	Mean	S.D	SE of Mean	t	P-Value
Skull bones	Male	82.54	10.49	1.02	0.706	0.481
	Female	83.52	8.93	0.92		

DISCUSSION

Foramen magnum is one of the primary centres of ossification on the cranial base during growth and development and is located inferior to the sagittal suture on the cranial base. Characteristics of foramen magnum and cranial base have identifying features for sexing [7].

Development of a particular shape of the FM is explained on the basis of the embryologic data. It may be caused by ossification of primordial cranial residues, which join the endochondral ossification points in different locations, resulting in various shapes [6]. Irregular shape of FM is accentuated by the developmental anomalies of the bone and soft tissues at the craniovertebral junction [8].

In the present study, we have classified the foramen magnum into 8 shapes based on the study by Govsa et al [6]. Govsa et al [6] and Chethan et al [8] have found 7.93% and 15.1% of oval shape in their studies respectively, which is much lower than our findings. The difference observed in case of study by Govsa et al [6] could be because of racial variability among the studied population. The study done by Chethan et al [8] involves Indian population.

The percentage of irregular shape was 9% in the present study. Govsa et al [6] has found it to be 4.5%, which is much lower than our values. Chethan et al [8] have reported 15.1% which is slightly higher than our values. This is because in their study, all the FM which could not be classified into any shape was grouped as irregular shaped FM. Hence, they have a higher percentage of irregular shape compared to our study.

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Egg shape was also the least common type in female skull bones. This may be explained on the basis that the cranial base is directly affected by the cervical vertebrae, which play a substantial role in the development and modification of the foramen magnum. Structures in the neck are more massive in males, resulting in a wide anterior margin of FM. Therefore, percentage of egg shape FM was more in case of male skull bones compared to female skull bones.

The shape of the foramen magnum can be determined by using foramen magnum index. Muthukumar et al [9] have considered FM to be oval when the FM index was $\geq$ 1.2, and they considered the rest (FM index < 1.2) as circular. A similar sized lesion located anterior to the brainstem will require more extensive bone removal in a person with an ovoid FM than in a person with a circular FM. In 20% of the skulls the occipital condyle protruded significantly into the foramen magnum. Therefore, a patient with a round foramen magnum, without significant protrusion of the occipital condyles into the foramen magnum, will require less bony resection than a patient with an ovoid foramen magnum with medially protuberant and sagittaly inclined occipital condyles, even though both patients harbour similar lesions.

The authors concluded that the approach becomes easier in case of round, oval and hexagonal shapes, because the working space will be more for surgical approaches in these shapes. It becomes difficult in case of tetragonal, pentagonal and egg shape FM, with narrow posterior margin. In case of combination of 2 different semicircles and irregular shape FM, with narrow anterior part the anterior approach becomes difficult.

Tubercle at the anterior margin of the foramen magnum: We found that in 2 out of 200 skull bones (1%), a tubercle was projecting posteriorly from the anterior margin of the FM. Both of them were female skull bones. So when gender was considered, the percentage of tubercle in female skull bones was 2.11%.

Tubercles are formed by exostoses, the chief factor governing the expressions of these variants was the genetic make-up of the individual and the minor skeletal variants were under complex multigenic control. Bony tubercle occurring at the margins of foramen magnum can cause compression of the spinal medulla, because of close relation of bony, vascular and nervous elements of cranio-vertebral junction, any malformation of one tissue may produce a variety of signs and symptoms of neurological deficits. The frequency of tubercles at foramen magnum has been reported as 0.8 to 1.5% by numerous authors [10].

The results of various dimensions of FM (measurable parameters) in the present study will be compared with the results of other studies. This is more important because metric approach is more objective and less dependent on observer experience. So, interobserver variations might be less. Its replicability is high and is also more amenable to statistical analysis. This facilitates comparisons between samples and also between studies.

Table 4: Comparison of foramen magnum variables in male skulls

Variables	Gapert et al, 2009 [12]	Macaluso et al, 2011 [5]	Babu raghavendra et al, 2012 [13]	Present study, 2012
APD	35.91 ± 2.41	35.38 ± 2.27	35.68 ± 1.77	**33.37 ± 2.33**
TD	30.51 ± 1.77	30.72 ± 2.11	28.91 ± 1.62	**27.40 ± 2.44**
Circumference	99.07 ± 5.97	98.90 ± 4.85	-	**102.58 ± 4.68**
Area 1	862.41 ± 94.79	854.80 ± 93.79	811.67 ± 69.90	**718.41 ± 83.75**
Area 2	868.65 ± 96.36	860.27 ± 94.54	821.36 ± 70.10	**727.50 ± 83.12**
Area 3	783.82 ± 94.47	780.22 ± 76.43	-	**838.77 ± 75.94**

Other studies have reported slightly higher mean values of FM in male skulls when compared to the present study. This may be due to racial differences as the study population are different or may be due to methodological differences and also due to variations in the sample size.

Based on the development of skull base, Tubbs et al stated that anomalies and malformations of the occipital sclerotomes result in irregular geometry of the FM and related structures. Shape and size of the foramen are critical parameters for the manifestation of clinical signs and symptoms in craniocervical pathology. These include motor myelopathy, sensory abnormalities, brainstem and lower cranial nerve dysfunctions, and signs and symptoms referable to vascular compromise. Diseases associated with anomalies of the FM include occipital vertebra, basilar invagination, condylar hypoplasia, and atlas assimilation. Interestingly, one report found that the persistence of the spheno-occipital synchondrosis, aggravated by the coexistence of basilar invagination, resulted in stenosis at the foramen magnum. It is well known that FM size is enlarged in Arnold Chairi malformations and reduced in achondroplasia [11].

The degree of expression of sexual dimorphism within the FM dimensions may be explained by its development. Compared to many other skeletal elements, the foramen magnum reaches its adult size rather early in childhood and is unlikely to respond to significant secondary sexual changes. No muscles act upon the shape and size of the FM, its prime function is to accommodate the passage of structures into and out of the cranial base region particularly the medulla oblongata, which occupies the greatest proportion of the foramina space. As the nervous system is the most precocious of all body systems, it reaches maturity at a very young age and therefore has no requirement to increase in size. This is evidenced by the completion of fusion of the different elements of the occipital bone by 5-7 years of age [12].

Table 5: Comparison of foramen magnum variables in female skulls.

Variables	Gapert et al, 2009 [12]	Macaluso et al, 2011 [5]	Babu raghavendra et al, 2012 [13]	Present study, 2012
APD	34.71 ± 1.91	34.90 ± 2.26	32.57 ± 2.08	**29.72 ± 1.89**
TD	29.36 ± 1.96	29.40 ± 2.93	28.91 ± 1.76	**24.73 ± 2.05**
Circumference	95.65 ± 5.36	97.06 ± 5.64	-	**92.65 ± 437**
Area 1	801.78 ± 85.43	807.86 ± 107.58	722.66 ± 78.20	**577.52 ± 64.36**
Area 2	808.14 ± 85.40	815.13 ± 106.29	727.31 ± 78.70	**583.71 ± 63.58**
Area 3	783.82 ± 94.47	752.10 ± 88.16	-	**684.36 ± 64.10**

Gapert et al [12] and Macaluso et al [5] have reported a mean of circumference of FM, which are slightly higher than our findings, which is in contrast to that seen in male skulls. Eventhough the sample size was smaller in their studies, this may indicate the nutritional status of the sample studied or it may also depend on the mean age of the population studied.

CONCLUSION

It can be concluded that the several anatomic parameters such as shape and dimensions of FM should be taken into consideration during surgery involving the craniovertebral junction. Also these can be used during forensic and anthropological investigation of unknown individuals for determining gender, ethnicity, etc. By combining qualitative data with quantitative ones, the authenticity in sex determination from skull would enhance.

ABBREVIATIONS

FM – Foramen Magnum
APD – Antero-Posterior Diameter
TD – Transverse Diameter
C – Circumference

Conflicts of Interests: None

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