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Anatomical analysis of Foramen Magnum at the posterior part of the base of the skull in dried skull bone

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ABSTRACT

Background: Foramen magnum (FM) is a clinically important landmark present at the skull base due to its close association with brain stem and spinal cord. The FM dimensions are necessary because the structures passing through it may be compressed in cases of FM meningioma, FM achondroplasia and FM herniation, additionally as also required to determine some malformations such as Arnold Chiari syndrome, which shows expansion of transverse diameter.

Aim: To evaluate the various shapes of FM in dry human skulls of Malwa region Indian population.

Materials and methods: A total 150 (86 male and 64 female) dry skulls of adult human being were studied. Anteroposterior diameters (APD) and transverse diameters (TD) of foramen magnum FM were calculated using vernier caliper and shapes were visually assessed. Additionally, the area and index of foramen magnum (FMI) were also calculated using formulae (FM =APD/TD).

Results: The average anteroposterior diameter and transverse diameter of FM were 33.92±2.39mm and 29.90±2.33mm respectively. The average area and FMI were calculated as 796.96±84.73mm2 and 1.13±0.168respectively. The incidence of the morphological types of FM were noted as anoval shape of FM was commonly seen (55.3%). This was followed by round (14.0%), egg shaped (12.7%), tetragonal (9.3%), pentagonal (4.0%), hexagonal (2.7%), and irregular (2.0%).

Conclusion: Our study results will serve as an aid to neurosurgeons in evaluating the morphology of carnio-vertebral junction in lateral transcondylar surgical proceduresin case of lesions in the middle and posterior part of cranial base. Our findings are also informative for the anatomists, radiologists, orthopaedic surgeon, anaesthetist, forensic experts and anthropologists.

Keywords: Foramen magnum, Skull, morphology, morphometry, shape.

Introduction:

Craniovertebral bony abnormalities have been recorded for many years in morphological and clinic-radiological studies [1]. Because many of these abnormalities result in clinical complaints, craniovertebral junction anomalies are of interest to clinicians as well as anatomists. This region can have anomalies that are congenital, developmental, acquired, traumatic, tumorigenic, inflammatory, or occur singly or in combination [2]. The occipital condyles represent the cranial portion of the craniocervical junction. A ventral or dorsal approach can be used to access the space-occupying lesion at the level of the foramen magnum, ventral to the spinal canal. Information on the morphometric features of the occipital condyle is needed for the recently published transcondylar technique [3]. It is necessary to adopt a dorsal approach to the foramen magnum due to the challenges and high risk of morbidity associated with ventral techniques. In order to access the ventral and ventrolateral portions of the foramen magnum during transcondylar surgical techniques, partial excision of the occipital condyle is a crucial step [4]. In order to access lesions in the middle and posterior regions of the cranial base, lateral surgical techniques benefit from an evaluation of the morphometry of the foramen magnum and occipital condyles. Because of its near proximity to important components like the brain and spinal cord, the foramen magnum, which serves as a transition zone between the spine and the skull, is an important landmark. There are several developmental variations in the region of cranio-cervical junction, many of which resemble deformities. Understanding the morphological characteristics of the variants and how their distinctive features manifest in standard radiological procedures is necessary for a precise and dependable radiologic diagnosis [5]. The dura mater adheres to the internal surfaces of the cranial bones, particularly at the sutures, the cranial base and around the foramen magnum [6]. The foramen magnum includes specific neuroanatomical structures and their lesions in that region which require particularly microsurgical interventions. The occipital condyles, which extend downward to articulate with the superior articular facets on the lateral masses of the atlas, slightly overhang the edge of the foramen magnum anteriorly. The anterior end of each occipital condyle is positioned obliquely, bringing it closer to the midline than the posterior end, giving it an oval form. Its medial surface is roughened by ligamentous attachments, and it is noticeably convex antero-posteriorly and less so transversely. The hypoglossal canal travels deep to each condyle, lateral and somewhat forward [7]. This foramen allows a number of important and difficult-to-reach structures to enter the skull, the most important ones being the spinal cord, meninges, medulla bulb, vertebral arteries, and several spinal nerve roots [8]. The complex that forms the atlanto-occipital joint and the membranes that surround it are among the other structures linked to the boundaries of the FM that are crucial for the support and mobility of the skull in respect to the spine [9]. Relevant to forensic practice is the relationship between the gender of the deceased to which the skull belongs and the morphological patterns of the FM. When it comes to the sexual recognition of bodies in a condition of advanced deterioration, such as carbonised victims, where identification cannot be achieved based just on surface features, this method is a rather easy and affordable substitute [10]. Knowing the anatomy of the FM and its variants facilitates improved planning and technical refinement of neurosurgical approaches to this region, as well as a larger perspective in the radiological research of disorders connected with it [11], such as, for example, the Arnold-Chiari Syndrome, which causes structural herniations of the central nervous system (CNS) through the foramen; patients with achondroplastic disease; certain meningiomas associated with this structure; bulbar tumours; and cases of platybasia involving invagination of the odontoid process through the FM [12, 13]. After a study of literature, it was exposed that foramen magnum morphological variations are seen in many populations and that these variations are

influenced by genetic, environmental, and socioeconomic variables. These variations have become significant due to newer imaging techniques like computed tomography and magnetic resonance imaging in the subject of diagnostic medicine [14]. So, most suitable surgical techniques are to be established for a careful planning mainly based on FM size to refrain from any neurological injury [15] Therefore, the foramen magnum, located in the posterior region of the skull base in dried skull bone, are the subject of the current study's anatomical examination. It is hoped that the information would be helpful, especially for radiologists, orthopaedicians, and neurosurgeons when making preoperative decisions.

Aim: To evaluate the various shapes of FM in dry human skulls of Malwa region Indian population.

Material & Methods

The present morphometric observational study conducted in Department of Anatomy, Index Medical College, Hospital and Research Centre Indore MP, India from January 2022 to December 2023 after approval of Institutional Ethical committee. The study included 150 dry human skulls (86 males and 64 females). Dry fragile Skulls, incomplete or damaged skulls, congenital deformities with the skulls, any pathological changes in skulls and fetal, neonatal & children's skulls, etc. excluded from the study.

The following parameters were measured:

Foramen Magnum

- In present study different varieties of FM shapes were observed like 1- Oval, 2- Tetragonal, 3-Egg-shaped, 4 -Pentagonal, 5- Round, 6- Hexagonal, and 7- Irregular.
- Antero-posterior diameter of FM in between the Basion & Opisthion
- Transverse diameter of FM, measured at the right angles to anteroposterior diameter.
- Area- Radinsky et al gave a formula for the calculation of FM area, it was determined by using the parameter length and width of FM and applying the accompanying formulae [16]:

$$\text{Area} = 1/4 \text{ LFM} \times \text{WFM} \times 3.14$$

Whereas,

LFM means the length of the foramen magnum

WFM means the width of the foramen magnum.

Index of Foramen Magnum: The index calculated by dividing anteroposterior diameter through transverse diameter of FM (APD/TD).

Statistical Analysis: Data was analysed using Statistical Package for Social Sciences, version 20 (SPSS Inc., Chicago, IL). Results for continuous variables was presented as mean±standard deviation, whereas results for categorical variables was presented as frequency/number (percentage). Continuous two independent groups were compared by parametric independent Student's t test. Discrete (categorical) groups were compared by chi-square ($\chi 2$) test. The level $P < 0.05$ was considered as the cutoff value or significance.

Result and Discussion:

The present research is related to physical and morphometric assessment of the human skull base. The study was focused on foramen magnum & occipital condyles, study was carried-out on one hundred fifty dry adult human skulls (86 males and 64 females) i.e., One hundred fifty foramen magnum and three hundred occipital condyles were observed. The mean anteroposterior diameter of FM was 33.57±4.35mm and the mean transverse diameter was 29.90±2.33mm. The area of FM observed was 796.96±84.73mm2 and FM index was found to be 1.13±0.168. The commonest shape of the foramen magnum is oval shape the percentage is 58.1% in males and 51.6% in females which was lesser than values of males. Followed by second common shape of FM is round shape the percentage is 12.8% in males and 15.6% in females and egg shape the percentage is 10.5% in males and 15.6% in females, which was

higher than the values of males. In our study tetragonal, pentagonal, hexagonal and irregularshape of FM is less common in both male and female. The distribution of shape of FM insignificantly distributed in both male and female groups ($p>0.05$). The anteroposterior diameter is 34.06±2.1& 32.9±6.1, the transverse diameter is 30.40±3.5& 29.49±3.6 and the index is 1.16±0.33&1.14±0.28male & female respectively the value is statically analyzed ($p<0.05$), there is a significant observed in TD among male & females but p-value ($p>0.05$) is higher in foramen index so no significance observed in APD &foramen index. The area of FM of oval shape is 810.6±84.6&756.8±151 in male & female correspondingly values are statically significant($p<0.05$).

Figure 1: Distribution of the gender in present study of the adult dry human skulls

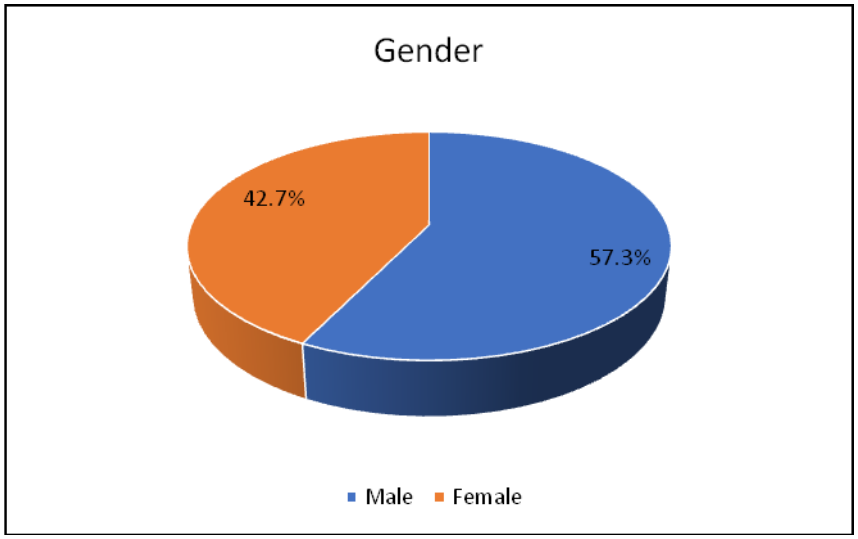
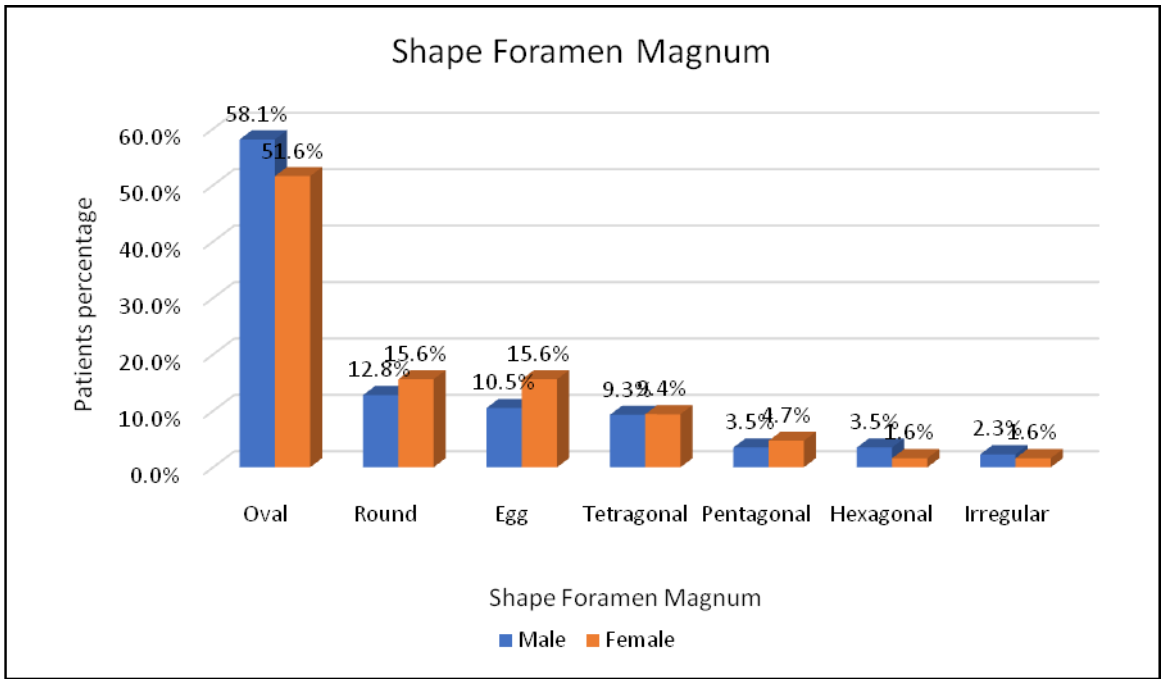


Table 1: Means dimensions of FM in the studied dry skulls

	Mean ± SD	Minimum	Maximum
APD (mean)	33.92±2.39	28.0	39.2
TD (mean)	29.90±2.33	26.0	34.5
Index	1.13±0.168	0.06	1.41
Area (mm2)	796.96±84.73	602.91	1047.20

Figure 2: Distribution of Shape of FM in both male and female groups



The foramen magnum is a transition zone between skull and vertebral column. It plays a significant role as a landmark because of its close relationship to key structures such as brain, spinal cord, accessory spinal nerves and vertebral arteries.

In our study, oval shape of FM was commonly seen (55.3%). This was followed by round (14.0%), egg shaped (12.7%), tetragonal (9.3%), pentagonal (4.0%), hexagonal (2.7%), and irregular (2.0%).In a similar Decca plateau region study **Manuva DR & Edulla NK [17]**reported that the oval shaped FM was more common in 53.03%, followed by round type in 13.63%, hexagonal type in 13.63% and pentagonal type in 7.57%.while in a North Indian Region study **Singh D et al**[14] reported that FM was observed to have oval shape in 29.7%, round in 26.2%, tetragonal in 16.6%, egg shape in 10.7%, hexagonal in 5.9%, irregular in 5,9% and pentagonal in 4.8% cases. The oval-shaped foramen magnum was determined to be commonest form among the numerous types studied. Previous studies According to **Sampada PK et a [18],Singh KC et al [19],Rajkumar et al**[20] and **Mishra AK et al [21]**, oval shape is main type; while it is round shape rendering to **Rohinidevi M et al [22]**, **Mursheed KA et al**[23] and **Sharma S et al [24]**. The variances in sexual dimorphism, sample size, ethnic diversity, and population types may have contributed to the variances in the morphology of FM.

Table2: The comparison of the shapes of the foramen magnum

	Present study		Lucena JD et al [25]		Sholapurkar et al [26]		Radhakrishna et al [27]	
	Male (n=86)	Female (n=64)	Male (n=81)	Female (n=77)	Male (n=50)	Female (n=50)	Male (n=55)	Female (n=55)

Oval	50	33	5	9	25	11	22	17
Round	11	10	9	6	0	2	16	12
Egg	9	10	--	--	4	15	--	--
Tetragonal	8	6	15	5	10	10	10	9
Pentagonal	3	3	16	9	9	5	--	--
Hexagonal	3	1	18	4	2	7	8	6
Irregular	2	1	5	6	--	--	--	--

In present study on comparing shape of FM based on gender (male/female)we noted that Commonest shape of FM is oval shape the percentage is 58.1% in males and 51.6% in females which is lesser than values of males. Followed by second common shape of FM is round shapethe percentage is 12.8% in males and 15.6% in females and egg shapethe percentage is 10.5% in males and 15.6% in females,higher than the values of males.According to our research, the foramen magnum's tetragonal, pentagonal, hexagonal, and irregular shapes are less prevalent in both males and females. In both the male and female groups, the distribution of the foramen magnum's shape was insignificant ($p>0.05$). while a study conducted in NortheasternBrazil by **Lucena JD et al [25]** According to their findings, tetragonal, pentagonal, and hexagonal FM forms were found in men, with 15, 18, and 16 occurrences, respectively. With 19 cases, the biconvex FM was most prevalent in females. The study found that the average transverse diameter of FM was 29.90±2.33mm, and average antero-posterior diameter was 33.92±2.39mm, ranging from minimum 28.0 to maximum 39.2mm (with minimum 26.0 to maximum 34.5mm). **Muthukumar N** et al [15] found that FM's transverse diameter was 27.9 mm and its average anteroposterior length measured 33.3 mm. **Sampada P K et al**[18] found that the foramen magnum had an average transverse diameter of 29.39±1.73 mm and an average anteroposterior diameter of 34.84±2.32 mm. The mean transverse and anteroposterior diameters of FM were 28.22 ± 2.19 mm and 34.09 ± 2.23 mm, respectively, in research conducted on 71 skulls from Uttar Pradesh [106]. However, **Gruber P et al**[28] The average transverse diameter of FM, according to his study on skulls from western Europe, was 31.1 mm, within a range of 25 mm to 38.9 mm, while average anteroposterior diameter was 36.6 mm, within a range of 30.1 mm to 42.6 mm. **Wanebo JE & Chicoine MR**[29] found that the foramen magnum's typical sizes were 31 mm for breadth and 36 mm for length. **Solan S**[30] After examining sixty human skulls, researchers found that the foramen magnum's mean transverse and anteroposterior diameters were 32.2±2.9 mm and 36±2.9 mm, respectively.

The foramen magnum's observed area in the current research was 796.96±84.73 mm2, ranging from a low of 602.91 to a maximum of 1047.20 mm2. In a study done by **Praveen T et al**[31] on 92 dried skulls reported mean area of the foramen magnum was 792.61±91.01mm2. **SharmaS et al [24]** studied 50 skulls and observed mean area of FM was 970.57mm2. **Rajkumar et al**[20] Measurements on 298 dry skulls of the unknown sex were conducted in 2017, and the results showed that the foramen magnum's area was 754.32±105.6 mm2. According to research conducted on a population in South India, the average foramen magnum area was found 803.8±83.42 mm2 [32].**Rohinidevi et al**[22] examined 35 skulls and found that the foramen magnum measured 820.53 mm^2. The size of

research sample and the ethnic group represented may have contributed to the variances seen in the aforementioned studies.

Table3: Gender disparity in male and female craniometric measures and FM

	Present Study		**de Lucena et al [25]**	
	Male	**Female**	**Male**	**Female**
APD (mm)	34.06±2.1	32.9±6.1	35.01±3.03	33.92±3.19
TD (mm)	30.40±3.5	29.49±3.6	30.12±2.95	28.91±2.83
Area (mm2)	810.6±84.6	756.8±151	839.83±131.46	765.47±130.52

The present study noted that anteroposterior diameter is 34.06±2.1& 32.9±6.1, the transverse diameter is 30.40±3.5& 29.49±3.6 and the index is 1.16±0.33&1.14±0.28male & female respectively the value is statically analyzed ($p<0.05$), there is a significant observed in TD among male & females but ($p>0.05$) is higher in foramen index so no significance observed in APD &foramen index. The area of FM of oval shape is 810.6±84.6&756.8±151 in male & female correspondingly values are statically significant($p<0.05$). Our findings were accordance with previous study conducted by **de Lucena et al** [25].

Table4: Comparison of the Present findings with the South Indian study

		Present study	**Veeramani et al [31]**	**Present study**	**Veeramani et al [31]**
		APD (mm)		**TD (mm)**	
Oval	**Male**	34.1±2.1	35.9±0.31	30.2±2.3	39.4±0.15
	Female	32.1±8.1	--	28.9±1.9	--
Round	**Male**	34.5±2.8	35.1±0.46	31.4±2.4	30.7± 0.34
	Female	34.1±3.5	33.1±0.31	29.7±1.8	31± 0.21
Egg	**Male**	33.7±1.8	37.3±0.46	29.9±2.3	33.3±0.4
	Female	34.5±1.7	36.4±0.25	29.2±2.6	34.4±0.4
Tetragonal	**Male**	34.1±1.6	38.9±0.39	29.3±1.4	34.5± 0.35
	Female	32.8±1.6	--	29.8±2.9	--
Pentagonal	**Male**	34.0±2.0	38.4±0.32	30.6±2.4	30.1±0.38
	Female	32.0±1.5	--	30.7±2.8	--
Hexagonal	**Male**	32.2±0.25	37.7±0.3	31.2±2.9	33.5±0.35
	Female	29.7±0.0	35±0.05	31.5±0.0	32.3±0.61
Irregular	**Male**	34.1±2.9	36.3±0.46	28.0±2.7	32.2±0.5
	Female	35.0±0.0	36.4±0.32	34.1±0.0	32.3± 0.52

In male skulls, the gender variation in FM anteroposterior diameter was shown to be substantially greater in tetragonal, pentagonal, and hexagonal shapes, however it was significantly smaller in male skulls compared to female skulls in cases of irregular form. However, there were negligible variations in the oval, round, and egg-shaped foramen magnum between male and female groups. In this study, transverse diameter of FM gender variation was shown to be substantially larger in male skulls that were oval or round, and significantly smaller in males that had an irregular form. However, there were negligible

changes in the forms of FM (egg, tetragonal, pentagonal, and hexagonal) between the groups of men and women. Additionally, our research revealed that the area of FM gender variation was considerably greater in round oval, round pentagonal, and hexagonal shapes than in egg, tetragonal, and irregular shapes; however, the difference was not statistically significant between male and female instances.Our findings were similar with previous study conducted by **Veeramani et al** [31].

The dimensions of FM are the effective indicator for the sex determination of skeletal remains in emergency context [33]. However, few studies opined that the area of FM is not an effective parameter for sex determination and can be considered only as supportive finding [34]. **Uysal et al** stated that with accuracy rate of 81%, FM can be considered as effective tool for the sex determination [35]. Knowledge about the sexual dimorphism and topographic anatomy of the basioccipital region and FM is vital to neurosurgeons following transcondylar approach to access cervicomedullary junction and ventral aspect of brain stem [31].

Limitation:

The primary constraint on our research was the lack of precise information on the origin, age, and lineage of the skull. The current study's sample size was tiny, it examined a dry human skull, and it did not distinguish between various regions.

Conclusion:

The mean anteroposterior diameter of FM was 33.92mm and the mean transeverse diameter was 29.90mm. These parameters should be taken during craniovrtebral and cervical spine surgical procedures. Morphometric analysis of the foramen magnumcan be used as supportive findings in estimation of sex of fragmented in- complete or damaged dry human skulls. The knowledge of dimensions of the FM also helpful in determination of malformation (Arnold Chiari Syndrome) and in transcondylar approach to make a safe occipital condyle resection. Though the present study has a limitation as the age of the skull were not determined, this study may provide an important reference and the measurement may be used as a data for the description of morphological variant of FM. The FM is taken as the anatomical landmark in transcondylar approach for a safe occipital condyle resection. The present study illustrates the morphometric data and the variations in the morphology of the FM with emphasis on their clinical implications. This study is also helpful in medicolegal cases for the identification of unknown individuals. With the advancement of the CT and MRI scans as investigation the anatomy of the FM and occipital condyles becomes interesting in the field of medicine.

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