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Morphological and Morphometric Study of the Foramen Magnum in Dried Adult Human Skulls: An Observational Analysis

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ABSTRACT

Background: The foramen magnum is a key opening at the base of the skull, located centrally at the back of its underside, connecting to the posterior cranial fossa. Oval in shape and wider at the back, it allows passage for the medulla oblongata, cerebrospinal fluid, meninges, vertebral vessels, accessory nerves, the apical ligament of the dens, and the tectorial membrane. Its front edge is slightly covered by the occipital condyles, which join with the atlas to enable head movement.

Methods: The present study was conducted on 60 adult dry human skulls of unknown gender, obtained from the Department of Anatomy, VAMC & RH, Shahjahnpur, Uttar Pradesh and PGIMS Rohtak, Haryana. The measurements of the foramen magnum were obtained using a digital Vernier calliper (0–200 mm) with a precision of 0.01 mm. The foramen magnum was observed and categorized into various shapes, including oval, round, tetragonal, pentagonal, hexagonal, and irregular.

Results: The most frequently encountered shape was oval, representing 38.3% (23 cases) of the total. Tetragonal FMs were the next most common at 26.7% (16 cases), followed by hexagonal at 15% (9 cases). Round shapes accounted for 13.3% (8 cases), while the irregular type was the least common, observed in only 10% (6 cases).

Conclusion: The present study analyzes the shapes of the foramen magnum in the Indian population, highlighting their clinical importance. The oval shape was the most common, which has key implications for neurosurgeons in surgical planning. The findings also benefit radiologists, orthopedicians, anesthesiologists, and anatomists by improving anatomical understanding and supporting anthropological and forensic research in population-specific identification.

Key-words: Anatomical variation, Foramen magnum, Forensic research, Morphologic, Morphometric

INTRODUCTION

The foramen magnum, a crucial gateway at the base of the skull, sits centrally in the posterior region of its inferior surface, opening into the posterior cranial fossa. This oval-shaped passage is broader towards the back, with its longest axis running Antero posteriorly.

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Through this vital opening pass the lower end of the medulla oblongata, cerebrospinal fluid, meninges, vertebral arteries and veins, as well as the accessory nerves. Additionally, the apical ligament of the dens and the tectorial membrane traverse the foramen magnum, anchoring themselves to the internal basiocciput. Anteriorly, its edges are subtly overlapped by the occipital condyles, which extend downward to form a joint with the superior articular facets of the atlas, facilitating head movement [1].

The base of the skull, cushioned by a dense layer of soft tissue, acts as a natural safeguard for the foramen magnum. Even in cases of extreme trauma such as high-

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impact injuries, fires, or explosions this critical structure often remains intact. Its preserved dimensions play a crucial role in forensic investigations, aiding in gender determination and ultimately assisting in the identification of individuals [2,3].

The foramen magnum, a crucial anatomical structure at the base of the skull, plays a pivotal role in diagnosing and managing various neurological and skeletal disorders. Its dimensions and morphological variations are key factors in conditions such as Arnold-Chiari malformation, foramen magnum meningioma, achondroplasia, and other posterior fossa pathologies. Understanding its size and shape is not just a matter of anatomical curiosity—it directly influences the outcomes of surgical interventions in this region. Neurosurgical procedures, particularly those involving the brainstem and cervicomedullary junction, rely heavily on precise knowledge of foramen magnum anatomy [3,4]. The transcondylar approach, a sophisticated technique used to minimize brainstem retraction while accessing deep-seated lesions, underscores the significance of these structural details. Any deviation in its normal parameters can impact surgical accessibility and patient prognosis [5,6].

Beyond the realm of neurosurgery, the clinical and forensic importance of the foramen magnum extends to multiple disciplines. Anesthesiologists must be aware of its variations to anticipate potential challenges in airway management, while orthopedists and radiologists use foramen magnum measurements to evaluate congenital and acquired craniovertebral anomalies. Forensic specialists leverage these anatomical features for identification in medico-legal cases, whereas anatomists and anthropologists analyze them to study evolutionary and genetic patterns across populations [7,8].

The study of the foramen magnum extends beyond a technical necessity; it serves as a fundamental aspect of medical diagnostics, surgical preparation, and scientific inquiry. A deep understanding of its anatomy contributes to improved patient care and enhances the precision of forensic investigations.

MATERIALS AND METHODS

Place of study- The present study was conducted on 60 adult dry human skulls of unknown gender, obtained from the Department of Anatomy, VAMC & RH, Shahjahnpur, Uttar Pradesh and PGIMS Rohtak, Haryana.

Inclusion criteria- Full ossified and adult human skull.

Exclusion criteria- Damaged skulls and skulls with broken foramen magnum were excluded from this study.

The measurements of the foramen magnum were obtained using a digital Vernier calliper (0–200 mm) with a precision of 0.01 mm. The foramen magnum was observed and categorized into various shapes, including oval, round, tetragonal, pentagonal, hexagonal, and irregular.

Fig. 1 illustrates key dimensions used to evaluate the foramen magnum: anteroposterior (A-P) diameter, transverse diameter, area (calculated using Radinsky's formula), and foramen index. These parameters were employed to assess morphological variations across different FM shapes. The oval shape, most frequently observed (38.3%), showed balanced A-P and transverse diameters, while tetragonal and irregular types displayed the largest areas.

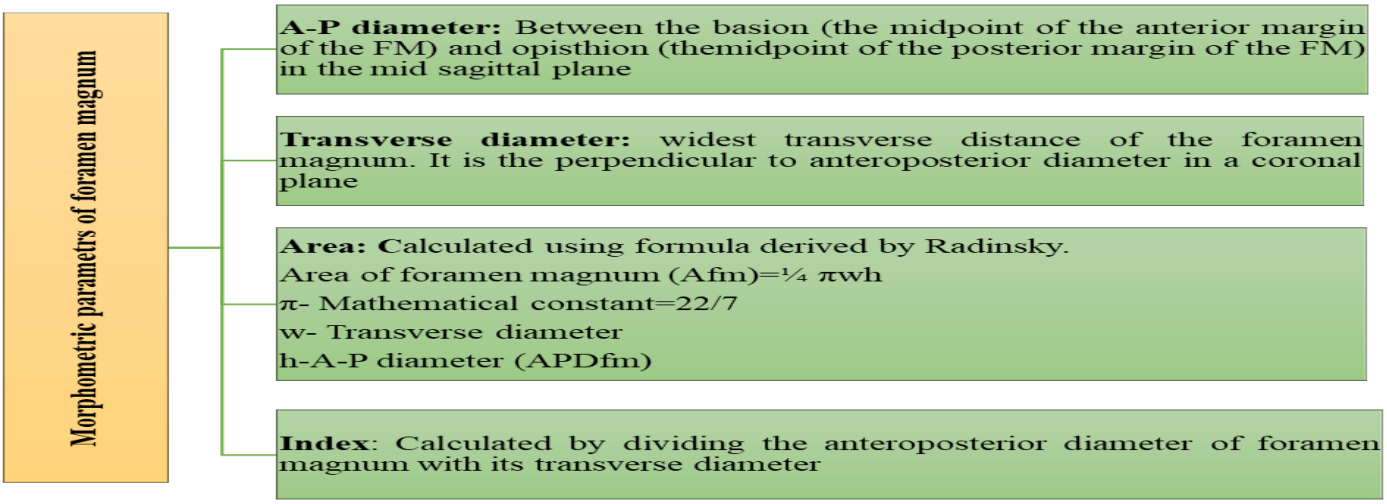

Fig. 1: Flow chart describing the measurement of Foramen magnum

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Fig. 2 displays the representative shapes of the foramen magnum as observed in dry human skulls. The most frequently encountered shape was oval (A), accounting for 38.3% (23 cases) of the total. This shape exhibited the most balanced anterior-posterior and transverse diameters. The tetragonal shape (B) was the next most common, seen in 26.7% (16 cases), followed by the hexagonal type (C), observed in 15% (9 cases). Round foramina (D) accounted for 13.3% (8 cases) and were characterized by a higher foramen index, indicating a more circular configuration. The irregular shape (E) was the least common, appearing in only 10% (6 cases), but it exhibited the largest individual area, reaching up to 872 mm², and the greatest overall dimensions. Tetragonal and hexagonal shapes were generally associated with larger foramen areas, with the tetragonal type showing the highest mean area of 596.5 mm². Each shape demonstrated distinct morphometric features, contributing to a comprehensive understanding of foramen magnum variability.

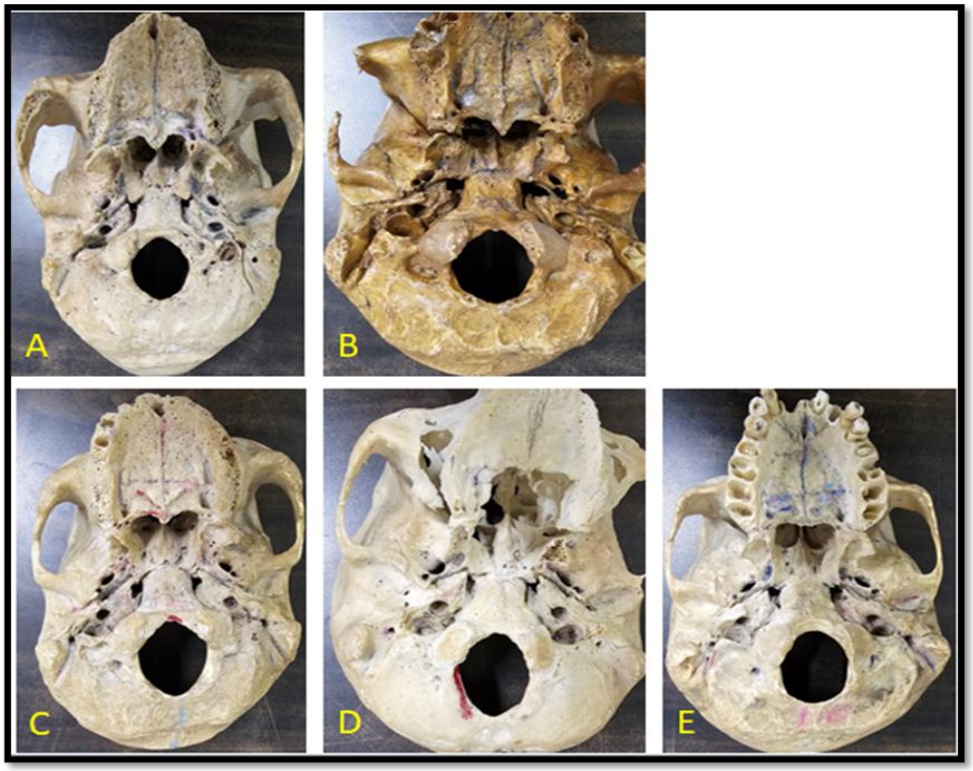

Fig. 2: Showing the various shapes of foramen magnum (A) Oval, (B) Round, (C) Tetragonal, (D) Hexagonal and (E) Irregular

Fig. 3 illustrates the measurement methodology of the foramen magnum. Two key dimensions are demonstrated: the anterior-posterior diameter (A-P), which extends from the basion (the midpoint of the anterior margin of the foramen magnum) to the opisthion (the midpoint of the posterior margin), and the transverse diameter (T), representing the widest horizontal distance of the foramen magnum perpendicular to the A-P diameter. These measurements are critical for calculating the area and index of the foramen magnum, contributing to the assessment of its morphometric variations.

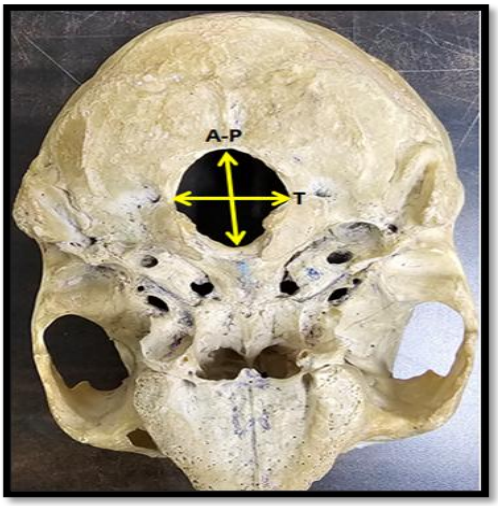

Fig. 3: Showing the measurement of foramen magnum; (A-P: Anterior-posterior diameter, T: transverse diameter)

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Statistical Analysis- All morphometric parameters were measured twice to minimize errors, and the average of the two measurements was used. The data collected from the study were tabulated and analyzed using SPSS software version 21.0. For each osteometric parameter, the maximum, minimum, mean, and standard deviation were calculated.

RESULTS

Table 1 illustrates the incidence of various foramen magnum shapes observed in the study sample of 60 skulls. The oval shape was the most common, found in 38.3% of cases, followed by the tetragonal shape at 26.7%. Hexagonal and round shapes were less frequent, accounting for 15% and 13.3%, respectively. The irregular shape was the least common, observed in only 10% of the samples. This distribution highlights the predominance of the oval and tetragonal shapes in the population studied.

Table 1: Incidence of morphological changes of foramen magnum shape (Maximum frequency was observed).

Shape of foramen magnum	Number (60)	Percentage (%)
Oval	23	38.3
Round	8	13.3
Tetragonal	16	26.7
Hexagonal	9	15
Irregular	6	10

Table 2 presents the descriptive statistics of morphometric parameters for different shapes of the foramen magnum. Among all types, tetragonal and irregular shapes exhibited the largest mean area (596.5 mm^2 and 690 mm^2, respectively), suggesting greater variability in their dimensions. The round shape had the highest foramen index (mean=83.8), indicating it is nearly circular. Irregular types showed the least variability in A-P and transverse diameters, reflected in their minimal standard deviations. Overall, significant morphometric differences are evident among the various shapes, relevant for anatomical and forensic applications.

Table 2: Descriptive statistics of the morphometric parameters of various types of foramen magnum

Shape of foramen magnum		Min (mm)	Max (mm)	Mean	SD
Oval	A-P diameter	28.4	38	33.2	6.7
	Transverse diameter	22.7	29.5	26.1	4.8
	Foramen area mm^2	404.8	633.3	519	114.2
	Foramen index	56.1	79.9	68	16.8
Round	A-P diameter	27.5	37	32.25	6.7
	Transverse diameter	26	30.4	28.2	3.1
	Foramen area mm^2	377	561	469	92
	Foramen index	71.2	96.5	83.8	17.8
Tetragonal	A-P diameter	36.2	39.8	38	2.5
	Transverse diameter	27.5	32	29.7	3.2
	Foramen area mm^2	412.1	781	596.5	184.4
	Foramen index	61.1	93	77	22.5
Hexagonal	A-P diameter	33.4	40.1	36.7	4.7
	Transverse diameter	25.9	31.2	28.5	3.7
	Foramen area mm^2	432	660	546	113.9
	Foramen index	50.1	90.2	70.15	28.3
Irregular	A-P diameter	37.6	38	37.8	0.28
	Transverse diameter	31.6	32.2	31.9	0.42
	Foramen area mm^2	508	872	690	182
	Foramen index	49.5	85.1	67.3	25.2

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DISCUSSION

Anatomical knowledge of the foramen magnum is essential for understanding the clinical signs and symptoms associated with various cranio-cervical disorders. This is because the foramen magnum serves as a passageway for several critical structures, including the lower end of the medulla oblongata, vertebral arteries, meninges, spinal accessory nerve, apical ligament of the dens, and the membranatectoria. It is formed through the interaction of bony, ligamentous, and muscular components that constitute the complex craniovertebral junction. Additionally, understanding the bony dimensions of the foramen magnum is crucial for procedures such as the transcondylar surgical approach [7-12].

Variations in the shape of the foramen magnum are of considerable importance due to their influence on critical neurovascular structures that traverse this opening, as well as their relevance in numerous surgical procedures. In the current study, the most frequently observed shape was oval, identified in 23 skulls (38.3%). This finding aligns with results reported in earlier studies by Singh *et al.* [5]; Arora *et al.* [13]; Sampada *et al.* [14]; and Revankar *et al.* [15]. The second most prevalent shape was tetragonal (26.7%), followed by hexagonal (15%) and irregular forms (10%). These distributions are largely consistent with previous research. Notably, round-shaped foramina were present in only 13.3% of cases slightly lower than the frequencies reported in earlier studies [16].

Various studies have examined the dimensions of the foramen magnum across different Indian populations, with sample sizes ranging from 32 to 100 participants displayed in. The anteroposterior (AP) diameter reported across studies typically ranged between 31 mm and 40.2 mm. The highest AP measurement was noted by Patel *et al.* [11] at 40.2 mm, while the lowest was recorded by Chethan *et al.* [10] at 31 mm. Transverse diameters varied from 25.2 mm to 29.39 mm, with the highest values reported by Sampada *et al.* [14]. Area measurements were available in several studies, ranging from 564 mm² in the present 2025 study to 803.8 mm² in the 2017 study by Sampada *et al.* [14] Index values, although less frequently reported, varied widely—from 1.2 noted by Jasuja *et al.* [12] to 82.1 in the 2019 study by Singh *et al.* [5].

CONCLUSIONS

The present study provides a detailed morphometric analysis of various foramen magnum shapes within the Indian population, emphasizing their clinical relevance. Among the different morphological types observed, the oval shape emerged as the most prevalent. This anatomical insight holds significant value for neurosurgeons, particularly in preoperative planning and skull base surgeries, as the oval configuration suggests a narrower operative field near the craniovertebral junction. Beyond neurosurgery, the findings also offer practical implications for radiologists, orthopedicians, anesthesiologists, and anatomists by enhancing their understanding of cranial anatomy. Furthermore, the study contributes to anthropological and forensic research, aiding in population-specific identification and comparative anatomical studies across different ethnic groups.

CONTRIBUTION OF AUTHORS

Research concept- Sagun Shukla, Akhil Sathyan
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Final approval- Akhil Sathyan, Vibhash Kumar Vaidya

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