



Original Article

Morphometric and Morphological Analysis of the Foramen Ovale in Dry Adult Human Skulls

Prem Lata¹, Prabhat Kumar², Umesh Choudhary³, Birendra Kumar Sinha⁴

¹Tutor, Department of Anatomy, Patna Medical College and Hospital, Patna, Bihar (India).

²Tutor, Department of Anatomy, Nalanda Medical College and Hospital, Patna, Bihar (India).

³Associate Professor, Department of Anatomy, Institute of Medical Sciences, Banaras Hindu University, Varanasi, U.P., (India).

⁴Professor and Head, Department of Anatomy, Patna Medical College and Hospital, Patna, Bihar (India).

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Corresponding Author:

Prabhat Kumar

Tutor, Department of Anatomy,
Nalanda Medical College and
Hospital, Patna, Bihar (India).

Email: dr.prabhat25@gmail.com

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ABSTRACT

Background: The foramen ovale (FO) is an important opening located in the greater wing of the sphenoid bone that transmits several vital neurovascular structures between the middle cranial fossa and the infratemporal fossa. Variations in its morphology and morphometry are of considerable clinical significance during skull base surgeries, percutaneous neurosurgical procedures, regional anaesthesia, and radiological interpretation. Published morphometric data on the foramen ovale from Bihar and Eastern India remain scarce, necessitating region-specific anatomical information.

Materials and Methods: This descriptive cross-sectional osteological study was conducted in the Department of Anatomy, Patna Medical College, Patna, Bihar, India. A total of 50 dry adult human skulls with intact foramina ovale were included, yielding 100 foramina for analysis. Morphological assessment included the evaluation of the shape of the foramen ovale and the presence of bony spurs, tubercles, bony plates, and the foramen of Vesalius. Morphometric measurements, including the maximum anteroposterior length and maximum transverse width, were obtained bilaterally using a digital Vernier calliper. Data were analysed using SPSS version 25.0, and a p-value <0.05 was considered statistically significant.

Results: The oval shape was the predominant morphological configuration of the foramen ovale, observed in 61 (61.0%) foramina, followed by the almond-shaped (21.0%), round (12.0%), and D-shaped (6.0%) variants. The foramen of Vesalius was identified adjacent to the foramen ovale in 9 (9.0%) specimens. Among the bony variations, bony spurs were the most frequently encountered finding (7.0%), followed by bony tubercles (4.0%) and bony plates (3.0%). The mean anteroposterior length of the foramen ovale measured 7.64 ± 1.18 mm on the right side and 7.52 ± 1.14 mm on the left side, while the mean transverse width measured 4.21 ± 0.59 mm and 4.16 ± 0.56 mm, respectively. No statistically significant bilateral difference was observed in either the anteroposterior length or transverse width of the foramen ovale ($p > 0.05$).

Conclusion: The present study demonstrates that the oval shape is the predominant morphological configuration of the foramen ovale in the Eastern Indian population, while the morphometric dimensions showed no significant bilateral differences. The findings provide valuable baseline anatomical data that may assist anatomists, radiologists, and surgeons in skull base surgery, image-guided interventions, and radiological interpretation, while contributing to the limited morphometric literature from Bihar and Eastern India.

Keywords: Foramen ovale; Morphometry; Morphology; Dry adult human skulls; Skull base; Sphenoid bone; Eastern India; Trigeminal neuralgia.

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INTRODUCTION

The human skull base is a structurally complex anatomical region that supports the brain while providing multiple foramina and canals for the transmission of cranial nerves and blood vessels between the cranial cavity and extracranial structures. Among these openings, the foramen ovale (FO) is one of the most important foramina of the middle cranial fossa. It is situated in the posterior part of the greater wing of the sphenoid bone and establishes communication between the middle cranial fossa and the infratemporal fossa [1,2]. The foramen ovale transmits the mandibular division of the trigeminal nerve (V3), the accessory meningeal artery, the lesser petrosal nerve, and an emissary vein connecting the cavernous sinus with the pterygoid venous plexus [1,3]. Because of its strategic anatomical location and the critical neurovascular structures traversing it, the foramen ovale has considerable importance in anatomy, neurosurgery, neuroradiology, dentistry, maxillofacial surgery, pain management, and regional anaesthesia.

The sphenoid bone is one of the most intricate bones of the human skeleton and occupies a central position at the base of the skull. Embryologically, it develops from both intramembranous and endochondral ossification centres. The greater wings of the sphenoid originate primarily from the alisphenoid centres, and the foramen ovale is formed around the mandibular nerve during fetal development. Initially, the foramen appears as a ring-like opening within the cartilaginous sphenoid and gradually acquires its definitive morphology with progressive ossification. The ossification process is generally completed during early childhood; however, variations in ossification may persist into adult life, giving rise to accessory bony projections, septations, duplicated foramina, or irregular margins [4,5]. These developmental alterations contribute significantly to the anatomical diversity observed in the morphology of the foramen ovale.

The foramen ovale has traditionally been described as an oval opening; however, numerous anatomical investigations have demonstrated considerable variability in its morphology. Depending upon the population studied, the foramen may present as oval, almond-shaped, round, slit-like, D-shaped, pear-shaped, elongated, or irregular. Furthermore, variations such as bony spurs, tubercles, bony plates, septa, duplicated foramina, and adjacent accessory foramina, including the foramen of Vesalius and canaliculus innominatus, have been reported [3,5–7]. Ossification of the pterygospinous or pterygoalar ligaments may further modify the morphology of the foramen and occasionally obstruct surgical access to the skull base. Such variations are of considerable clinical importance because they may alter the course of the neurovascular structures passing through the foramen or complicate percutaneous surgical procedures.

Morphometric evaluation of the foramen ovale is equally important because precise knowledge of its dimensions assists clinicians in planning image-guided diagnostic and therapeutic procedures. Parameters such as maximum anteroposterior length, transverse width, surface area, and the distances from adjacent bony landmarks are valuable anatomical guides during skull base interventions. Several investigators have demonstrated significant differences in these measurements among various ethnic and geographical populations, suggesting that genetic background, developmental factors, and environmental influences may contribute to regional variations [4,6,8]. Consequently, the establishment of population-specific morphometric reference values is essential for improving the precision and safety of clinical procedures.

The clinical importance of the foramen ovale has increased remarkably with advances in minimally invasive neurosurgical techniques and interventional neuroradiology. It serves as the principal percutaneous route to the trigeminal ganglion within Meckel's cave and is routinely utilised for radiofrequency thermocoagulation, balloon compression, glycerol rhizotomy, and other procedures performed for the treatment of medically refractory trigeminal neuralgia [2,7,9]. In addition, it provides access for biopsies of cavernous sinus lesions, percutaneous treatment of skull base tumours, stereotactic procedures, electroencephalographic electrode placement, and mandibular nerve block anaesthesia. Successful performance of these interventions depends upon accurate localisation of the foramen ovale and a comprehensive understanding of its anatomical variations. Failure to recognise these variations may result in unsuccessful cannulation, injury to adjacent cranial nerves or vascular structures, haemorrhage, or other procedural complications.

Radiologically, the foramen ovale represents an important landmark during computed tomography (CT) and magnetic resonance imaging (MRI) of the skull base. Alterations in its size or morphology may indicate pathological conditions such as trigeminal schwannoma, meningioma, perineural spread of malignancy, metastatic lesions, vascular malformations, or congenital cranial anomalies [8,10]. Enlargement of the foramen may occur secondary to tumors involving the mandibular nerve, whereas narrowing or partial obstruction caused by ossified ligaments or bony projections may compress the mandibular nerve and associated vessels, leading to facial pain, sensory disturbances, or weakness of the muscles of mastication. Therefore, distinguishing normal anatomical variations from pathological changes is essential for accurate radiological interpretation and surgical planning.

Apart from its clinical significance, the morphology and morphometry of the foramen ovale have considerable anthropological and forensic relevance. Cranial foramina demonstrate population-specific variations that may reflect genetic diversity, evolutionary adaptations, and developmental influences. Detailed morphometric analyses, therefore, contribute not only to anatomical knowledge but also to comparative anatomy, forensic anthropology, and skeletal identification. Furthermore, the availability of normative morphometric data enhances the anatomical database required for educational, clinical, and research purposes.

Several studies have investigated the morphology and morphometry of the foramen ovale in different populations using dry skulls and radiological imaging techniques. Somesh et al. documented that the oval shape was the most common configuration in Indian skulls while also reporting various accessory bony projections and morphological variations [5]. Burdan et al. observed asymmetry in the dimensions of the foramen ovale and highlighted its importance during radiological evaluation of the skull base [4]. More recently, Alaftan et al. evaluated the foramen ovale in a Saudi population using computed tomography and demonstrated considerable variation in both morphology and morphometric parameters [8]. Similar studies conducted in different populations have consistently shown that the dimensions and morphology of the foramen ovale vary considerably among ethnic groups, highlighting the importance of region-specific anatomical investigations. Despite the availability of numerous morphometric studies from different parts of India and other countries, published data from Bihar and the Eastern Indian region remain scarce. Since cranial morphometric characteristics may exhibit geographical, ethnic, and population-specific variations, the absence of regional data limits the establishment of reliable anatomical reference standards applicable to the local population.

The objective of the study was to evaluate the morphology and morphometry of the foramen ovale in dry adult human skulls and to establish baseline anatomical data for the Eastern Indian population.

MATERIAL AND METHOD:

Study Design: The present study was a descriptive cross-sectional osteological study conducted in the Department of Anatomy, Patna Medical College, Patna, Bihar (India). The study was carried out using dry adult human skulls available in the departmental osteology museum and teaching collection.

Sample Size Calculation

The sample size for the present study was determined using a convenience sampling approach based on the availability of suitable osteological specimens in the Department of Anatomy, Patna Medical College, Patna, Bihar (India). A total of 50 dry adult human skulls with intact, well-preserved foramina ovale were available during the study period and met the predefined inclusion criteria. Since this was a descriptive osteological study utilising museum specimens rather than living participants, the sample size was governed by the availability and quality of eligible skulls rather than by formal statistical estimation. Both right and left foramina ovale of each skull were examined, resulting in the evaluation of 100 foramina ovale (50 right and 50 left).

Study Sample: The study included 50 dry adult human skulls of unknown age and sex obtained from the osteology museum and teaching collection of the Department of Anatomy, Patna Medical College, Patna, Bihar (India). Each skull was carefully examined before inclusion in the study to ensure preservation of the middle cranial fossa and the integrity of the foramen ovale.

Inclusion Criteria: The following skulls were included in the study:

- Intact dry adult human skulls.
- Skulls with bilaterally well-preserved foramina ovale.
- Skulls with intact middle cranial fossae and sphenoid bones.
- Skulls without visible postmortem damage affecting the foramen ovale or surrounding anatomical structures.

Exclusion Criteria: The following skulls were excluded from the study:

- Broken or incomplete skulls.
- Skulls showing fractures involving the sphenoid bone or middle cranial fossa.
- Skulls with damaged, eroded, or obliterated margins of the foramen ovale.
- Skulls showing congenital deformities, pathological lesions, or previous surgical modifications affecting the skull base.
- Juvenile skulls with incompletely ossified sphenoid bones.

Morphological Analysis: Each skull was examined from the endocranial aspect under adequate illumination. The morphology of the foramen ovale was assessed visually and classified according to its external appearance. The following morphological characteristics were recorded:

- Shape of the foramen ovale (oval, round, almond or D-shaped).

- Presence of accessory bony projections such as bony spurs, tubercles, or bony plates.

Representative photographs of morphological variations were obtained using a high-resolution digital camera.

Morphometric Analysis: Morphometric measurements were performed using a digital Vernier calliper (Mitutoyo, Japan) with a least count of 0.01 mm. The following parameters were measured bilaterally:

- **Maximum anteroposterior length (AP diameter) of the foramen ovale (mm):**
The maximum distance measured between the anterior-most and posterior-most margins of the foramen ovale.
- **Maximum transverse width (Transverse diameter) of the foramen ovale (mm):**
The maximum distance measured perpendicular to the anteroposterior axis, between the medial-most and lateral-most margins of the foramen ovale.

Measurements were performed by a single observer. Each measurement was recorded independently on two occasions by the same observer, and the average of the two readings was used for statistical analysis to minimise intra-observer measurement error.

Statistical Analysis: All collected data were entered into Microsoft Excel and analysed using IBM Statistical Package for the Social Sciences (SPSS) software, Version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean \pm standard deviation (SD), while categorical variables were presented as frequency and percentage. The normality of data distribution was assessed using the Shapiro–Wilk test. Morphometric measurements of the right and left sides were compared using the paired Student's t-test for normally distributed data. If normality assumptions were not satisfied, the Wilcoxon signed-rank test was applied. Morphological variables were analysed using descriptive statistics, and associations between categorical variables were evaluated using the Chi-square test or Fisher's exact test, wherever applicable. A p-value <0.05 was considered statistically significant.

RESULTS:

A total of 50 dry adult human skulls, comprising 100 foramina ovale (50 right and 50 left), were examined for morphological and morphometric analysis. The morphological distribution of the foramen ovale is presented in Table 1 and Figures 1 and 2. The oval-shaped foramen was the most frequently observed configuration, accounting for 61 (61.0%) of the total foramina, including 31 (62.0%) on the right side and 30 (60.0%) on the left side. The almond-shaped variant was the second most common morphology, observed in 21 (21.0%) foramina, comprising 10 (20.0%) on the right and 11 (22.0%) on the left. Round-shaped foramina were identified in 12 (12.0%) cases, with an equal distribution on both sides (6; 12.0% each). The D-shaped variant was the least frequent morphology, occurring in 6 (6.0%) foramina, with 3 (6.0%) observed on each side.

The morphological variations of the foramen ovale are summarised in Table 2. The foramen of Vesalius was identified adjacent to the foramen ovale in 9 (9.0%) specimens, being slightly more common on the right side (5; 10.0%) than on the left (4; 8.0%). Among the bony variations, bony spurs were the most frequently encountered finding, observed in 7 (7.0%) foramina, including 3 (6.0%) on the right side and 4 (8.0%) on the left side. Bony tubercles were present in 4 (4.0%) foramina, occurring equally on both sides (2; 4.0% each), while bony plates were observed in 3 (3.0%) foramina, including 1 (2.0%) on the right and 2 (4.0%) on the left. No duplicated or septated foramen ovale was identified in the examined specimens.

The morphometric measurements are presented in Table 3 and Figure 3. The mean anteroposterior length of the foramen ovale measured 7.64 ± 1.18 mm on the right side and 7.52 ± 1.14 mm on the left side. The mean transverse width measured 4.21 ± 0.59 mm on the right side and 4.16 ± 0.56 mm on the left side. The morphometric data showed a normal distribution on the Shapiro–Wilk test ($p > 0.05$); therefore, the paired Student's t-test was used for comparison. Although the mean dimensions were slightly greater on the right side, the differences were not statistically significant for either the anteroposterior length ($p = 0.421$) or the transverse width ($p = 0.587$). Overall, the morphometric analysis demonstrated comparable dimensions of the foramen ovale on both sides, with no significant bilateral differences.

Table 1. Morphological distribution of the foramen ovale (n = 50 skulls; 100 foramina)

Shape	Right n (%)	Left n (%)	Total n (%)
Oval	31 (62.0)	30 (60.0)	61 (61.0)
Almond	10 (20.0)	11 (22.0)	21 (21.0)
Round	6 (12.0)	6 (12.0)	12 (12.0)
D-shaped	3	3	6

	(6.0)	(6.0)	(6.0)
Total	50 (100)	50 (100)	100 (100)

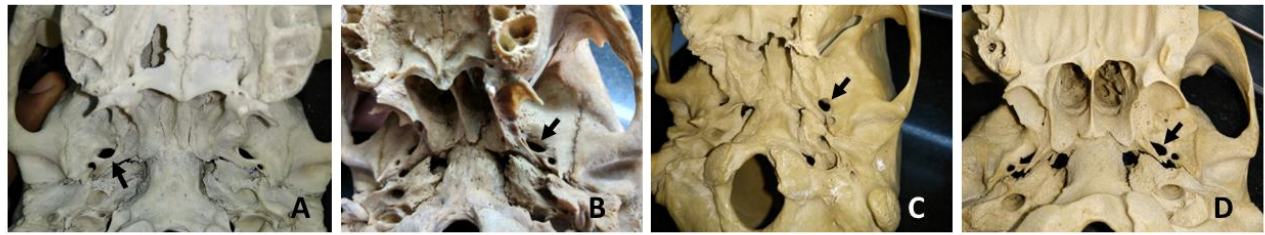


Figure 1. Representative morphological variants of the foramen ovale observed in the examined dry adult human skulls. (A) Oval-shaped foramen ovale, (B) Almond-shaped foramen ovale, (C) Round-shaped foramen ovale, and (D) D-shaped foramen ovale.

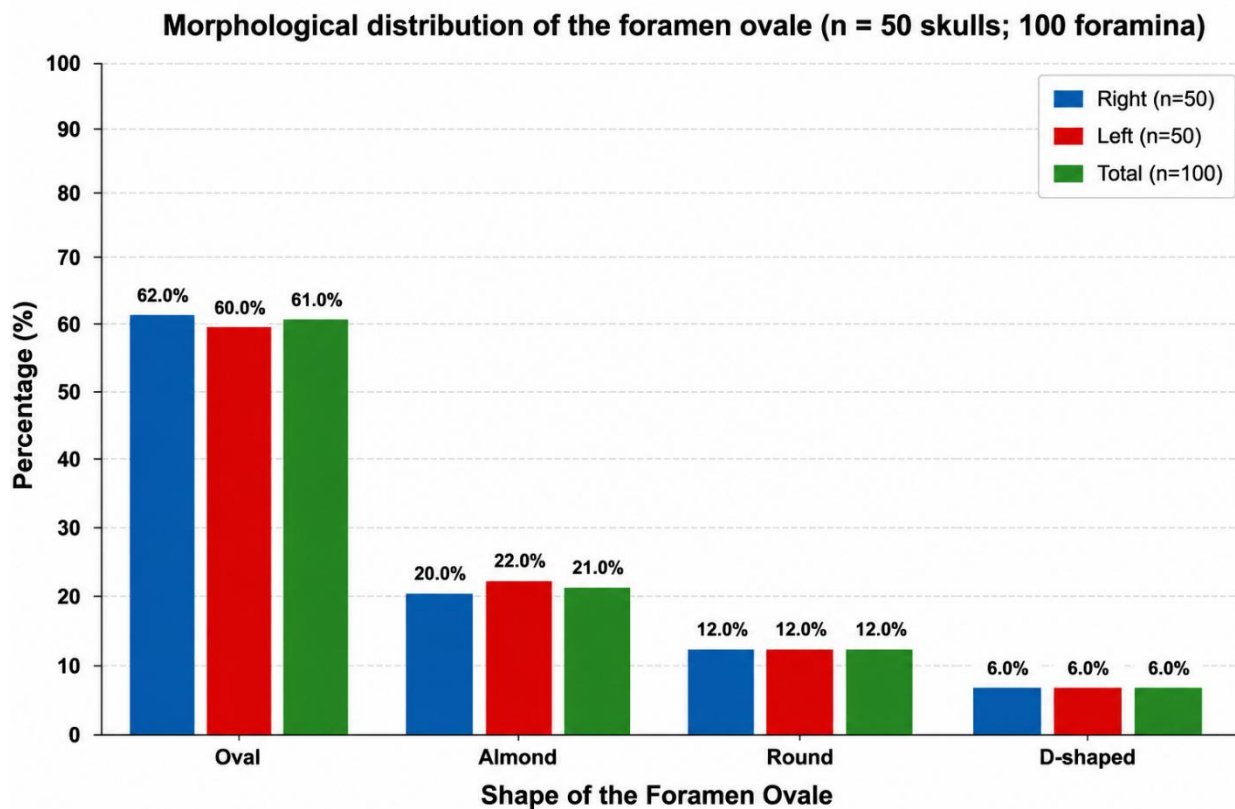


Figure 2: Percentage distribution of the morphological variants of the foramen ovale observed on the right side, left side, and in the overall study sample of dry adult human skulls.

Table 2. Morphological variations of the foramen ovale

Morphological variation	Right n (%)	Left n (%)	Total n (%)
Bony spur	03 (6.0)	04 (8.0)	07 (7.0)
Bony tubercle	02 (4.0)	02 (4.0)	04 (4.0)

Bony plate	01 (2.0)	02 (4.0)	03 (3.0)
Presence of the foramen of Vesalius	05 (10.0)	04 (8.0)	09 (9.0)

Table 3. Comparison of morphometric measurements between the right and left sides

Parameter	Right Side (Mean ± SD)	Left Side (Mean ± SD)	p-value
Length (mm)	7.64 ± 1.18	7.52 ± 1.14	0.421
Width (mm)	4.21 ± 0.59	4.16 ± 0.56	0.587

(Measurements were taken in mm)

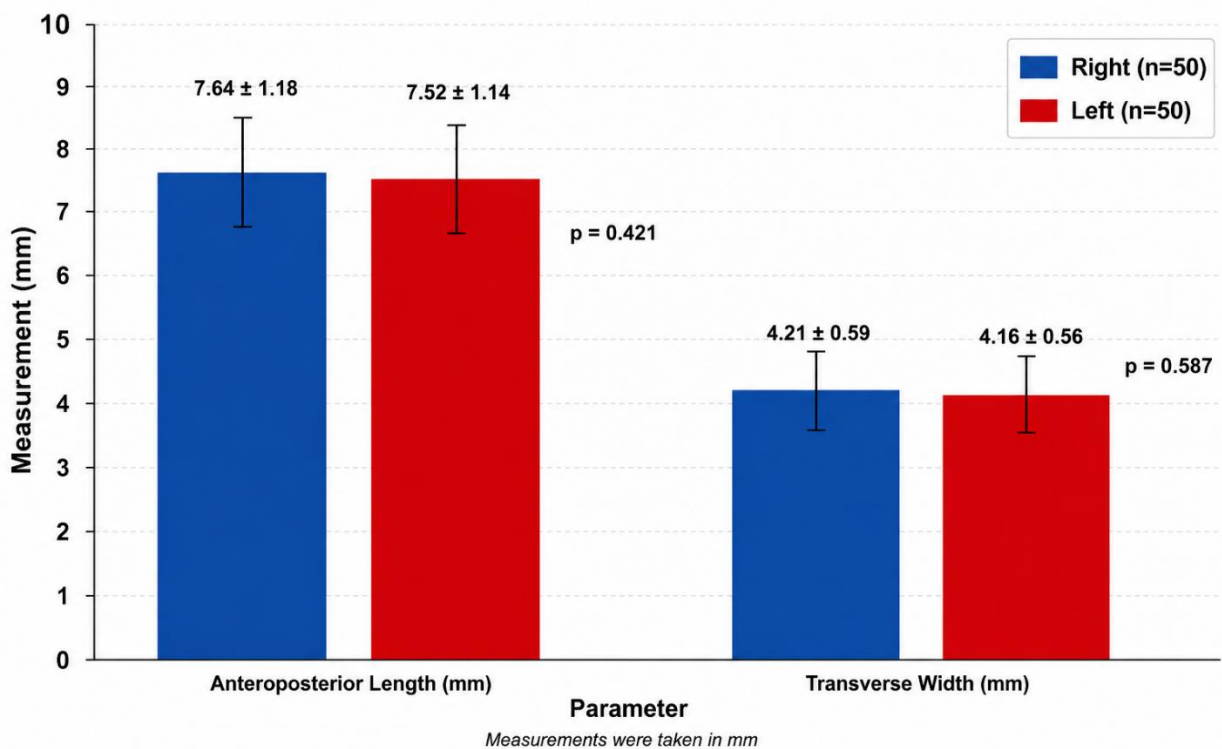


Figure 3: Comparison of the mean anteroposterior length and transverse width (mean ± SD) of the foramen ovale between the right and left sides.

DISCUSSION:

The present study evaluated the morphological variations and morphometric characteristics of the foramen ovale in dry adult human skulls from Bihar, Eastern India. The principal findings demonstrated that the oval shape was the predominant morphological pattern, the foramen of Vesalius was the most frequently observed anatomical variation, bony spurs represented the most common bony variation, and no statistically significant bilateral differences were observed in the morphometric dimensions of the foramen ovale. These findings provide region-specific anatomical data that may facilitate safer skull base procedures and improve radiological interpretation.

The morphology of the foramen ovale is clinically important because it serves as a major gateway for several neurosurgical and interventional procedures, including percutaneous treatment of trigeminal neuralgia, biopsies of Meckel's cave and cavernous sinus lesions, mandibular nerve block, and placement of foramen ovale electrodes for

epilepsy evaluation [2,3,7]. Variations in its shape or the presence of accessory bony structures may increase procedural difficulty and the risk of neurovascular injury.

In the present study, the oval configuration was the most common shape, accounting for 61.0% of all foramina. This observation is consistent with previous studies conducted in different populations. Khairnar and Bhusari [2] reported oval morphology in 70% of specimens, Murugan and Saheb [9] in 69%, Somesh et al. [3] in 56.7%, Kodialbail et al. [7] in 56%, and Ray et al. [10] in 61.4%. The close agreement between our findings and those reported by Ray et al. suggests that the oval configuration represents the normal anatomical pattern of the foramen ovale across different populations.

The almond-shaped variant was the second most common morphology (21.0%), followed by the round (12.0%) and D-shaped (6.0%) variants. Similar distributions have been described by Somesh et al. [3], Murugan and Saheb [9], and Das et al. [6], although minor differences in frequency exist. Such variability is expected because the morphology of the foramen ovale is influenced by genetic background, ethnicity, developmental factors, and differences in the criteria used for morphological classification.

The developmental basis of these variations has been well described. The sphenoid bone develops through both intramembranous and endochondral ossification. During fetal development, the mandibular nerve becomes enclosed by cartilage, around which the foramen ovale is formed. Progressive ossification during early childhood establishes the definitive margins of the foramen. Variations in ossification or persistence of embryonic connective tissue may result in alterations in the shape of the foramen as well as the formation of accessory bony projections, septa, or duplicated foramina [3,5,7]. Consequently, the observed morphological diversity represents normal developmental variation rather than pathological change.

The foramen of Vesalius was identified in 9.0% of the examined specimens, while among the bony variations, bony spurs were the most frequently encountered finding (7.0%), followed by bony tubercles (4.0%) and bony plates (3.0%). Similar bony projections have been reported by Mishra et al. [1], Khairnar and Bhusari [2], Das et al. [6], and Kodialbail et al. [7], although the reported incidences vary considerably among populations. These osseous structures are generally attributed to partial or complete ossification of the pterygospinous and pterygoalar ligaments during development [5,7]. Their clinical importance lies in the potential to compress the mandibular nerve or interfere with needle passage during percutaneous procedures involving the foramen ovale.

The foramen of Vesalius was identified in 9.0% of the examined specimens, which falls within the range reported in previous anatomical investigations [11-14]. This accessory foramen transmits an emissary vein connecting the cavernous sinus with the pterygoid venous plexus and should be recognised during skull base interventions to minimise the risk of inadvertent vascular injury. Awareness of its presence is also important during radiological assessment, where it should not be mistaken for a pathological lesion.

The mean anteroposterior length of the foramen ovale measured 7.64 ± 1.18 mm on the right side and 7.52 ± 1.14 mm on the left side. These values are remarkably similar to those reported by Somesh et al. [3] and are also comparable with the findings of Kodialbail et al. [7], Patil et al. [5], and Ray et al. [10]. Likewise, the mean transverse width measured 4.21 ± 0.59 mm on the right side and 4.16 ± 0.56 mm on the left side, which lies within the range documented in previous morphometric studies [2,3,5,7]. Minor differences among studies are likely attributable to ethnic diversity, geographical variation, measurement techniques, sample size, and differences in specimen selection. No statistically significant bilateral difference was observed in either the anteroposterior length or transverse width of the foramen ovale in the present study. Similar observations have been reported by Somesh et al. [3] and Patil et al. [5], suggesting that the foramen ovale develops with a high degree of bilateral symmetry in most individuals. Although some investigators have reported asymmetry in selected populations [4], these differences are generally small and are thought to reflect normal developmental and population-related variation rather than clinically significant anatomical asymmetry.

The dimensions and morphology of the foramen ovale possess considerable clinical importance. Accurate knowledge of its anatomy facilitates successful cannulation during radiofrequency thermocoagulation, balloon compression, glycerol rhizotomy, and other procedures performed for trigeminal neuralgia. It also assists in CT-guided biopsies of Meckel's cave and cavernous sinus lesions, administration of mandibular nerve blocks, and placement of intracranial electrodes for epilepsy surgery [2,3,7]. Furthermore, familiarity with normal anatomical variations improves the interpretation of CT and MRI by helping differentiate developmental variants from pathological enlargement caused by trigeminal schwannoma, meningioma, perineural tumour spread, or other skull base lesions [8].

An important strength of the present study is the generation of baseline morphometric and morphological data from Bihar, a region for which published information on the foramen ovale remains limited. While the overall findings are broadly consistent with previous Indian and international studies, slight differences in morphometric values reinforce

the importance of establishing population-specific reference standards. Such regional anatomical data may contribute to safer surgical planning and more accurate radiological interpretation for patients from Eastern India. Overall, the findings of the present study support previous observations that the oval shape is the predominant morphology of the foramen ovale and that minor anatomical variations are relatively common. The morphometric values obtained provide useful reference data for the Eastern Indian population and further expand the existing anatomical literature on skull base morphology.

Limitations of the study: The findings of the present study contribute important baseline anatomical data for the Eastern Indian population. Further multicentric studies with larger sample sizes and radiological correlation are warranted to validate and expand these observations across diverse populations.

CONCLUSIONS:

The present study demonstrates that the oval shape is the predominant morphological configuration of the foramen ovale in dry adult human skulls from the Eastern Indian population. The foramen of Vesalius was the most frequently observed anatomical variation, while bony spurs represented the most common bony variation. The morphometric analysis revealed no statistically significant bilateral differences in the anteroposterior length or transverse width of the foramen ovale. These findings provide valuable baseline anatomical data for the Eastern Indian population and may serve as a useful reference for anatomists, radiologists, neurosurgeons, maxillofacial surgeons, and anesthesiologists during skull base surgeries, percutaneous procedures, regional nerve blocks, and radiological interpretation. Furthermore, the study contributes to the limited morphometric literature on the foramen ovale from Bihar and Eastern India and provides a foundation for future multicentric anatomical and radiological investigations.

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