International Journal of Medical and Pharmaceutical Research

Online ISSN-2958-3683 | Print ISSN-2958-3675
Frequency: Bi-Monthly
Available online on: https://ijmpr.in/

Original Article

Morphological Variations and Morphometric Analysis of the Foramen Spinosum in Adult Human Skulls

Prem Lata[1], Prabhat Kumar[2], Umesh Choudhary[3], Birendra Kumar Sinha[4]

[1]Tutor, Department of Anatomy, Patna Medical College and Hospital, Patna, Bihar (India).
[2]Tutor, Department of Anatomy, Nalanda Medical College and Hospital, Patna, Bihar (India).
[3]Associate Professor, Department of Anatomy, Institute of Medical Sciences, Banaras Hindu University, Varanasi, U.P., (India).
[4]Professor and Head, Department of Anatomy, Patna Medical College and Hospital, Patna, Bihar (India).

OPEN ACCESS

Corresponding Author:

Prabhat Kumar
Tutor, Department of Anatomy, Nalanda Medical College and Hospital, Patna, Bihar (India).
Email: dr.prabhat25@gmail.com

Received: 30-05-2026
Accepted: 20-06-2026
Available online: 05-07-2026

ABSTRACT

Background: The foramen spinosum is an important anatomical landmark located in the greater wing of the sphenoid bone. It transmits the middle meningeal vessels and the meningeal branch of the mandibular nerve and serves as a key reference point during skull base surgery and neuroradiological evaluation. Detailed knowledge of its morphology and morphometry is essential because anatomical variations may influence surgical planning and radiological interpretation.
Materials and Methods: This descriptive cross-sectional osteological study was conducted on 50 dry adult human skulls (100 foramina spinosa) obtained from the Department of Anatomy, Patna Medical College, Patna, Bihar, India. The shape of the foramen spinosum was classified as round, oval, pinhole, or irregular. Morphometric parameters, including anteroposterior diameter, transverse diameter, area, and distances from the root of the zygoma (ZA–FS), midline of the skull base (Mid–FS), foramen ovale (FO–FS), and carotid canal (CC–FS), were measured using a screw-adjusted compass and Vernier calliper. Statistical analysis was performed using GraphPad Prism version 10.0, and bilateral comparisons were made using the paired Student's t-test and Chi-square test.
Results: The foramen spinosum was present bilaterally in all skulls examined (100%). The round shape was the predominant morphological variant (52.0%), followed by oval (38.0%), pinhole (6.0%), and irregular (4.0%) configurations, with no significant bilateral difference ($p=0.894$). The mean anteroposterior diameter measured 3.98 ± 0.71 mm on the right and 3.76 ± 0.81 mm on the left, while the transverse diameter measured 2.43 ± 0.32 mm and 2.53 ± 0.62 mm, respectively. The mean area was 7.68 ± 2.31 mm² on the right and 7.54 ± 2.46 mm² on the left. The mean ZA–FS, Mid–FS, FO–FS, and CC–FS distances also showed no statistically significant bilateral differences (all $p>0.05$).
Conclusion: The foramen spinosum exhibited consistent morphology and morphometry with a predominance of the round shape and no significant bilateral asymmetry in the studied Eastern Indian population. These findings provide valuable baseline anatomical data that may facilitate safer skull base surgery, improve neuroradiological interpretation, and support anatomical and forensic research.

Keywords: *Foramen spinosum; Sphenoid bone; Morphometry; Morphological variation; Skull base; Middle meningeal artery.*

INTRODUCTION

The sphenoid bone forms the central component of the cranial base and plays a pivotal role in the architecture of the middle cranial fossa. Its greater wing contains several foramina that provide essential pathways for the passage of neurovascular structures between the intracranial and extracranial compartments [1]. These foramina serve as important anatomical landmarks during surgical and radiological procedures involving the skull base. Because their morphology and dimensions exhibit considerable variability, a thorough understanding of these anatomical features is essential for accurate radiological interpretation and safe surgical navigation. Furthermore, distinguishing normal anatomical variants from pathological abnormalities is critical in clinical practice [2,3]. The foramen spinosum (FS) is a small but anatomically significant opening situated posterolateral to the foramen ovale on the greater wing of the sphenoid bone. It transmits the middle meningeal artery and vein, the meningeal branch of the mandibular nerve (nervus spinosus), and accompanying vascular structures, thereby establishing communication between the middle cranial fossa and the infratemporal fossa [1,4,5]. Despite its relatively small size, the FS is of considerable clinical importance because of its intimate relationship with vital neurovascular structures and its value as a dependable landmark in skull base anatomy.

The morphology of the foramen spinosum is closely related to the developmental pattern of the middle meningeal artery. Variations in the origin or course of this artery may alter the configuration of the foramen or even result in its absence. For example, when the middle meningeal artery originates from the ophthalmic artery instead of the maxillary artery, it may enter the cranial cavity through the superior orbital fissure, eliminating the need for a distinct foramen spinosum. Likewise, duplication of the FS has been attributed to an early division of the middle meningeal artery before it enters the cranial cavity [6,7,8]. Recognition of these anatomical variations is important for interpreting radiological images correctly and for planning surgical procedures involving the middle cranial fossa.

From a surgical perspective, the FS is regarded as a reliable landmark during microsurgical approaches to the skull base. It facilitates identification of the middle meningeal artery, which may serve as a donor vessel for extracranial–intracranial bypass procedures involving the internal carotid or posterior cerebral arteries [9,10]. Consequently, precise knowledge of its morphology and morphometric characteristics is essential to minimise intraoperative complications, preserve adjacent neurovascular structures, and improve surgical precision. In addition to its neurosurgical significance, detailed anatomical information regarding the FS is valuable in neuroradiology, forensic anthropology, and anatomical education.

Embryologically, the sphenoid bone demonstrates a complex pattern of development, arising through both intramembranous and endochondral ossification. The greater wing (alisphenoid) begins ossification during the eighth week of intrauterine life and develops from one of the eight ossification centres of the postsphenoid region. The foramen spinosum becomes distinguishable approximately eight months after birth and continues to mature until nearly seven years of age. Postnatal developmental changes affecting the FS have been described by Lang et al. [11]. This intricate developmental process likely contributes to the wide spectrum of anatomical variations observed in the shape, size, symmetry, and marginal features of the foramen.

Several anatomical investigations have demonstrated population-based differences in the morphology and morphometric dimensions of the foramen spinosum. With the increasing use of high-resolution imaging and minimally invasive skull base procedures, detailed anatomical knowledge of this foramen has become increasingly relevant. Reliable morphometric data assist clinicians in preoperative planning, facilitate safer surgical approaches, improve radiological assessment, and enhance the understanding of normal anatomical variations. Such information also provides an important anatomical foundation for studies in anthropology and forensic science [12].

In view of its anatomical and clinical significance, the present study was undertaken to evaluate the morphological characteristics, identify anatomical variations, and determine the morphometric dimensions of the foramen spinosum in adult human skulls. The findings are expected to provide baseline anatomical data that may support clinical practice, neurosurgical planning, radiological interpretation, and future anatomical research.

MATERIAL AND METHOD:

Study Design: The present study was a descriptive cross-sectional osteological investigation conducted in the Department of Anatomy, Patna Medical College, Patna, Bihar, India. The study was designed to evaluate the morphological variations and morphometric dimensions of the foramen spinosum in adult human skulls. The investigation was carried out using dry human skulls preserved in the departmental osteological museum, which serves as a repository for teaching, academic research, and anatomical demonstrations. Since the study was based exclusively on preserved osteological specimens, no living subjects were involved.

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 spinosum 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 spinosum of each skull were examined, resulting in the evaluation of 100 foramina spinosum (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 spinosum.

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

- Fully ossified adult human skulls.
- Skulls with a well-preserved cranial base allowing clear visualisation of the middle cranial fossa.
- Specimens with intact greater wings of the sphenoid bone and clearly identifiable foramina spinosum on both sides.
- Skulls free from postmortem damage, erosion, or deformity affecting the region of the foramen spinosum.

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

- Juvenile skulls exhibiting incomplete ossification.
- Senile skulls showing severe degenerative changes or marked alveolar bone resorption that could interfere with anatomical assessment.
- Skulls with congenital craniofacial anomalies or gross anatomical deformities.
- Specimens exhibiting fractures, healed traumatic injuries, pathological lesions, or erosive defects involving the cranial base.
- Skulls with damaged, obliterated, or poorly preserved foramina spinosa that prevented accurate morphological evaluation or morphometric measurement.

Morphological Analysis: The foramen spinosum was examined bilaterally in each skull by direct visual inspection under adequate illumination. The shape of the foramen was carefully evaluated and classified into one of the following categories: Round, Oval, Pinhole or Irregular. In addition to the shape, special attention was given to identifying any anatomical variations involving the foramen spinosum. These included duplication, accessory foramina, absence of the foramen, incomplete formation, asymmetry between the two sides, and the presence of unusual bony projections or marginal irregularities. All observed variations were documented systematically for subsequent analysis.

Morphometric Analysis: Morphometric evaluation of the foramen spinosum was performed bilaterally on all skulls using standardised anatomical landmarks. The centre of the foramen spinosum was identified as the midpoint between its anatomical margins. The following morphometric parameters were recorded:

1. **Anteroposterior Diameter (Length, L):** The maximum linear distance between the anterior and posterior margins of the foramen spinosum (from point A to B) (Figure 1).
2. **Transverse Diameter (Breadth, B):** The maximum distance between the medial and lateral margins of the foramen measured perpendicular to the anteroposterior diameter (from point C to D) (Figure 1).
3. **Area of the foramen spinosum:** It was calculated using the measured length and breadth according to the following formula:
   Area (A) = $(\pi \times L \times B) / 4$
   where L represents the maximum anteroposterior diameter, and B represents the maximum transverse diameter of the foramen.
4. **Distance from the Root of the Zygoma to the Foramen Spinosum (ZA–FS):** The shortest distance from the tubercle of the root of the zygoma (ZA) to the centre of the foramen spinosum (FS) (from point E to F) (Figure 2).
5. **Distance from the Midline of the Skull Base to the Foramen Spinosum (Mid–FS):** The shortest distance from the centre of the foramen spinosum to the midsagittal plane (midline) of the cranial base (from point F to G) (Figure 2).
6. **Distance between the Foramen Ovale and the Foramen Spinosum (FO–FS):** The shortest distance from the centre of the foramen ovale (FO) to the centre of the foramen spinosum (FS) (from point H to I) (Figure 2).
7. **Distance between the Carotid Canal and the Foramen Spinosum (CC–FS):** The shortest distance from the centre of the carotid canal (CC) to the centre of the foramen spinosum (FS) (from point I to J) (Figure 2).

The morphometric parameters assessed in the present study are illustrated in Figure 1.

Measurement Technique
All morphometric measurements were obtained directly on the dry skulls using a screw-adjusted compass and a precision Vernier calliper under adequate illumination. The screw-adjusted compass was used to determine the shortest distances between the selected anatomical landmarks, and the measured span was subsequently transferred to the Vernier calliper for recording in millimetres. The maximum anteroposterior and transverse diameters of the foramen spinosum were measured directly using the Vernier calliper.

To enhance the precision and reproducibility of the observations, each measurement was performed three times by the same investigator following a standardised measurement protocol. The average of the three readings was used as the final value for statistical analysis, thereby minimising intra-observer variability and improving measurement accuracy.

Data Collection: A structured proforma was prepared before the commencement of the study to ensure uniform recording of all observations. For each skull, the morphology of the foramen spinosum, the presence or absence of anatomical variations, and bilateral morphometric measurements were documented systematically. The collected data were subsequently verified for completeness and accuracy before statistical analysis.

Statistical Analysis: Data were analysed using GraphPad Prism (Version 10.0). Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. The normality of continuous data was assessed using the Shapiro–Wilk test. Comparisons between the right and left sides for morphometric parameters were performed using the paired Student's t-test. The distribution of morphological variants between the two sides was analysed using the Chi-square test. A p-value of <0.05 was considered statistically significant.

Figure 1. Morphometric measurements of the foramen spinosum. AB: Maximum anteroposterior diameter (length); CD: Maximum transverse diameter (width).

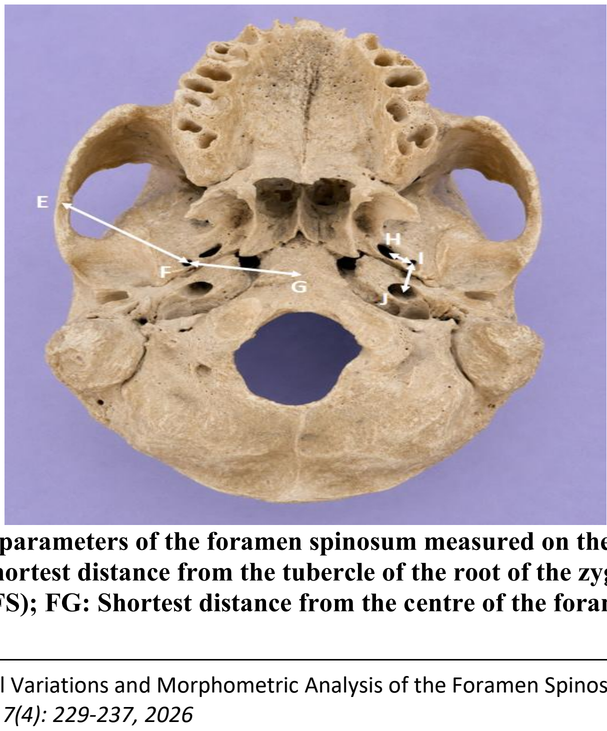

Figure 2: Morphometric parameters of the foramen spinosum measured on the external surface of a dry adult human skull. EF: Shortest distance from the tubercle of the root of the zygoma (ZA) to the centre of the foramen spinosum (FS); FG: Shortest distance from the centre of the foramen spinosum (FS) to the

midline of the cranial base (Mid); HI: Shortest distance from the centre of the foramen ovale (FO) to the centre of the foramen spinosum (FS); IJ: Shortest distance from the centre of the carotid canal (CC) to the centre of the foramen spinosum (FS).

RESULTS:

The morphological assessment of 100 foramina spinosa obtained from 50 dry adult human skulls revealed that the round shape was the predominant morphological variant, accounting for 52 (52.0%) foramina. The oval shape was the second most common configuration, observed in 38 (38.0%) foramina. Pinhole and irregular shapes were identified in 6 (6.0%) and 4 (4.0%) foramina, respectively. On the right side, the round shape was observed in 27 (27.0%) foramina, followed by the oval shape in 18 (18.0%), pinhole shape in 3 (3.0%), and irregular shape in 2 (2.0%) foramina. Similarly, on the left side, the round shape was present in 25 (25.0%) foramina, followed by the oval shape in 20 (20.0%), pinhole shape in 3 (3.0%), and irregular shape in 2 (2.0%) foramina. Statistical analysis demonstrated no significant difference in the distribution of the morphological patterns between the right and left sides ($\chi^2 = 0.61$, $p = 0.894$) (Table 1 and Figure 3).

The morphometric measurements of the foramen spinosum are presented in Table 2 and Figure 4. The mean anteroposterior diameter (length) measured 3.98 ± 0.71 mm on the right side and 3.76 ± 0.81 mm on the left side. The mean transverse diameter (width) was 2.43 ± 0.32 mm on the right side and 2.53 ± 0.62 mm on the left side. The calculated mean area of the foramen spinosum was 7.68 ± 2.31 mm^2 on the right side and 7.54 ± 2.46 mm^2 on the left side.

The mean shortest distance from the tubercle of the root of the zygoma to the centre of the foramen spinosum (ZA–FS) measured 36.82 ± 2.48 mm on the right side and 37.14 ± 2.63 mm on the left side. The mean distance from the centre of the foramen spinosum to the midline of the cranial base (Mid–FS) was 28.12 ± 1.78 mm on the right side and 28.39 ± 1.65 mm on the left side. Similarly, the mean distance between the centre of the foramen ovale and the centre of the foramen spinosum (FO–FS) measured 3.82 ± 0.76 mm on the right side and 3.69 ± 0.82 mm on the left side, whereas the mean distance between the centre of the carotid canal and the centre of the foramen spinosum (CC–FS) was 9.74 ± 1.46 mm on the right side and 9.52 ± 1.41 mm on the left side.

Statistical comparison of the morphometric parameters between the right and left sides demonstrated no statistically significant bilateral differences in the anteroposterior diameter ($p = 0.152$), transverse diameter ($p = 0.314$), area ($p = 0.770$), ZA–FS distance ($p = 0.533$), Mid–FS distance ($p = 0.433$), FO–FS distance ($p = 0.413$), or CC–FS distance ($p = 0.445$), indicating comparable morphometric characteristics of the foramen spinosum on both sides.

Table 1. Distribution of the Shape of the Foramen Spinosum in Adult Human Skulls

Shape of the Foramen Spinosum	Right Side n (%)	Left Side n (%)	Total n (%)	Chi-square value (χ^2)	p-value
Round	27 (27.0%)	25 (25.0%)	52 (52.0%)	0.61	0.894
Oval	18 (18.0%)	20 (20.0%)	38 (38.0%)		
Pinhole	3 (3.0%)	3 (3.0%)	6 (6.0%)		
Irregular	2 (2.0%)	2 (2.0%)	4 (4.0%)		
Total	50 (50.0%)	50 (50.0%)	100 (100%)	-	-

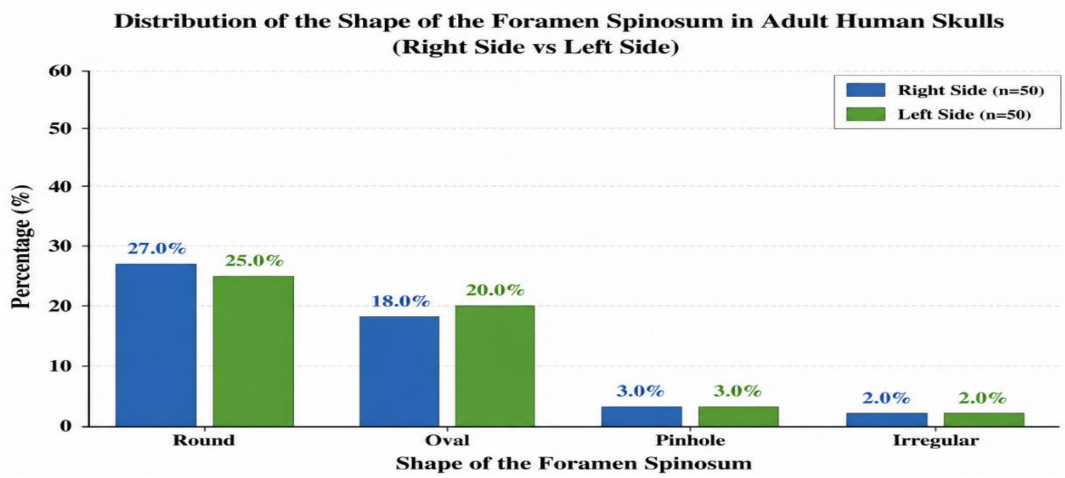

Figure 4. Bar diagram showing the distribution of morphological shapes of the foramen spinosum on the right and left sides.

Table 2. Morphometric Measurements of the Foramen Spinosum in Adult Human Skulls

Morphometric Parameters	Right Side (Mean ± SD)	Left Side (Mean ± SD)	p-value
Anteroposterior Diameter (Length)	3.98 ± 0.71	3.76 ± 0.81	0.152
Transverse Diameter (Width)	2.43 ± 0.32	2.53 ± 0.62	0.314
Area (mm²)	7.68 ± 2.31	7.54 ± 2.46	0.770
ZA–FS Distance (mm)	36.82 ± 2.48	37.14 ± 2.63	0.533
Mid–FS Distance (mm)	28.12 ± 1.78	28.39 ± 1.65	0.433
FO–FS Distance (mm)	3.82 ± 0.76	3.69 ± 0.82	0.413
CC–FS Distance (mm)	9.74 ± 1.46	9.52 ± 1.41	0.445

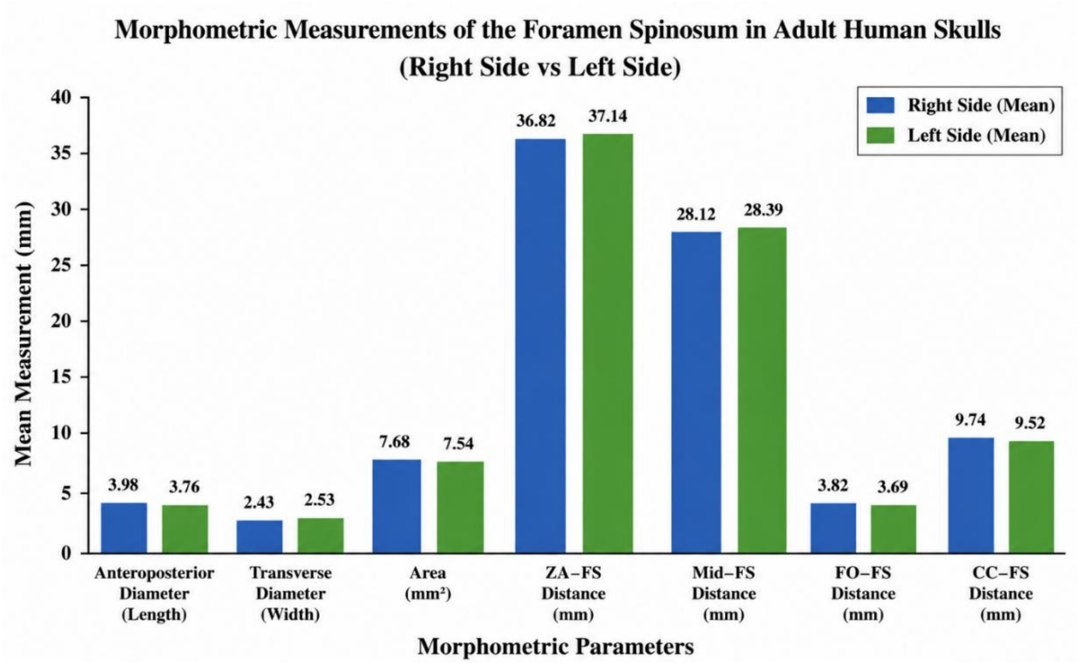

Figure 4: Comparison of the mean morphometric measurements of the foramen spinosum between the right and left sides in adult human skulls.

DISCUSSION:

The foramen spinosum is an important anatomical opening located in the greater wing of the sphenoid bone, posterolateral to the foramen ovale. It transmits the middle meningeal artery, middle meningeal vein, and the meningeal branch of the mandibular nerve (nervus spinosus), thereby establishing communication between the infratemporal fossa and the middle cranial fossa [13-15]. Owing to its intimate relationship with these vital neurovascular structures, the foramen spinosum serves as a reliable surgical landmark during skull base procedures and plays an important role in the radiological interpretation of the middle cranial fossa. Variations in its morphology or dimensions may influence surgical orientation, increase the risk of vascular injury during neurosurgical interventions, and complicate the interpretation of computed tomography (CT) and magnetic resonance imaging (MRI).

In the present study, the foramen spinosum was identified bilaterally in all examined skulls, with no evidence of congenital absence, duplication, accessory foramina, or incomplete formation. This observation is in agreement with previous studies that reported the presence of the foramen spinosum in 98.5–99.6% of specimens [11,16,17]. The complete presence observed in the present study further supports the anatomical constancy of the foramen spinosum in the Indian population. Lindblom [16] suggested that congenital absence of the foramen spinosum is usually associated with an anomalous origin of the middle meningeal artery from the ophthalmic artery, resulting in its entry into the cranial cavity through the superior orbital fissure rather than the foramen spinosum. Similarly, duplication of the foramen has been attributed to early bifurcation of the middle meningeal artery before entering the cranial cavity [16]. Although none of these variations was encountered in the present study, awareness of such anomalies is essential during skull base surgery, middle meningeal artery embolisation, and endovascular procedures, where unexpected vascular anatomy may increase the risk of intraoperative complications.

Morphological analysis demonstrated that the round shape was the predominant configuration (52.0%), followed by the oval shape (38.0%), while pinhole (6.0%) and irregular (4.0%) configurations were comparatively uncommon. No statistically significant bilateral difference was observed in the distribution of morphological patterns. These findings differ from those of Wood-Jones [18], who reported partial or complete closure of the foramen spinosum in a considerable proportion of skulls, whereas all foramina in the present study were patent. Our observations are comparable with those of Osunwoke et al. [19], who also reported round and oval configurations as the predominant morphological patterns, although triangular foramina described in their study were not observed in the present series. The predominance of regular round and oval foramina suggests relatively uniform ossification of the sphenoid bone and provides a dependable anatomical landmark during extradural surgical approaches. From a radiological perspective, familiarity with these normal morphological patterns helps differentiate anatomical variations from pathological enlargement, erosion, or destruction caused by skull base tumours, meningiomas, metastatic lesions, or neurofibromatosis.

The morphometric evaluation revealed a mean anteroposterior diameter of 3.98 ± 0.71 mm on the right side and 3.76 ± 0.81 mm on the left side, while the mean transverse diameter measured 2.43 ± 0.32 mm and 2.53 ± 0.62 mm, respectively. The calculated mean area of the foramen spinosum was 7.68 ± 2.31 mm^2 on the right and 7.54 ± 2.46 mm^2 on the left. None of these parameters demonstrated statistically significant bilateral differences. Lang et al. [11] reported smaller average dimensions in adult skulls, whereas Osunwoke et al. [19] documented transverse diameters ranging between 1 and 2 mm. The comparatively larger dimensions observed in the present study may reflect population-specific characteristics, differences in measurement techniques, or variations in sample composition. The absence of significant bilateral asymmetry indicates a high degree of anatomical symmetry, which is advantageous during image-guided neurosurgical procedures because surgeons may expect relatively similar anatomical relationships on both sides of the skull base.

A recent morphometric study conducted in a South Indian population by Tewari et al. [20] demonstrated findings that closely resemble those of the present study. They reported round (55.56%) and oval (33.33%) shapes as the predominant morphological patterns, with no statistically significant bilateral differences in any morphometric parameter. Although the present study demonstrated slightly larger anteroposterior diameter, transverse diameter, and calculated area than those reported by Tewari et al. [20], the distances from the root of the zygoma, midline of the cranial base, foramen ovale, and carotid canal were remarkably similar. These findings suggest that while minor morphometric differences may exist among regional Indian populations, the overall topographical position and anatomical relationships of the foramen spinosum remain highly consistent. Such consistency strengthens the reliability of the foramen spinosum as an intraoperative landmark during skull base surgery.

In addition to measuring the dimensions of the foramen itself, the present study evaluated its relationship with important neighbouring anatomical landmarks. The mean distance from the root of the zygoma to the centre of the foramen spinosum measured 36.82 ± 2.48 mm on the right side and 37.14 ± 2.63 mm on the left side. The distance from the midline of the cranial base measured 28.12 ± 1.78 mm and 28.39 ± 1.65 mm, respectively, while the distance between the foramen ovale and the foramen spinosum measured 3.82 ± 0.76 mm on the right and 3.69 ± 0.82 mm on the left. The corresponding distance from the carotid canal measured 9.74 ± 1.46 mm on the right and 9.52 ± 1.41 mm on the left. None of these measurements demonstrated statistically significant bilateral differences. These morphometric relationships are of considerable clinical importance because they provide reliable anatomical reference points during surgical exposure of the middle cranial fossa, percutaneous approaches to the foramen ovale, extradural dissection, and microsurgical identification of the middle meningeal artery. Furthermore, knowledge of these distances assists neuroradiologists in accurately identifying the foramen spinosum and differentiating it from adjacent foramina during CT and MRI evaluation of skull base pathology.

Yanagi [21] demonstrated that the foramen spinosum attains a well-defined circular configuration during early childhood as ossification of the sphenoid bone progresses, with the majority of adult specimens exhibiting a round morphology. This developmental pattern closely corresponds with the present findings, in which the round shape was the predominant configuration. The predominance of the round morphology probably reflects normal postnatal maturation of the alisphenoid component of the sphenoid bone. From a clinical perspective, a well-developed circular foramen provides an unobstructed passage for the middle meningeal vessels and facilitates easier identification during neurosurgical procedures involving the middle cranial fossa.

The present study provides baseline morphometric and morphological data on the foramen spinosum in adult skulls from Bihar, Eastern India. The constant presence of the foramen, predominance of round morphology, absence of significant bilateral asymmetry, and consistent relationships with adjacent anatomical landmarks highlight its reliability as an anatomical landmark. These findings have important implications for neurosurgeons performing skull base procedures, management of extradural haematomas, microsurgical approaches to the middle cranial fossa, and endovascular interventions involving the middle meningeal artery. They also provide useful reference data for neuroradiologists interpreting skull base imaging and for anatomists and forensic experts involved in osteological identification. Further multicentric studies using larger sample sizes and three-dimensional imaging techniques would enhance the understanding of population-specific anatomical variations and further improve the clinical applicability of these findings.

Limitations of the study: The present study was conducted on a limited number of dry adult human skulls obtained from a single institution, and the age and sex of the specimens were not available. Consequently, sex- and age-related variations could not be evaluated. In addition, the study was based on osteological specimens and did not include radiological or cadaveric correlation, which may provide further insight into the relationship of the foramen spinosum with adjacent neurovascular structures. Nevertheless, the study provides valuable baseline morphometric and morphological data for the Eastern Indian population. Future multicentric studies involving larger sample sizes, advanced three-dimensional imaging techniques, and demographic stratification are recommended to validate and expand these findings.

CONCLUSIONS:

The present study demonstrates that the foramen spinosum is a constant anatomical structure in the studied Eastern Indian population, with the round shape being the predominant morphological variant. No significant bilateral differences were observed in its morphology or morphometric parameters, indicating symmetrical anatomical characteristics. These findings provide valuable baseline anatomical data that may aid neurosurgeons, neuroradiologists, and anatomists in skull base surgery, radiological interpretation, and related clinical procedures. Further studies involving larger and more diverse populations are recommended to validate these observations.

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