



Original Article

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

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ABSTRACT

Background: The foramen spinosum (FS), located in the greater wing of the sphenoid bone, is a clinically significant structure in the middle cranial fossa. It transmits the middle meningeal artery and vein, the meningeal branch of the mandibular nerve, and the nervus spinosus. Morphological and morphometric variations of the FS have important implications in neurosurgery, neuroradiology, and skull base approaches. This study aimed to evaluate the morphology and morphometric dimensions of the FS in adult human skulls.

Materials and Methods: A descriptive cross-sectional osteological study was conducted on 60 dry adult human skulls (120 foramina) from the departmental repository of Bhagwan Mahavir Institute of Medical Sciences, Pawapuri, Bihar. The shape of the FS was categorised as round, oval, pinhole, or irregular. Anteroposterior diameter (length) and transverse diameter (width) were measured bilaterally using a digital Vernier calliper (accuracy 0.1 mm). Data were analysed using descriptive statistics and paired Student's t-test, with $p < 0.05$ considered statistically significant.

Results: The most common shape was round (55.01%), followed by oval (34.16%), irregular (6.66%), and pinhole (4.17%). No significant side-to-side difference was observed in shape distribution ($\chi^2 = 0.48$, $p = 0.923$). The mean anteroposterior diameter was 3.98 ± 0.71 mm on the right and 3.76 ± 0.81 mm on the left ($p = 0.268$). The mean transverse diameter was 2.43 ± 0.32 mm on the right and 2.53 ± 0.62 mm on the left ($p = 0.432$).

Conclusion: The foramen spinosum exhibits predominantly round and oval shapes with no significant bilateral asymmetry in morphology or dimensions. These baseline anatomical data may assist neurosurgeons and radiologists in planning safe surgical interventions and interpreting imaging studies of the skull base.

Keywords: Foramen spinosum, Middle meningeal artery, Dry skull, Sphenoid bone, Morphometry.

INTRODUCTION

The sphenoid bone occupies a central position within the cranial base and contributes significantly to the formation of the middle cranial fossa. The greater wing of the sphenoid contains several important foramina that transmit critical neurovascular structures connecting the intracranial and extracranial compartments [1]. These foramina are predominantly located on the floor of the middle cranial fossa and serve as essential anatomical landmarks for neurosurgeons, radiologists, and anatomists. Variations in the morphology, size, shape, and position of these foramina have been widely reported in anatomical and radiological studies. Such variations are important not only for understanding the complex neurovascular anatomy of the cranial base but also for differentiating normal anatomical variants from pathological conditions during diagnostic imaging and surgical interventions [2,3]. Among these openings, the foramen spinosum (FS) is a small but clinically significant foramen 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, and the nervus spinosus

[1]. Through these neurovascular structures, the foramen spinosum establishes communication between the middle cranial fossa and the infratemporal fossa [4,5]. Owing to its strategic anatomical location and relationship with vital neurovascular structures, the FS serves as an important landmark in skull base anatomy and neurosurgical procedures. The foramen spinosum primarily transmits the middle meningeal artery, the nervus spinosus, and occasionally the posterior trunk of the middle meningeal sinus. Anatomical variations in the origin and course of the middle meningeal artery may influence the morphology and even the presence of the foramen. In some cases, the middle meningeal artery may arise from the ophthalmic artery rather than the maxillary artery and enter the cranial cavity through the superior orbital fissure, resulting in the absence of the foramen spinosum. Similarly, duplication of the foramen spinosum may occur due to an early bifurcation of the middle meningeal artery before its entry into the cranial cavity [6,7,8]. Such variations have important implications during radiological interpretation and surgical approaches involving the middle cranial fossa. The foramen spinosum is regarded as a valuable surgical landmark during microsurgical procedures involving the middle cranial fossa. It assists in identifying the course of the middle meningeal artery and is particularly useful when the artery is employed as a donor vessel for extracranial–intracranial bypass procedures involving the internal carotid or posterior cerebral arteries [9,10]. Accurate knowledge of its morphology and morphometric dimensions is therefore essential for minimising intraoperative complications and improving surgical outcomes. Furthermore, detailed anatomical understanding of the FS is beneficial in neuroradiological evaluation, skull base surgeries, and forensic investigations. Developmentally, the sphenoid bone is unique because it arises from both intramembranous and endochondral ossification centres. The greater wing of the sphenoid, also known as the alisphenoid, begins ossification during the eighth week of intrauterine life through membranous ossification and represents one of the eight ossification centres of the postsphenoid region. The foramen spinosum becomes identifiable approximately eight months after birth and continues to develop until around seven years of age. Postnatal developmental changes affecting the foramen spinosum have been described by Lang et al. [11]. The complex developmental pattern of the sphenoid bone may explain the occurrence of asymmetry in the shape and dimensions of the foramen spinosum, as well as the presence of accessory bony projections and other morphological variations affecting its margins. Previous studies have demonstrated considerable variability in the morphology and morphometric characteristics of the foramen spinosum across different populations. Knowledge of these variations is increasingly important in the era of advanced imaging techniques and minimally invasive skull base surgeries. Detailed morphometric data can provide valuable guidance for neurosurgeons, radiologists, and anatomists, helping to reduce procedural risks and improve diagnostic accuracy. Morphometric studies also contribute significantly to the practical application of surgical approaches involving the middle cranial fossa and adjacent neurovascular structures [12]. Therefore, the present study was undertaken to evaluate the morphology, 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 be useful for clinical, surgical, radiological, and anthropological purposes.

MATERIAL AND METHODS

Study Design and Setting: The present descriptive cross-sectional osteological study was conducted in the Department of Anatomy, Bhagwan Mahavir Institute of Medical Sciences (BMIMS), Pawapuri, Bihar. The study was carried out on dry adult human skulls available in the departmental osteological collection, which are routinely utilised for undergraduate and postgraduate teaching, research, and demonstration purposes.

Sample Size Estimation: The minimum required sample size was estimated using G*Power software (Version 3.1.9.7, Heinrich Heine University, Düsseldorf, Germany). Considering an effect size of 0.50, an alpha error probability of 0.05, and a study power of 80%, the minimum sample size required was calculated to be 54 skulls. The effect size was derived from previous morphometric studies of the foramen spinosum. To enhance the reliability of observations and compensate for any potential exclusions due to damage or incompleteness, a total of 60 dry adult human skulls were included in the study.

Study Material: A total of 60 dry adult human skulls of unknown age and sex were examined. Each skull was carefully inspected to assess the morphology and morphometric dimensions of the foramen spinosum on both the right and left sides. Since the specimens belonged to the institutional osteological repository, no personal identifiers were associated with the samples. Ethical approval was waived because the study utilised archived osteological specimens.

Inclusion Criteria:

The following skulls were included in the study:

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

Exclusion Criteria:

- The following skulls were excluded from the study:
- Juvenile skulls with incomplete ossification.

- Senile skulls showing marked alveolar bone resorption and age-related deformities.
- Skulls exhibiting congenital anomalies or gross anatomical deformities.
- Specimens with fractures, erosions, pathological lesions, or healed traumatic defects involving the cranial base.
- Skulls with damaged, broken, or obscured foramina that could interfere with accurate measurements.

Study Parameters:

The foramen spinosum was examined bilaterally for both morphological and morphometric characteristics.

A. Morphological Parameters: The shape of the foramen spinosum was assessed visually and categorised into the following types:

- Round
- Oval
- Pinhole
- Irregular

Any accessory foramina, duplication, absence, or unusual anatomical variations were also noted whenever present.

B. Morphometric Parameters

The following linear dimensions of the foramen spinosum were measured:

- Anteroposterior Diameter (PQ) (Length): The maximum distance measured between the anterior and posterior margins of the foramen spinosum.
- Transverse Diameter (RS) (Width): The maximum distance measured perpendicular to the anteroposterior diameter between the medial and lateral margins of the foramen.

Method of Measurement

All measurements were performed directly on the dry skulls using a digital Vernier calliper with an accuracy of 0.1 mm. Each parameter was measured bilaterally under adequate illumination. To minimise observer-related variability and ensure consistency, all observations and measurements were recorded by a single investigator. The recorded values were entered into a predesigned data collection sheet for subsequent statistical analysis.

Statistical Analysis:

The collected data were entered into Microsoft Excel 2019 and analysed using GraphPad Prism software (Version 10.0). Descriptive statistics were calculated for all morphometric parameters and expressed as mean \pm standard deviation (SD), along with minimum and maximum values. The normality of the data distribution was assessed prior to inferential analysis. Comparisons between the right and left sides of the same skull were performed using the Paired Student's t-test, as the measurements represented paired observations obtained from identical specimens. A p-value of less than 0.05 was considered statistically significant. The results were presented in the form of tables and graphical representations wherever appropriate.

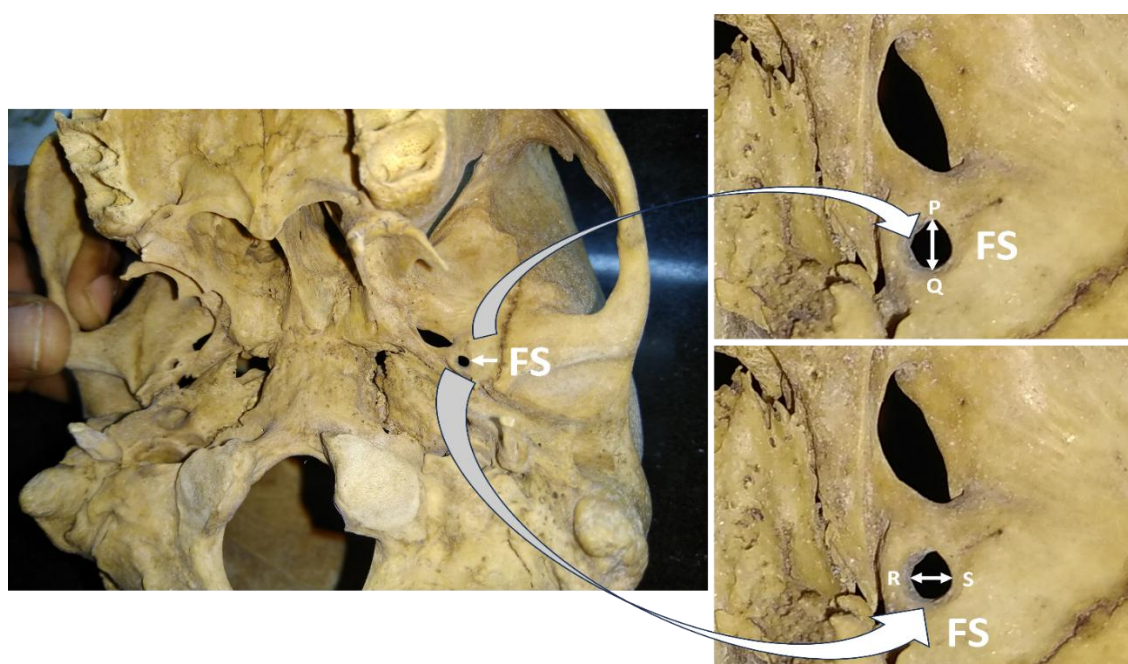


Figure 1: Showing the morphometric measurement of the foramen spinosum (FS); PQ: Anteroposterior Diameter and RS: Transverse Diameter

RESULTS

A total of 120 foramina spinosum were examined, with 60 (50%) on the right side and 60 (50%) on the left side. The round shape was the most common morphology, accounting for 66 (55.01%) foramina, followed by the oval shape in 41 (34.16%), irregular shape in 8 (6.66%), and pinhole shape in 5 (4.17%) foramina. On the right side, round, oval, pinhole, and irregular shapes were observed in 34 (28.34%), 19 (15.83%), 3 (2.50%), and 4 (3.33%) foramina, respectively. On the left side, the corresponding frequencies were 32 (26.67%), 22 (18.33%), 2 (1.67%), and 4 (3.33%). There was no statistically significant difference in the distribution of foramen spinosum shapes between the right and left sides ($\chi^2 = 0.48$, $p = 0.923$). Thus, the morphological distribution of the foramen spinosum was comparable on both sides [Table 1]. No accessory, duplicated, or absent foramen spinosum was observed.

Table 1: Showing the incidence of the different shapes of the Foramen Spinosum.

Shape of the Foramen Spinosum.	Right Side n (%)	Left Side n (%)	Total n (%)	Chi-Square value (X ²)	p-value
Round	34 (28.34%)	32 (26.67%)	66 (55.01%)	0.48	0.923
Oval	19 (15.83%)	22 (18.33%)	41 (34.16%)		
Pinhole	03 (2.50%)	02 (1.67%)	05 (4.17%)		
Irregular	04 (3.33%)	04 (3.33%)	08 (6.66%)		
Total	60 (50%)	60 (50%)	120 (100%)	--	

The mean anteroposterior diameter was 3.98 ± 0.71 mm on the right side and 3.76 ± 0.81 mm on the left side. The difference was not statistically significant ($p = 0.268$). The mean transverse diameter was 2.43 ± 0.32 mm on the right side and 2.53 ± 0.62 mm on the left side, with no statistically significant difference between the two sides ($p = 0.432$) [Table 2].

Table 2: Showing the different diameters of the Foramen Spinosum.

Diameters	Right Side (in mm) (Mean±SD)	Left Side (in mm) (Mean±SD)	p-value
Anteroposterior Diameter (Length)	3.98 ± 0.71	3.76 ± 0.81	0.268
Transverse Diameter (Width)	2.43 ± 0.32	2.53 ± 0.62	0.432

DISCUSSION

The foramen spinosum is a distinct osseous opening located in the greater wing of the sphenoid bone. It serves as a crucial conduit connecting the middle cranial fossa with the infratemporal fossa, situated posterolateral to the foramen ovale. This foramen typically transmits the middle meningeal artery, the nervus spinosus, and the middle meningeal vein [13-15]. The middle meningeal artery, being a terminal branch of the maxillary artery, enters the middle cranial fossa through this foramen and supplies a significant portion of the dura mater. Any anatomical variation in this foramen can therefore have direct clinical consequences during surgical procedures or in the event of traumatic injury. Additionally, the foramen spinosum houses the middle meningeal vein, which establishes an important venous communication between the cavernous sinus and the pterygoid venous plexus. This anatomical relationship is of particular clinical significance when interpreting radiological images of the affected region in routine clinical practice, as pathological processes involving these venous channels may manifest as abnormal findings on imaging studies.

In the present study, the foramen spinosum was observed to be present in all 60 dry adult human skulls examined (100% bilaterally). No case of congenital absence was encountered. This finding is consistent with previous reports by various authors, who documented the presence of the foramen spinosum in 99.6% [16], 99.2% [17], and 98.5% [11] of cases, respectively. The slight discrepancy between our observation of complete presence and the aforementioned studies may be attributed to population-specific variations, ethnic differences, or sampling variations. Our result of 100% presence falls on the higher end of the reported spectrum, suggesting that the foramen spinosum is an extremely consistent anatomical feature in the population studied. Lindblom [16] proposed that absence of the foramen spinosum in approximately 0.4% of cases results from an anomalous origin of the middle meningeal artery from the ophthalmic artery rather than the maxillary artery, causing the vessel to enter the cranial cavity through the superior orbital fissure instead of the foramen spinosum. In such cases, the foramen spinosum may be either hypoplastic or completely absent. In rare instances, early bifurcation of the middle meningeal artery into anterior and posterior divisions before its intracranial entry may lead to duplication of the foramen spinosum [16]. The presence of an accessory foramen spinosum, when present, can be a source of confusion during surgical exploration if the surgeon is not aware of this possibility. Although we did not observe any accessory or duplicated foramina in our sample, such rare variations warrant careful consideration during surgical planning and

radiological assessment. The absence of such variations in our study may be due to the relatively modest sample size, as these are uncommon findings in the general population.

Wood-Jones [18] reported that the foramen spinosum was partially or completely closed in approximately 44% and 16% of cases, respectively, with an open foramen observed on the right side in 84% of specimens. These figures represent a much higher incidence of foramen closure than observed in our study. Our morphological findings differ from these observations, as we encountered no completely or partially closed foramina. Instead, we classified the shape of the foramen spinosum into four distinct categories: round, oval, pinhole, and irregular. The round shape was the most common morphology, accounting for 66 (55.01%) of 120 foramina, followed by oval in 41 (34.16%), irregular in 8 (6.66%), and pinhole in 5 (4.17%). No statistically significant side-to-side difference was observed ($\chi^2 = 0.48$, $p = 0.923$). These morphological patterns are broadly comparable to those described by Osunwoke et al. [19], who observed oval, circular, and triangular shapes in a Nigerian population, although triangular morphology was not encountered in our study. The predominance of round and oval shapes in our series suggests that the vast majority of foramina spinosum possess a regular, smoothly contoured margin, which is an important observation for radiologists attempting to differentiate normal foramina from those affected by erosive pathological processes such as neurofibromatosis or metastatic disease.

Regarding the postnatal development of the foramen spinosum, Lang et al. [11] reported that the anteroposterior length measured approximately 2.25 mm in newborns and increased to 2.56 mm in adults, while the width varied from 1.05 mm to approximately 2.1 mm in adult specimens. These figures indicate a modest degree of postnatal enlargement. Our findings demonstrate larger mean dimensions, with an anteroposterior diameter of 3.98 ± 0.71 mm on the right side and 3.76 ± 0.81 mm on the left side, and a transverse diameter of 2.43 ± 0.32 mm on the right and 2.53 ± 0.62 mm on the left. These differences may reflect population-specific characteristics, methodological variations in measurement techniques (such as the use of digital Vernier callipers versus other instruments), or the fact that our study included only adult skulls with complete ossification, whereas comparative studies may have included juvenile specimens or used different landmarks for measurement. Similarly, Osunwoke et al. [19] reported a maximum length of 4.0 mm, a minimum length of 1.0 mm (with most lengths ranging between 2.0 and 2.5 mm), and a maximum width of 2.0 mm with a minimum width of 1.0 mm. Our mean values fall within the upper range of these previously reported measurements, indicating that the foramen spinosum in our study population tends toward the larger side of the normal spectrum. Additionally, Osunwoke et al. [19] noted that some foramina were partially separated into two components by bony spurs; however, we did not observe such incomplete division in our specimen set, further confirming the anatomical integrity of the foramen in our sample.

Yanagi [20] investigated the developmental timeline of the foramen rotundum, foramen ovale, and foramen spinosum, and observed that a fully circular foramen spinosum became identifiable as early as eight months after birth and continued to develop until approximately seven years of age. This extended period of postnatal development reflects the gradual ossification and maturation of the sphenoid bone, particularly the alisphenoid component. In that study, the majority of foramina examined in adult skulls were round in shape [20]. This observation aligns well with our findings, in which the round shape was the predominant morphological variant, constituting more than half (55.01%) of all foramina examined. The predominance of the round configuration likely represents the end result of normal postnatal maturation and ossification of the alisphenoid component of the sphenoid bone. The round shape is generally considered the most favourable morphology from a surgical perspective, as it typically indicates a smooth, unobstructed passage for the traversing neurovascular structures.

The present study, therefore, provides region-specific baseline data on the morphology and morphometry of the foramen spinosum in an adult Indian population. The consistent presence of the foramen in all specimens, the predominance of round and oval shapes, and the absence of significant side-to-side asymmetry in both morphological distribution and linear dimensions are the key findings. These observations may serve as useful anatomical references for neurosurgeons performing middle cranial fossa procedures such as extradural haematoma evacuation or trigeminal nerve decompression, for radiologists interpreting skull base imaging where identification of normal foramina is essential, and for anatomists and forensic experts engaged in osteological identification and comparative studies. Future research incorporating three-dimensional imaging modalities and larger, more diverse population samples would further enrich our understanding of this anatomically and clinically significant foramen.

Limitations of the Study: The limitations of this study include the unknown age and sex of the skull specimens, the single institutional source limiting generalizability, the absence of radiological correlation, and the measurement of only two linear dimensions. Observer bias and the lack of three-dimensional imaging techniques are additional constraints.

CONCLUSIONS

The present study demonstrated that the foramen spinosum exhibits notable morphological variability, with the round shape being the most prevalent form, followed by oval, irregular, and pinhole configurations. Morphometric assessment revealed mean anteroposterior and transverse diameters comparable to those reported in previous anatomical studies. No statistically significant differences were observed between the right and left sides with respect to either morphological distribution or morphometric dimensions. The findings provide important baseline anatomical data regarding the morphology and

morphometry of the foramen spinosum in the studied population. Such information is valuable for neurosurgeons, radiologists, anatomists, and forensic experts during skull base surgeries, radiological interpretation, and anatomical identification of neurovascular structures in the middle cranial fossa. Further studies incorporating larger sample sizes, radiological correlations, and population-based comparisons are recommended to enhance the understanding of anatomical variations of the foramen spinosum and their clinical significance.

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