RESEARCH PAPER

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

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ABSTRACT

Background:

The foramen ovale is an important anatomical structure in the middle cranial fossa that transmits the mandibular nerve and serves as a key landmark for several neurosurgical and interventional procedures. Variations in its morphology and dimensions may have some influence on the procedural safety and radiological interpretation.

Aim:

To evaluate the morphological and morphometric variations of the foramen ovale in dry human skulls and to assess their clinical significance.

Materials and Methods: This cross-sectional osteological study was conducted on 60 dry adult human skulls (120 sides). The foramen ovale was examined bilaterally for presence, shape, and anatomical variations such as septation, duplication, bony spurs, and bridges. Morphometric measurements, including anteroposterior diameter, transverse diameter, and calculated area, were recorded using a digital vernier calliper. Side-wise comparisons were performed, and correlations between morphometric parameters were analysed using appropriate statistical tests.

Results:

The foramen ovale was present bilaterally in all skulls. The most common shape observed was oval (56%), followed by almond (28%), round (12%), and irregular (4%). Septation was noted in 10.8% of cases, bony spurs in 15%, duplication in 5%, and bony bridges in 5%. The mean length and width of the foramen ovale were 7.60

± 0.79 mm and 5.11 ± 0.71 mm, respectively, with a mean calculated area of 30.47 ± 6.73 mm². No significant side-wise differences were observed. A positive correlation was found between morphometric parameters.
Conclusion:
The foramen ovale is consistently present, with notable morphological variability. These variations may influence percutaneous procedures involving the mandibular nerve and should be considered during surgical planning and radiological evaluation.

KEYWORDS

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Introduction

The foramen ovale is an important opening located in the greater wing of the sphenoid bone in the middle cranial fossa. It provides passage for the mandibular division of the trigeminal nerve along with accompanying vascular structures, and therefore serves as a key anatomical landmark in skull base procedures. Precise knowledge of this foramen is essential for neurosurgeons, anaesthetists, and radiologists, particularly when performing interventions that require accurate localisation of the mandibular nerve.[1]

The foramen ovale is routinely accessed during procedures such as percutaneous trigeminal rhizotomy, trigeminal nerve block, and biopsy of cavernous sinus lesions. In these settings, variations in the size or shape of the foramen may influence needle trajectory and procedural success. In addition, radiological evaluation of the skull base requires differentiation between normal anatomical variations and pathological changes involving this region.[2,3]

Previous anatomical studies have demonstrated that the foramen ovale shows considerable variability in morphology. Differences in shape, septation, duplication, and the presence of bony spurs have all been described. These variations may alter the course of the mandibular nerve and create technical difficulty during percutaneous procedures. Accessory openings, such as the foramen of Vesalius, located close to the foramen ovale, may further increase the risk of misplacement of instruments and procedural complications.[4]

Although several studies have reported morphometric measurements of the foramen ovale, the values vary across populations. Detailed evaluation of both morphological variations and morphometric dimensions is therefore important for improving anatomical understanding and procedural safety. In addition, region-specific data may help provide clinically relevant reference values.[5]

Therefore, the present study was undertaken to evaluate the morphological variations and morphometric dimensions of the foramen ovale in dry adult human skulls and to assess their clinical significance.

Methods and materials

Study Design and Setting

This cross-sectional osteological study was conducted in the Department of Anatomy of Meenakshi Medical College Hospital and Research Institute, a tertiary care teaching institution. The study was carried out from November 2024 to January 2026. The study proposal was approved by the institutional ethics committee (IEC No-MMCH & RI IEC/PG/36/NOV/24).

Study Sample

The sample size was determined based on previously published morphometric studies on the middle cranial fossa foramina,[6,7] which have utilised comparable sample sizes to ensure adequate precision in anatomical assessment. Based on these studies on the middle cranial fossa foramina, an SD of approximately 1.5 mm was considered for the principal dimension of the foramen ovale. With a 95% confidence level and an allowable error of 0.4 mm, the minimum sample size was calculated to be 54 skulls. To enhance statistical reliability and account for the potential exclusion of damaged specimens, 60 dry adult human skulls were included in the present study.

Inclusion and Exclusion Criteria

Intact dry adult human skulls with a clearly identifiable middle cranial fossa and well-preserved foramen ovale were included in the study. Specimens showing distortion of the foramen ovale or adjacent anatomical landmarks were not considered. Skulls that were damaged or fractured in the middle cranial fossa region, those with gross deformities or pathological changes, and specimens with poorly defined or indistinct foramen ovale or foramen of Vesalius were excluded from the analysis**.**

Methodology

Each skull was examined bilaterally, yielding a total of 120 sides. The foramen ovale was identified on both sides and assessed for morphological variations, including shape, septation, duplication, bony spurs, and bony bridges. The shape of the foramen ovale was categorized as oval, round, almond, or irregular based on visual assessment. Morphometric measurements of the foramen ovale were obtained using a digital vernier calliper with an accuracy of 0.01 mm. The anteroposterior diameter (length) and transverse diameter (width) of the foramen ovale were measured. The area of the foramen ovale was calculated using the formula $\pi \times \text{length} \times \text{width} / 4$. In addition, the distance of the foramen ovale from the midline and from the petrous apex was measured to assess its anatomical location.

The presence of the foramen of Vesalius was also noted whenever observed. The foramen of Vesalius, when present, was identified anteromedially to the foramen ovale and recorded for its presence. Its occurrence was documented in relation to the foramen ovale due to its potential clinical relevance during percutaneous approaches.

All measurements were recorded twice, and the mean values were used for analysis to reduce observational error.

The measurements obtained for the foramen ovale were analysed to determine morphological variations and morphometric dimensions. Side-wise comparison between the right and left foramina was performed. The relationship between length, width, and calculated area of the foramen ovale was also assessed. The presence of the foramen of Vesalius was recorded as a frequency.

Statistical Analysis:

Data were entered into Microsoft Excel and analysed using SPSS version XX. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequency and percentage. Side-by-side comparisons were performed using a paired t-test. Correlation between morphometric parameters of the foramen ovale was assessed using the Pearson correlation coefficient. A p-value < 0.05 was considered statistically significant.

Reliability Assessment

To assess measurement reliability, morphometric parameters of the foramen ovale were re-measured in a subset of 15 skulls after a one-week interval. Intra-observer agreement was evaluated using the intraclass correlation coefficient (ICC). The ICC value was 0.92, indicating excellent measurement reliability. Agreement for the classification of foramen ovale shape was assessed using Cohen's kappa coefficient, which showed substantial agreement ($\kappa = 0.86$).

Results:

A total of 60 dry adult human skulls were examined, yielding 120 sides for analysis. The foramen ovale was identified bilaterally in all specimens. The foramen of Vesalius was observed in 30 of the 120 sides, corresponding to a frequency of 25%.

The shape of the foramen ovale showed variability among specimens. The oval configuration was the most frequent, followed by almond, round, and irregular shapes. The distribution of these morphological patterns is presented in Table 1.

Structural variations of the foramen ovale were also noted. Bony spurs were the most commonly encountered variation, followed by septation. Duplication and bony bridges were less frequent findings. A representative specimen demonstrating septation of the foramen ovale is shown in Figure 3, and the overall distribution of anatomical variations is summarised in Table 2.

Morphometric measurements of the foramen ovale showed a mean length of 7.60 ± 0.79 mm and a mean width of 5.11 ± 0.71 mm. The calculated mean area was 30.47 ± 6.73 mm^2. These measurements are detailed in Table 3.

Table 1: Shape distribution of the foramen ovale

Shape	Number (n=120)	Percentage (%)
Oval	**67**	**56%**
Almond	**34**	**28%**
Round	**14**	**12%**
Irregular	**5**	**4%**

Table 2: Anatomical variations of the foramen ovale

Variation	Number (n=120)	Percentage (%)
Septation	13	10.8%
Duplication	6	5%
Spur/Tubercle	18	15%
Bony bridge	6	5%

Table 3: Morphometric parameters of foramen ovale

Parameter	Mean ± SD
FO Length (mm)	7.60 ± 0.79
FO Width (mm)	5.11 ± 0.71
FO Area (mm²)	30.47 ± 6.73

Comparison between the right and left sides showed similar values for all morphometric parameters. No statistically significant side-wise difference was observed for length, width, or calculated area of the foramen ovale ($p > 0.05$). The side-wise comparison is presented in Table 4, and the distribution of foramen ovale length between sides is illustrated in Figure 1.

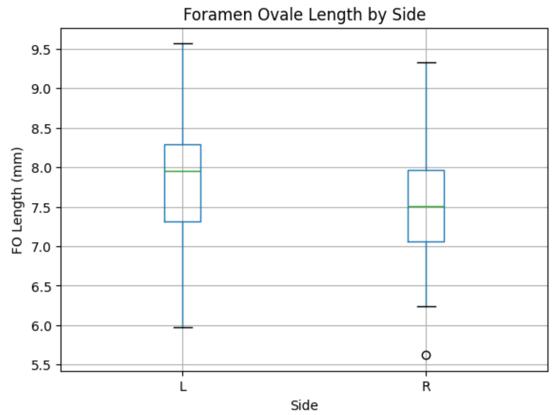

Figure 1:Box plot showing comparison of foramen ovale length between right and left sides.

Table 4: Side-wise comparison of foramen ovale morphometric parameters

Parameter	Mean Difference (R–L)	95% Confidence Interval	p-value
FO Length (mm)	0.12	−0.18 to 0.42	0.41
FO Width (mm)	0.03	−0.21 to 0.27	0.43
FO Area (mm²)	0.34	−1.05 to 1.73	0.36

Paired t-test; $p < 0.05$ considered statistically significant

Correlation analysis demonstrated a positive relationship between the morphometric parameters of the foramen ovale. The strongest correlation was observed between length and area, followed by width and area. A moderate correlation was noted between length and width. These findings are summarised in Table 5, and the relationship between length and area is shown in Figure 2.

Table 5: Correlation between morphometric parameters of foramen ovale

Variables	Correlation Coefficient (r)	p-value
FO Length vs FO Width	0.52	<0.05
FO Length vs FO Area	0.78	<0.001
FO Width vs FO Area	0.72	<0.001

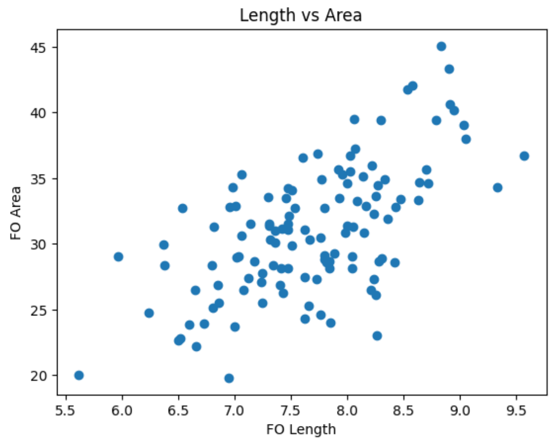

Figure 2: Scatter plot demonstrating a positive correlation between foramen ovale length and area, indicating proportional enlargement of the foramen with increasing dimensions.

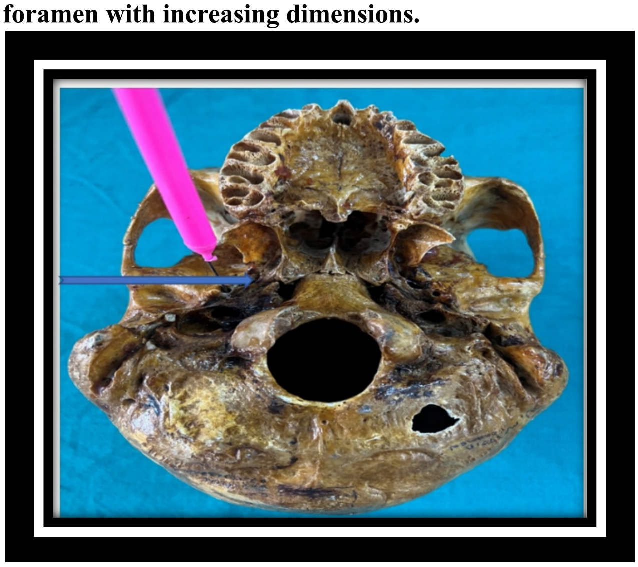

Figure 3: Photograph of the cranial base showing septation of the foramen ovale (blue arrow), dividing it into two compartments. The foramen spinosum is indicated by the probe. This variation may have implications for percutaneous procedures targeting the mandibular nerve.

DISCUSSION

The present study examined the shape variations and morphometric measurements of the Foramen ovale in dry adult human skulls. The foramen ovale was consistently present in all specimens, while the foramen of Vesalius showed variable occurrence. This variability in the location of accessory foramina near the foramen ovale has been previously described. It is clinically relevant because of the potential for misdirected needle placement during percutaneous procedures. The proximity of the foramen of Vesalius to the foramen ovale may lead to inadvertent cannulation, particularly during trigeminal nerve interventions, and therefore awareness of its occurrence is important during skull base procedures.[8,9]

In the present study, the foramen ovale demonstrated variation in shape, with the oval configuration being the most common, followed by almond, round, and irregular forms (Table 1). Similar observations have been reported in earlier anatomical studies, where the oval shape predominates in more than half of the specimens. Variations in shape are thought to arise from differences in ossification of the sphenoid bone and surrounding ligaments during development. These morphological differences may influence the orientation of instruments during percutaneous access and may partly explain technical difficulty encountered in some procedures.[10,11]

Structural variations of the foramen ovale were also observed, including septation, duplication, bony spurs, and bony bridges (Table 2). Septation of the foramen ovale has been attributed to ossification of the pterygospinous or pterygoalar ligaments, which may divide the foramen into separate compartments. Such variations may alter the course of the mandibular nerve or restrict passage of instruments. A representative example of septation is shown in Figure 3. Similar findings have been documented in previous morphometric analyses, which emphasize the importance of recognizing these variations during trigeminal nerve block and related procedures.[12]

The morphometric measurements obtained in the present study showed a mean length of 7.60 mm and mean width of 5.11 mm for the foramen ovale (Table 3). These values fall within the range reported in earlier studies, where the length has generally been described between 6 and 8 mm and width between 3 and 5 mm. Minor differences in morphometric values may reflect population-based variation, measurement techniques, or sample size. Nevertheless, the overall similarity suggests that the morphometric characteristics of the foramen ovale remain relatively consistent across populations.[13,14,15]

Side-wise comparison did not reveal any significant difference between the right and left foramina (Table 4). The distribution of measurements on both sides also appeared comparable, as illustrated in Figure 1. Symmetry of the foramen ovale has been reported in previous anatomical studies, which have noted minimal lateral variation in cranial base foramina. This bilateral similarity may be useful when planning procedures that rely on contralateral anatomical reference points.[16] The relatively consistent position of the foramen ovale also supports its use as a reliable anatomical landmark during skull base procedures.[17]

Correlation analysis demonstrated a positive relationship between length, width, and calculated area of the foramen ovale (Table 5). The strongest association was observed between length and area, followed by width and area, while a moderate correlation existed between length and width. These findings suggest that a proportional increase in overall size generally accompanies enlargement of one dimension. The relationship between length and area is illustrated in Figure 2. Comparable correlations have been reported previously and may be useful for estimating overall foramen size from limited radiological measurements.[18]

The anatomical variations observed in this study have practical implications for clinical procedures involving the foramen ovale. Variations such as septation, duplication, and bony spurs may alter needle trajectory or restrict entry into the foramen. In addition, the presence of accessory foramina such as the foramen of Vesalius may increase the risk of vascular injury or intracranial penetration if mistaken for the foramen ovale. These factors highlight the importance of detailed anatomical knowledge when performing percutaneous trigeminal procedures and interpreting skull base imaging.[19]

The present findings provide morphometric reference values and highlight the range of anatomical variations of the foramen ovale. The consistent presence of the foramen, with measurable variability in size and shape, underscores the need for careful anatomical consideration during skull-base interventions.

Conclusion:

The present study demonstrates a consistent presence of the foramen ovale, with notable morphological variability. Despite symmetrical morphometric parameters, variations such as septation, duplication, and accessory foramina are clinically significant. These findings underscore the importance of precise anatomical knowledge for safer neurosurgical interventions, accurate radiological interpretation, and improved procedural outcomes.

Aknowledgement: NIL

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