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Morphometric Characterization of the Foramen Lacerum and Its Relationships with Adjacent Skull Base Structures

Foramen Lacerum'un Morfometrik Özellikleri ve Komşu Kafa Tabanı Yapılarıyla İlişkileri

Hilal GÖREN[1]
0000-0002-3408-0155
Nilgün Tuncel ÇİNİ[1]
0000-0003-1412-2634
Serdar BABACAN[2]
0000-0002-7410-7738
Semahat DOĞRU YUVARLAKBAŞ[3]
0000-0003-4069-1806

[1]Department of Anatomy, Faculty of Medicine, Bilecik Şeyh Edebali University, Bilecik, Türkiye
[2]Department of Anatomy, Faculty of Medicine, Bursa Uludağ University, Bursa, Türkiye
[3]Department of Anatomy, Faculty of Medicine, Harran University, Şanlıurfa, Türkiye

Corresponding Author
Sorumlu Yazar
Hilal GÖREN
hilal.goren@bilecik.edu.tr

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ABSTRACT

Aim: This study aimed to characterize the morphological types of the foramen lacerum (FL), perform detailed morphometric measurements, and analyze its anatomical relationships with adjacent structures to provide reliable reference data for surgical planning.
Material and Methods: Nineteen dry human skulls obtained from Bilecik Seyh Edebali and Harran University Faculties of Medicine were evaluated. Morphometric measurements were conducted using ImageJ software based on standardized inferior-view photographs. The FL was classified into three types based on patency: normal, partially obliterated, and partially ossified. Measurements included intrinsic dimensions of the FL and linear distances from the posteromedial corner of the FL to adjacent anatomical landmarks.
Results: No completely closed FL was observed. Bilateral partial-type FL was identified in 3 skulls. Partial type was observed in 6 (31.6%) skulls on the right and 3 (15.8%) on the left; while open type was observed in 13 (68.4%) and 16 (84.2%) skulls, respectively. Significant differences in transverse diameter and surface area were found between FL types (both $p<0.001$). High positive correlations were observed between key linear measurements, particularly between the FL to the anterior (FL-FO_A) and posterior (FL-FO_P) margins of the foramen ovale, and between the FL to the anterior (FL-FS_A) and posterior (FL-FS_P) margins of the foramen spinosum.
Conclusion: This study provides a distinctive contribution by combining detailed morphometric analysis with a classification-based evaluation of the FL and its relationships with neighboring foramina. The resulting anatomical data offer valuable insights that may support safer and more precise surgical interventions at the skull base.
Keywords: Foramen lacerum; adjacent anatomical landmarks; skull base anatomy; morphometric analysis.

ÖZ

Amaç: Bu çalışmada foramen lacerumun (FL) morfolojik tiplerinin belirlenmesi, detaylı morfometrik ölçümlerinin yapılması ve komşu yapılarla anatomik ilişkilerinin analiz edilerek cerrahi planlama için güvenilir referans verisi sağlanması amaçlanmıştır.
Gereç ve Yöntemler: Bilecik Şeyh Edebali ve Harran Üniversitesi Tıp Fakültelerinden temin edilen on dokuz kuru insan kafatası değerlendirilmiştir. Morfometrik ölçümler, standardize edilmiş alt görünüm fotoğrafları üzerinden ImageJ yazılımı kullanılarak gerçekleştirilmiştir. FL, açıklık durumuna göre normal, kısmen obliterasyon ve kısmen ossifikasyon olmak üzere üç tipe ayrılmıştır. Ölçümler, FL'nin içsel boyutlarını ve FL'nin posteromedial köşesinden komşu anatomik yapılara olan doğrusal mesafeleri kapsamıştır.
Bulgular: Tamamen kapalı bir FL gözlenmemiştir. Üç kafatasında bilateral kısmi tip FL saptanmıştır. Sağda 6 (%31,6) ve solda 3 (%15,8) kafatasında kısmi tip gözlenirken, sırasıyla 13 (%68,4) ve 16 (%84,2) kafatasında açık tip gözlenmiştir. FL tipleri arasında transvers çap ve yüzey alanı açısından istatistiksel olarak anlamlı farklılıklar bulundu (her ikisi de $p<0,001$). Anahtar doğrusal ölçümler arasında, özellikle FL ile foramen ovale'nin anterior (FL-FO_A) ve posterior (FL-FO_P) kenarları arasında ve FL ile foramen spinosum'un anterior (FL-FS_A) ve posterior (FL-FS_P) kenarları arasında yüksek pozitif korelasyonlar gözlenmiştir.
Sonuç: Bu çalışma, FL'un ayrıntılı morfometrik analizini ve komşu foraminalarla ilişkilerini sınıflandırmaya dayalı bir değerlendirme ile birleştirerek özgün bir katkı sunmaktadır. Elde edilen anatomik veriler, kafa tabanında daha güvenli ve daha hassas cerrahi girişimlerin gerçekleştirilmesine katkı sağlayabilecek değerli bilgiler sunmaktadır.
Anahtar kelimeler: Foramen lacerum; komşu anatomik yapılar; kafa tabanı anatomisi; morfometrik analiz.

INTRODUCTION

The foramen lacerum (FL) is an irregular opening situated at the central skull base (1,2). Although referred to as a foramen, it does not form a true bony canal; instead, its inferior part becomes filled with fibrocartilaginous tissue after birth, while the internal carotid artery (ICA) courses above its superior surface (3-5). The FL is closely related to important neurovascular structures, including the Vidian nerve, emissary veins linking the pterygoid venous plexus to the cavernous sinus, and the sympathetic plexus surrounding the ICA (6-10). Accurate knowledge of the anatomical relationships among the FL, foramen ovale, foramen spinosum, carotid canal, and basion is crucial for enhancing surgical safety. These structures are located near vital vessels, including the ICA, which passes through the carotid canal adjacent to the FL, and the middle meningeal artery, which passes through the foramen spinosum (11,12). Accidental injury to these vessels during surgical procedures may result in severe hemorrhagic or ischemic complications. The basion, positioned at the anterior margin of the foramen magnum, also serves as a key reference point in midline cranial base surgeries (13,14). Considering these intricate anatomical relationships, variations in the patency of the FL can significantly influence surgical access and alter regional anatomy. These variations-classified as fully open, partially open, or completely closed types-may also increase the risk of intraoperative complications, particularly during skull base procedures (1). Therefore, detailed morphometric assessment of the FL and its adjacent structures is essential to support safer surgical planning and improve intraoperative navigation. Despite its well-recognized clinical significance, detailed morphometric studies delineating the dimensional characteristics of the FL and its spatial relationships with adjacent anatomical structures, such as the foramen ovale, foramen spinosum, and carotid canal, remain markedly limited in the current literature (7). Moreover, the correlation patterns between the FL and neighboring landmarks have yet to be comprehensively characterized. Detailed morphometric information would play a crucial role in supporting surgical navigation and improving intraoperative anatomical orientation, particularly during skull base approaches through endonasal and transcranial routes (15,16).

Therefore, the present study aimed to characterize the morphological types of the FL, perform detailed morphometric measurements, and analyze its anatomical relationships with adjacent structures to provide reliable reference data that may contribute to safer surgical approaches to the skull base.

MATERIAL AND METHODS

The study protocol was approved by the Clinical Research Ethics Committee of Harran University (date: 30.06.2025, approval no: 12/14). The study was conducted on a total of 19 dry human skulls obtained from the Departments of Anatomy at Bilecik Şeyh Edebali University Faculty of Medicine and Harran University Faculty of Medicine. Skulls exhibiting any form of deformation or damage likely to compromise measurement accuracy were excluded from the analysis. Information regarding the age and sex of the specimens was unavailable. Morphological and morphometric characteristics of the FL and its adjacent anatomical structures were systematically assessed.

Morphometric measurements of the FL and adjacent anatomical structures were performed by accessing the inferior aspect of the skulls. All measurements were conducted using ImageJ software (National Institutes of Health, Bethesda, MD, USA) based on standardized digital photographs obtained from the skull base. The measurements of all parameters were performed by the same researcher at one-week intervals to ensure intra-observer reliability, and the mean values were used for statistical analysis. Each skull was positioned securely on a flat surface to ensure standardized imaging of the cranial base. Photographs were captured from the inferior aspect using a tripod-mounted digital camera placed approximately 30 cm above the specimen under uniform lighting and perpendicular orientation. These standardized images allowed clear visualization of the anatomical landmarks, and measurements included linear distances, diameters, and area calculations of the FL and its spatial relationships with adjacent structures.

Classification of the Foramen Lacerum

Based on morphological characteristics, the FL was classified into three distinct types (1). Type I represented an FL with normal anatomical morphology. Type II was defined as a circular-shaped opening resulting from the complete obliteration of the elongated portion of the FL. Type III referred to a structural variation characterized by partial ossification of the FL, resulting in the formation of a bony bridge (Figure 1A). The classification was recorded separately for the right and left sides of each skull, depending on the anatomical preservation of the structures.

Morphometric Measurements of the Foramen Lacerum and Neighboring Structures

Morphometric evaluations were performed to assess both the intrinsic dimensions of the FL and its spatial relationships with adjacent anatomical landmarks. The parameters measured for each specimen included: anteroposterior diameter of the FL (FL-AP), the maximum linear distance between the anterior and posterior margins of the FL; transverse diameter of the FL (FL-T), the widest horizontal distance across the FL, and surface area of the FL, calculated based on the outlined perimeter using ImageJ software. In addition to the intrinsic measurements of the FL, linear distances from the posteromedial corner of the FL to surrounding foramina and landmarks were recorded as follows (Figure 1B): distance from the posteromedial corner of the FL to the anterior margin of the foramen ovale (FL-FO_A), the posterior margin of the foramen ovale (FL-FO_P), the anterior margin of the foramen spinosum (FL-FS_A), the posterior margin of the foramen spinosum (FL-FS_P), the anterior margin of the carotid canal (FL-CC_A), the posterior margin of the carotid canal (FL-CC_P), and the basion (FL-B), corresponding to the anterior margin of the clivus.

All measurements were performed bilaterally (right and left sides) where anatomical preservation allowed.

Statistical Analysis

IBM SPSS Statistics version 28.0 was used for statistical analysis of the data. The Shapiro-Wilk test was used to determine the data's normality. Descriptive statistics were

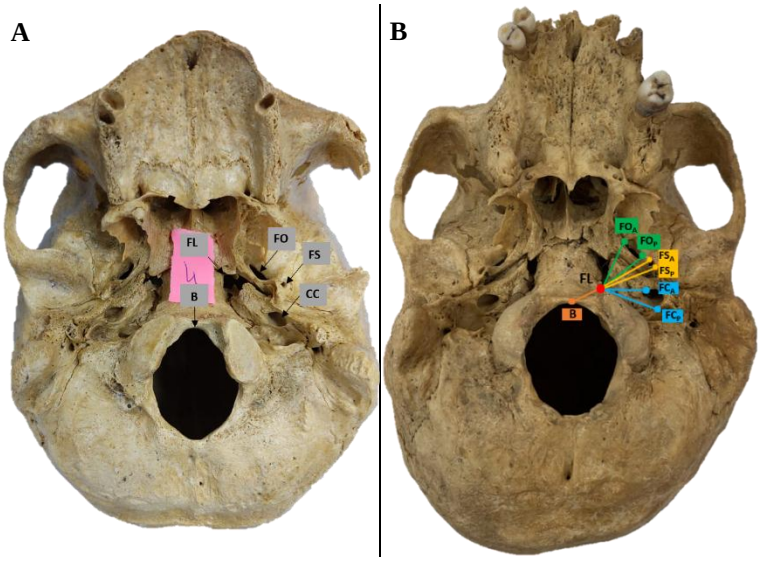


Figure 1A. Visualization of the skull base foramina and adjacent landmarks from an inferior perspective. The foramen lacerum (FL), foramen ovale (FO), foramen spinosum (FS), carotid canal (CC), and basion (B) are labeled. The right FL exhibits a partially obliterated configuration, whereas the left FL appears fully open.

Figure 1B. Inferior view of the skull base demonstrating the measurement points and linear distances recorded in the study. The posteromedial corner of the foramen lacerum (FL) served as central reference point. Linear distances were measured from the FL to the anterior and posterior margins of the foramen ovale (FO_A and FO_P, green), the anterior and posterior margins of the foramen spinosum (FS_A and FS_P, yellow), the anterior and posterior margins of the carotid canal (CC_A and CC_P, blue), and the basion (B, orange), corresponding to the anterior margin of the foramen magnum.

given as mean±standard deviation and minimum-maximum values. Student's t-test and Mann-Whitney U test were used when comparing parameters according to side (right and left) and FL morphometry (normal and partial type). Pearson's or Spearman's correlation was used to determine the correlation coefficients between variables. Statistical significance level was accepted as a p-value of 0.05.

RESULTS

According to the FL typing performed on 19 skulls (38 right and left sides), the closed type was not observed, while the opened and partial types of FL were detected. While bilateral partial type foramina were observed in 3 of the 19 bones, a unilateral opened or partial type was observed in the other skulls. When the FL types were examined according to the sides in 19 bones, 6 (31.6%) partial types and 13 (68.4%) opened types were seen on the right side. 3 (15.8%) partial types and 16 (84.2%) opened types were also seen on the left side.

When the morphometric measurements were examined according to the side, there was no statistically significant difference in any measurement between the left and right sides (Table 1). In addition, morphometric measurements of the FL were also compared according to FL types, and the results of this comparison are reported in Table 2. Accordingly, it was determined that the FL-T and FL Area measurements differed statistically significantly between the groups (both $p<0.001$). No measurement other than these two measurements showed a statistically significant difference between FL types.

A high positive correlation was found between the FL-FO_A and FL-FO_P ($r=0.760$, $p<0.001$ for right, and $r=0.844$, $p<0.001$ for left), and a moderate positive correlation between the FL-FO_A and FL-FS_A ($r=0.646$, $p=0.003$ for right, and $r=0.631$, $p=0.004$ for left) was observed. There was a moderate positive correlation between the FL-FO_A and FL-FS_P ($r=0.635$, $p=0.003$ for right, and $r=0.518$, $p=0.023$ for left). Similarly, a high positive correlation was also observed between the FL-FO_P and FL-FS_A ($r=0.911$, $p<0.001$ for right, and $r=0.845$, $p<0.001$ for left), and between the FL-FO_P and FL-FS_P ($r=0.926$, $p<0.001$ for right, $r=0.764$, $p<0.001$ for left), respectively. Another high positive correlation was seen between the FL-FS_A and FL-FS_P ($r=0.963$, $p<0.001$ for right, $r=0.952$, $p<0.001$ for left). No other high correlation was observed between other parameters.

Table 1. Comparison of the morphometric measurements of the FL and neighboring structures for the right and left sides

	Right (n=19)	Left (n=19)	Cohen's d	95% CI	p
FL-AP (mm)	7.06±2.36 [3.08-10.92]	7.14±2.31 [3.57-10.84]	-0.034	-0.670 to 0.602	0.917
FL-T (mm)	5.15±2.14 [1.29-10.07]	5.55±2.15 [1.37-9.07]	-0.190	-0.826 to 0.448	0.561
FL Area (mm^2)	33.26±13.52 [14.45-56.69]	34.17±11.12 [18.51-58.78]	-0.073	-0.709 to 0.563	0.644
FL-FO_A (mm)	16.31±2.61 [11.45-21.29]	16.22±2.85 [10.99-20.47]	0.035	-0.601 to 0.671	0.914
FL-FO_P (mm)	16.91±2.37 [12.78-22.45]	16.48±2.13 [12.29-20.57]	0.194	-0.445 to 0.830	0.555
FL-FS_A (mm)	17.34±2.30 [13.44-21.52]	17.48±1.98 [12.59-20.28]	-0.006	-0.702 to 0.570	0.839
FL-FS_P (mm)	18.26±2.25 [14.27-22.73]	17.83±1.95 [13.73-20.38]	0.206	-0.433 to 0.842	0.529
FL-CC_A (mm)	13.50±2.46 [7.59-18.78]	13.94±2.34 [9.95-19.92]	-0.183	-0.819 to 0.456	0.577
FL-CC_P (mm)	18.75±2.88 [12.16-23.43]	18.25±2.52 [12.76-23.02]	0.188	-0.451 to 0.824	0.567
FL-B (mm)	16.82±1.10 [15.16-18.57]	16.82±1.26 [13.65-19.27]	0.004	-0.632 to 0.640	0.990

FL: foramen lacerum, FL-AP: anteroposterior diameter of the FL, FL-T: transverse diameter of the FL, FL Area: surface area of the FL, FL-FO_A: distance from FL to the anterior margin of the foramen ovale, FL-FO_P: distance from FL to the posterior margin of the foramen ovale, FL-FS_A: distance from FL to the anterior margin of the foramen spinosum, FL-FS_P: distance from FL to the posterior margin of the foramen spinosum, FL-CC_A: distance from FL to the anterior margin of the carotid canal, FL-CC_P: distance from FL to the posterior margin of the carotid canal, FL-B: distance from FL to the basion, CI: confidence interval, descriptive statistics are presented as mean±standard deviation [min-max]

Table 2. Comparison of the morphometric measurements of the FL and neighboring structures according to FL types

	Open (n=29)	Partial (n=9)	Cohen's d	95% CI	p
FL-AP (mm)	7.29±2.35 [3.57-10.92]	6.52±2.18 [3.08-9.63]	0.332	-0.422 to 1.082	0.390
FL-T (mm)	5.96±1.94 [2.69-10.07]	3.39±1.40 [1.29-5.68]	1.400	0.578 to 2.206	**0.001**
FL Area (mm^2)	37.45±11.44 [21.61-58.78]	21.65±4.29 [14.45-28.62]	1.536	0.700 to 2.305	**0.001**
FL-FO$_A$ (mm)	16.12±2.59 [10.99-20.50]	16.74±3.13 [11.45-21.29]	-0.227	-0.975 to 0.525	0.556
FL-FO$_P$ (mm)	16.60±1.94 [12.29-20.42]	17.00±3.13 [12.78-22.45]	-0.180	-0.928 to 0.570	0.640
FL-FS$_A$ (mm)	17.34±2.02 [12.59-20.52]	17.63±2.53 [13.99-21.52]	-0.136	-0.884 to 0.613	0.723
FL-FS$_P$ (mm)	18.04±2.10 [13.73-22.73]	18.08±2.20 [14.43-20.87]	-0.019	-0.767 to 0.729	0.961
FL-CC$_A$ (mm)	13.97±2.62 [7.59-19.92]	12.92±1.06 [11.71-14.39]	0.443	-0.315 to 1.195	0.253
FL-CC$_P$ (mm)	18.67±2.80 [12.16-23.43]	17.95±2.33 [12.76-20.91]	0.266	-0.486 to 1.015	0.490
FL-B (mm)	16.92±1.25 [13.65-19.27]	16.50±0.84 [15.16-17.96]	0.363	-0.384 to 1.089	0.348

FL: foramen lacerum, FL-AP: anteroposterior diameter of the FL, FL-T: transverse diameter of the FL, FL Area: surface area of the FL, FL-FO$_A$: distance from FL to the anterior margin of the foramen ovale, FL-FO$_P$: distance from FL to the posterior margin of the foramen ovale, FL-FS$_A$: distance from FL to the anterior margin of the foramen spinosum, FL-FS$_P$: distance from FL to the posterior margin of the foramen spinosum, FL-CC$_A$: distance from FL to the anterior margin of the carotid canal, FL-CC$_P$: distance from FL to the posterior margin of the carotid canal, FL-B: distance from FL to the basion, CI: confidence interval, descriptive statistics are presented as mean±standard deviation [min-max]

DISCUSSION

Although commonly termed a foramen, the FL is a fibrocartilaginous gap at the skull base rather than a true bony canal. Its proximity to major neurovascular structures makes a clear understanding of its anatomy clinically important. In this study, we performed a morphometric and morphological assessment of the FL using dry skulls. No completely closed foramina were observed, and the open type was the most frequent morphology on both sides. The transverse diameter and surface area of the FL showed significant associations with its morphological types. Notably, surface area measurements, rarely emphasized in previous research, were systematically evaluated and provided additional quantitative insight. These findings expand current anatomical knowledge of the FL and underline the importance of accounting for its variations during skull base procedures.

Previous studies on FL morphology also highlight considerable variation in its patency. Singh and Kumar (1) reported that open and partially obliterated forms were the most common, while completely closed foramina were uncommon in adult dry skulls. This finding is consistent with our results, as no fully closed foramina were observed. The predominance of open-type FLs in our sample reinforces the notion that the fibrocartilaginous filling of the FL remains incomplete or only partially ossified in most individuals. Understanding these variations is important, especially during skull base procedures where precise anatomical orientation helps reduce surgical risk. The absence of a completely closed type of FL in the present study may reflect both anatomical and developmental factors. Embryologically, the FL region forms at the junction of the sphenoid, temporal, and occipital bones, where postnatal ossification remains incomplete and is instead replaced by fibrocartilaginous tissue. This partial fusion prevents the formation of a true bony canal, which likely explains why open and partially obliterated types are more common in adult skulls. In addition, subtle population-related anatomical variability and the limited number of specimens in this study may also have contributed to the absence of the closed type. This classification highlights the potential clinical implications of FL patency variations, which may affect surgical accessibility and risk assessment during skull base procedures.

In the literature, the normal dimensions of the FL are reported to be approximately 9.4 mm in anteroposterior length and 7.5 mm in transverse breadth (7). In the present study, the mean anteroposterior diameters of the FL were found to be 7.06±2.36 mm on the right, and 7.14±2.31 mm on the left side, while the mean transverse diameters were 5.15±2.14 mm and 5.55±2.15 mm, respectively. Compared to the previously reported normative data, the anteroposterior dimensions observed in our study were slightly lower, and the transverse dimensions were also smaller. These discrepancies may be attributed to differences in sample size, ethnic variations, measurement techniques, or the postmortem shrinkage of fibrocartilaginous components. Additionally, the variability in FL morphology, as evidenced by the presence of both open and partially obliterated types in our sample, may also have influenced the dimensional differences observed.

When compared with another morphometric study in the literature, where the anteroposterior diameter of the FL ranged from 4.32 to 16.33 mm on the right and 4.69 to 16.48 mm on the left, with mean values of 10.89±2.84 mm and 10.88±2.96 mm, respectively, our results showed considerably lower mean AP diameters (1). Similarly, while the transverse diameters in that study ranged from 3.21 to 19.04 mm on the right and 2.97 to 17.79 mm on the left, with mean values of 6.85±3.15 mm and 6.59±3.16 mm, our study again demonstrated smaller transverse measurements. These differences may reflect anatomical variation among populations or differences inherent to sample composition and study methodology.

In the present study, a comparison of morphometric parameters according to FL types revealed that the transverse diameter and surface area significantly differed between the groups, with Type I foramina (open type) exhibited greater values compared to Type II (partially obliterated type). These findings suggest that the degree of patency influences the dimensional characteristics of the FL, whereas the anteroposterior diameter and distances to adjacent landmarks were not significantly affected. From a clinical perspective, reduced transverse diameters and smaller surface areas in partially obliterated foramina may complicate surgical exposure, emphasizing the importance of detailed anatomical assessment. To the best of our

knowledge, this study represents the first systematic morphometric analysis of the anteroposterior and transverse diameters, as well as the surface area, of the FL based on direct measurements, thus providing novel baseline data that may support future anatomical and surgical studies.

Recent CT-based research has provided further insight into the morphometric characteristics and variability of the FL. In a Turkish population, Muslu et al. (17) conducted a detailed 3D Slicer-based CT analysis and found that males exhibited significantly greater FL length and width than females, with no notable right-left asymmetry. They also identified a positive correlation between FL dimensions and the angle between the vidian canal and the pterygosphenoidal fissure, emphasizing the anatomical interdependence of these skull base landmarks. Consistent with the present osteological findings, the open-type FL was the most frequently observed morphology, supporting the view that complete ossification of the foramen is rare in adults. Similarly, a recent craniofacial morphometric study by Kırteke et al. (18) demonstrated high bilateral symmetry, highlighting the reliability of using contralateral anatomical landmarks in reconstructive and navigational procedures.

Given the clinical significance of the FL region, recent studies have emphasized the necessity of detailed anatomical knowledge for safe skull base interventions. Corvino et al. (19,20) demonstrated that the superior eyelid transorbital endoscopic approach (SETOA) provides a minimally invasive route to the FL, highlighting the importance of consistent landmarks such as the Vidian nerve and the lateral loop of the trigeminal nerve. In this context, the morphological variability of the FL observed in our study, particularly in transverse diameter and surface area, may have important surgical implications. Partially obliterated FLs with reduced dimensions could limit surgical access and increase technical complexity in both transorbital and endonasal approaches. Thus, preoperative anatomical assessment of this region is crucial for minimizing neurovascular risks and improving intraoperative orientation.

Accurate knowledge of the spatial relationships between the FL and adjacent structures is essential for safe surgical navigation, particularly during transorbital and endonasal skull base approaches. Linear measurements obtained from the posteromedial corner of the FL to neighboring foramina and the basion in the present study provide valuable reference data. Strong correlations, especially between the FL and the margins of the foramen ovale and foramen spinosum, suggest a predictable anatomical arrangement that may aid intraoperative orientation. These findings align with Alvernia et al. (11), who emphasized that precise interforaminal distances are critical to minimizing neurovascular risks during skull base procedures. Thus, the morphometric data presented herein may contribute to improving both anatomical understanding and surgical safety.

Zhu et al. (21) conducted a morphometric study evaluating the spatial relationships between key foramina at the skull base and reported that the mean distance between the FL and foramen ovale was approximately 13.0 mm, while the distance between the foramen ovale and foramen spinosum was about 3.0 mm. Although direct comparison with the present study is limited due to methodological differences, our findings similarly demonstrated consistent anatomical patterns, with strong correlations between the measured distances. Importantly, while Zhu et al. (21) emphasized the importance of recognizing these spatial relationships to avoid vascular injury, our results further suggest that detailed linear assessments from the FL may offer additional intraoperative guidance, especially when traditional landmarks are compromised. Thus, morphometric variations in this region should be carefully considered during skull base surgeries and preoperative planning to minimize neurovascular complications.

Limitations

As with all anatomical studies based on cadaveric specimens, this investigation has inherent limitations. Although the morphometric findings presented in this study provide valuable anatomical insights, the relatively small sample size (n=19) limits the generalizability of the results. Moreover, information on the age and sex of the specimens was not available, so possible variations related to these factors could not be evaluated. In addition, the absence of soft tissue and fibrocartilaginous structures in dry skulls may have resulted in slight underestimations of in vivo measurements. Despite these limitations, the study provides valuable morphometric data that may support safer skull base surgical planning.

CONCLUSION

This study provides a comprehensive morphometric evaluation and morphological classification of the FL and its spatial relationships with adjacent anatomical landmarks. The findings highlight considerable variability in FL morphology, particularly in transverse diameter and surface area, which may influence surgical access and intraoperative navigation. Strong anatomical correlations between the FL and neighboring foramina emphasize the structural predictability of this region. These results offer valuable reference data for skull base surgery, particularly in transorbital and endonasal approaches, where precise anatomical knowledge is essential for minimizing neurovascular risks and optimizing surgical outcomes. Future studies involving larger and more diverse populations, as well as correlations with radiological imaging modalities such as CT or MRI, are recommended to further validate these findings and enhance their clinical applicability.

Ethics Committee Approval: The study was approved by the Clinical Research Ethics Committee of Harran University (30.06.2025, 12/74).

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