

# Guiding Anatomical Structures in Skull Base Navigation: The Relationship Between the Foramen Lacerum and the Pterygoid Region

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## ABSTRACT

This study aimed to evaluate morphometrically the dimensions of the foramen lacerum (FL) and its spatial relationships with adjacent anatomical landmarks, including the pterygoid canal, medial and lateral pterygoid processes, foramen ovale, and the sphenoccipital junction, using dry human skulls, in order to provide anatomical guidance for defining safe working corridors in skull base surgery. Measurements were obtained bilaterally from 57 adult dry human skulls using a Vernier caliper with a precision of 0.01 mm; right-left comparisons were analyzed using Student's *t*-test, and relationships between variables were assessed using Pearson correlation analysis ( $p < 0.05$ ). The length and width of the FL, as well as its distances to surrounding anatomical structures, were determined, and no statistically significant differences were observed between the right and left sides. Morphological evaluation revealed that Type 1 (right:71.9; left:66.7) configuration was predominant, whereas Type 3 (right:10.5; left:8.8) was rarely encountered, and partial or complete obliteration of the FL was observed in a subset of specimens. Overall, the FL demonstrated bilateral dimensional symmetry and consistent spatial relationships with neighboring skull base structures despite notable interindividual morphological variation, and these findings provide a comprehensive morphometric reference that may facilitate accurate anatomical landmark identification and support safe surgical planning in both endoscopic and open skull base procedures.

**Keywords:** Foramen lacerum. Lateral pterygoid process. Medial pterygoid process. Morphometry. Pterygoid canal. Skull base.

**Kafa Tabanı Navigasyonunda Rehber Anatmik Yapılar: Foramen Lacerum-Pterygoid Bölge İlişkisi**

## ÖZET

Bu çalışmada, kafa tabanı cerrahisinde güvenli çalışma koridorlarının belirlenmesine anatomik katkı sağlamak amacıyla, kuru insan kafataslarında foramen lacerum'un (FL) boyutsal özellikleri ile pterygoid kanal, medial ve lateral pterygoid çıkıntılar, foramen ovale ve sphenoccipital bileşke ile olan mekânsal ilişkileri morfolojik olarak değerlendirildi. Ölçümler, 57 adet erişkin kuru insan kafatasında bilateral olarak 0,01 mm hassasiyetli Vernier kumpas kullanılarak yapıldı; sağ-sol karşılaştırmaları Student *t* testi ile, değişkenler arasındaki ilişkiler ise Pearson korelasyon analizi ile değerlendirildi ( $p < 0,05$ ). FL'nin uzunluk ve genişlik ölçümleri ile çevre anatomik yapılarla olan mesafeleri belirlendi ve sağ ile sol taraflar arasında istatistiksel olarak anlamlı fark saptanmadı. Morfolojik değerlendirmede Tip 1 (sağ:71,9; sol:66,7) yapı en sık gözlenen tip iken, Tip 3 (sağ:10,5; sol:8,8) oldukça nadir olarak izlendi ve bazı örneklerde FL'de parsiyel veya tam obliterasyon saptandı. Genel olarak, FL'nin boyutları ve komşu kafa tabanı yapılarıyla olan ilişkilerinin bilateral olarak tutarlı olduğu, ancak belirgin bireysel morfolojik varyasyonlar gösterdiği ortaya konmuş olup, bu bulgular endoskopik ve açık kafa tabanı cerrahilerinde güvenli cerrahi planlamayı destekleyebilecek kapsamlı bir morfolojik referans sunmaktadır.

**Anahtar Kelimeler:** Canalis pterygoideus. Foramen lacerum. Kafatabanı. Morfolometri. Processus pterygoideus lateralis. Processus pterygoideus medialis.

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The skull base is a highly complex anatomical region that contains numerous critical neurovascular structures and requires detailed anatomical knowledge for both surgical and radiological approaches. Accurate understanding of its morphometric characteristics is essential for defining safe dissection boundaries in neurosurgery, otorhinolaryngology, maxillofacial surgery, and endoscopic skull base interventions. Measurements obtained from dry skulls constitute a valuable foundation, as they directly reveal interindividual anatomical variations, provide reference data for surgical planning, and contribute to more accurate interpretation of radiological sections<sup>1</sup>.

Although the foramen lacerum (FL) is not a direct passageway for major neurovascular structures, it is considered a clinically critical anatomical region due to its close relationship with the cavernous segment of the internal carotid artery and its proximity to key skull base structures<sup>2</sup>. The surgical relevance of the FL has increased particularly with endoscopic endonasal approaches, in which precise definition of safe dissection limits in this region is required<sup>3,4</sup>. Wang et al. (2019) emphasized that anatomical variations in this area play a key role in determining surgical corridors and preventing complications<sup>3</sup>. In skull base navigation systems, accurate identification of stable anatomical landmarks related to the FL and the pterygoid region is crucial for surgical orientation and for establishing safe working corridors.

The FL is closely related to other key skull base structures, including the pterygoid canal (PC) (vidian canal, VC), foramen ovale (FO), and the pterygoid processes. Knowledge of these relationships forms the basis for both surgical navigation and radiological diagnosis. For example, a morphometric analysis of the PC in the Turkish population was conducted by Muslu et al. (2025), who reported sex-related differences<sup>5</sup>. Similarly, population-specific variations of skull base structures were investigated in the Egyptian population by Abd El Naeem (2019)<sup>6</sup>.

Morphologically, the FL exhibits considerable interindividual variation. These variations are commonly classified as Type 1 (normal open type), Type 2 (canal-shaped type), and Type 3 (bridged type), based on the presence of bony bridges or canal formations along the lateral and posterolateral margins of the FL. Awareness of these morphological variants is critical, as noted by Wang et al. (2019), because they may influence the anatomical relationships and vulnerability of the internal carotid artery during surgical procedures<sup>3</sup>. Studies by Muslu et al. (2025) further indicate that the distribution of these types may vary between populations and according to sex, underscoring the need to consider such differences<sup>5</sup>.

In clinical practice, particularly during percutaneous treatments of trigeminal neuralgia, access to the FO may be hindered by the anatomical position of the lateral pterygoid process (LPP)<sup>7,8</sup>. Therefore, precise delineation of the FL dimensions, as well as its distances to surrounding structures including the FO, is informative for both clinical and radiological assessments. However, the limited number of morphometric studies that simultaneously evaluate the distances between the FL and neighboring structures in the pterygoid region represents a gap in defining reliable reference points for surgical navigation.

Accordingly, the present study aims to morphometrically evaluate, in dry skulls, not only the right and left dimensions (length and width) of the FL but also the distances between the foramen lacerum

and the pterygoid canal (FL-PC), lateral pterygoid process (FL-LPP), medial pterygoid process (FL-MPP), foramen ovale (FL-FO), and the sphenooccipital junction (FL-SOJ). The findings are intended to provide clinically relevant data that will facilitate the identification of safe working corridors, improve the accuracy of anatomical landmark definition in both endoscopic and open skull base surgeries, and support more precise radiological interpretation of pathological processes.

## Materials and Methods

This study was conducted on 57 adult dry human skulls of unknown sex obtained from the anatomy laboratories of Ankara Medipol University and Erciyes University Faculties of Medicine. Ethical approval for the study was granted by the Ankara Medipol University Faculty of Medicine Ethics Committee (Decision No: 14, Date: 06.01.2026).

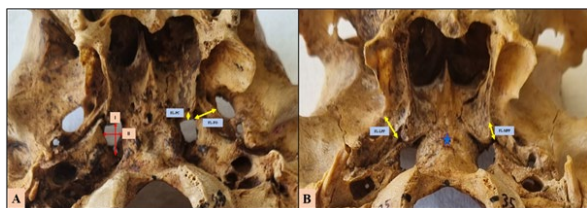
Skulls included in the study were selected from specimens with preserved bony integrity and no damage to the middle cranial fossa. Specimens presenting fractures or structural defects involving the foramen lacerum, foramen ovale, medial or lateral pterygoid processes, pterygoid canal, or the sphenooccipital junction were excluded from the analysis.

All measurements were performed in accordance with standardized protocols described by Wang et al. (2019) and Muslu et al. (2025), referred to as the Patat's protocols. The defined morphometric parameters were measured bilaterally (right and left) using a Vernier caliper with a precision of 0.01 mm (Figure 1)<sup>3,5</sup>.

### *Parameters Identified in the Internal Cranial Base (mm):*

- Foramen lacerum dimensions
  - Length
  - Width
- Distance between foramen lacerum and pterygoid canal (FL-PC)
- Distance between foramen lacerum and medial pterygoid process (FL-MPP)
- Distance between foramen lacerum and lateral pterygoid process (FL-LPP)
- Distance between foramen lacerum and foramen ovale (FL-FO)
- Distance between foramen lacerum and the midpoint of the sphenooccipital junction (FL-SOJ)

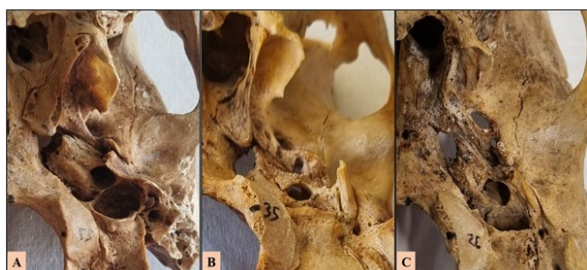
## Foramen Lacerum–Pterygoid Region Relationship



**Figure 1.**

Parameters measured. FL: foramen lacerum; I: foramen lacerum length; II: foramen lacerum width; asterisk: sphenooccipital junction; PC: pterygoid canal; FO: foramen ovale; LPP: lateral pterygoid process; MPP: medial pterygoid process

In addition, the morphological variability of the FL was evaluated. Based on previously established criteria and definitions<sup>5,6,9,10</sup>, the FL was classified into three types according to the morphological characteristics observed during anatomical assessment: Type 1, a normal opening with a standard configuration; Type 2, a canal-shaped FL characterized by the formation of a distinct bony canal; and Type 3, a bridged FL resulting from incomplete ossification of the FL and the development of a bony bridge (Figure 2).



**Figure 2.**

Types of the foramen lacerum. A: Normal shape; B: Canal shape; C: Bridged shape

### Statistical analysis

Statistical analysis was carried out using IBM SPSS Statistics software (version 25.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated and presented as mean±standard deviation (SD), along with minimum and maximum values. The distribution of the data was evaluated using the Shapiro-Wilk test. For the comparison of morphometric parameters between the right and left temporal bones of the same individual, a paired t-test was utilized for normally distributed variables. And a  $p$  value of  $<0.05$  was considered statistically significant. Categorical variables, were analyzed using the Chi-square test. All morphometric measurements were performed independently by two experienced anatomists who were blinded to the clinical data. To ensure methodological transparency and reproducibility, each measurement was taken twice, and the mean value

was used for statistical analysis. The inter-observer reliability was assessed and found to be high (Cronbach's alpha = 0.92).

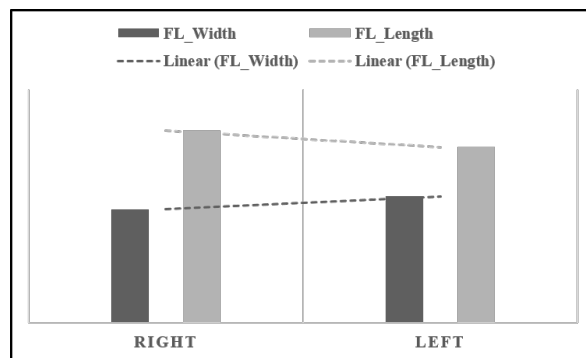
## Results

In this study, measurements of the FL and its distances to surrounding anatomical structures were evaluated in a total of 57 dry skulls. According to Table I, the mean FL width and length were  $6.82\pm 2.36$  mm and  $11.56\pm 4.49$  mm on the right side, and  $7.60\pm 2.69$  mm and  $10.58\pm 4.17$  mm on the left side, respectively, with no statistically significant difference between sides ( $p>0.05$ ). As shown in Figure 3, the right and left distributions of FL dimensions were highly comparable.

**Table I.** Dimensions of the foramen lacerum

mm	N	Right	Left	$p$
		Mean±SD	Mean±SD	
FL_Width	57	$6.82\pm 2.36$	$7.60\pm 2.69$	0.240
FL_Length	57	$11.56\pm 4.49$	$10.58\pm 4.17$	0.233

Figure 3 demonstrates that the dimensions of the foramen lacerum show a generally similar distribution on the right and left sides; however, the width is slightly greater on the left side, whereas the length is greater on the right side compared to the left.



**Figure 3.**

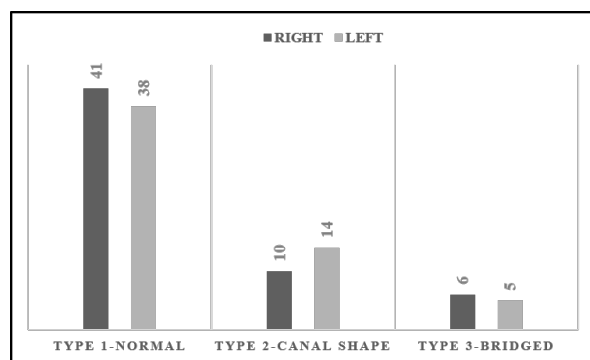
Comparison of right and left foramen lacerum dimensions

The distances between the FL and the pterygoid canal, lateral and medial pterygoid processes, foramen ovale, and the sphenooccipital junction did not show a statistically significant difference in right–left comparisons ( $p>0.05$ ; Table II). These findings support that the anatomical structures surrounding the FL are positionally stable and independent of side.

**Table II.** Distances between the foramen lacerum and surrounding anatomical structures

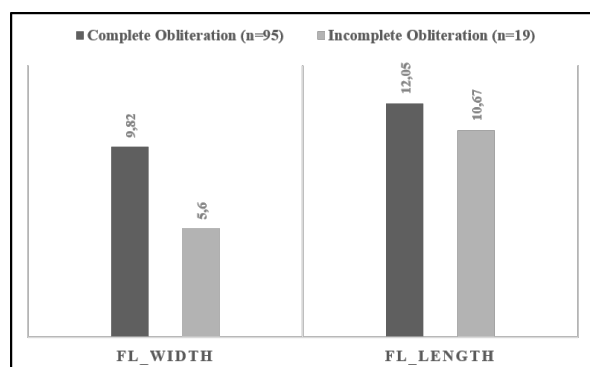
mm	N	Right	Left	p
		Mean±SD	Mean±SD	
FL_PC	57	4.91±2.12	5.25±2.44	0.432
FL_LPP	57	11.83±3.48	11.97±3.53	0.883
FL_MPP	57	6.04±2.80	5.97±2.52	0.745
FL_FO	57	7.79±2.05	7.96±2.06	0.610
FL_SOJ	57	10.71±2.47	10.39±1.98	0.256

The distribution of morphological types of the FL is shown in Figure 4. According to the analysis, Type 1 was the most frequently observed, whereas Type 3 was rare. These variations are particularly important for evaluating the presence of bony bridging and canalization of the FL.



**Figure 4.**  
*Classification of the foramen lacerum*

The obliteration status of the FL is presented in Figure 5, and partial or complete obliteration tendencies were observed in some specimens due to a reduction in FL width. This finding indicates that the patency of the FL should be carefully considered during surgical approaches.



**Figure 5.**  
*Obliteration of foramen lacerum dimensions*

Overall, the dimensions of the FL and its surrounding anatomical relationships are stable between the right and left sides, and morphological variations and obliteration patterns constitute important parameters that should be taken into consideration during surgical planning.

## Discussion and Conclusion

In this study, the morphometry of the FL and its distances to surrounding anatomical structures of surgical relevance (PC/VC, FO, MPP, LPP, SOJ) were analyzed in detail in dry skulls of undetermined sex. The obtained findings reveal anatomical variations in this region and provide important contributions to the identification of safe dissection corridors, particularly in endoscopic endonasal approaches (EEA) and skull base surgeries.

The FL dimensions and its surrounding anatomical relationships identified in the present study are generally consistent with the ranges reported in previous studies, including recent osteological investigations of the foramen lacerum morphology<sup>6,11</sup>. The mean width (right: 6.82±2.36 mm; left: 7.60±2.69 mm) and length (right: 11.56±4.49 mm; left: 10.58±4.17 mm) values are comparable to morphometric data reported in different populations; for instance, measurements obtained from Egyptian and larger osteological series show similar values<sup>6</sup>. This concordance suggests that the FL morphometry remains relatively stable despite geographic or population-related differences.

The absence of significant right–left differences in the distances between the FL and adjacent structures (PC/VC, FO, MPP, LPP, and SOJ) indicates that these relationships can be considered reliable anatomical landmarks for surgical and interventional procedures. Although relatively few studies have systematically measured these specific adjacency distances, data derived from imaging-based and dry skull studies support the clinical consistency of the positional relationships between the FL and neighboring structures<sup>3,8,10,12</sup>. In this respect, the present study provides applicable and practical morphometric data, particularly relevant for trigeminal interventions and craniofacial surgery.

The predominance of Type 1 and the rarity of Type 3 in the morphological type distribution of the FL are consistent with previously reported classifications and literature-reported patterns, confirming considerable anatomical variability<sup>5,6,13</sup>. Studies by Muslu et al. (2025) and Wang et al. (2019), as well as anatomical investigations addressing the lingual process of the sphenoid and its relationship with the foramen lacerum, have emphasized that bony variations in this region may be of particular surgical importance due to

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their close relationship with the internal carotid artery<sup>3,5,14</sup>. Additionally, the observation of partial or complete obliteration tendencies in some specimens highlights the clinical relevance of FL morphological diversity, aligning with previous reports of variable ossification/obliteration rates. However, since obliteration was evaluated only observationally without quantitative rates, direct numerical comparisons with the literature remain limited. Therefore, larger-sample studies prioritizing the definition and quantification of obliteration patterns would make a valuable contribution to both clinical and anatomical literature.

Among the strengths of this study are the systematic measurement of both FL dimensions and surrounding anatomical distances within the same sample, as well as bilateral comparisons, providing a practical and comprehensive anatomical dataset applicable to surgical planning. However, certain limitations should be acknowledged: the lack of information on age, sex, and ethnic background of the specimens, the observational nature of obliteration assessment, and the absence of correlation with imaging data partially limit the generalizability of the findings. Imaging-based studies in the literature (e.g., Muslu et al., 2025) have demonstrated the influence of sex and age on FL morphometry, and comparisons with such datasets in future research would be methodologically valuable.

In conclusion, the present study provides up-to-date anatomical data that contribute to the literature regarding the dimensions of the foramen lacerum, its morphological type distribution, and its relationships with surrounding structures. Nevertheless, quantitative evaluation of obliteration rates and validation through larger sample sizes incorporating demographic variables (using combined dry skull and imaging-based approaches) are warranted. Furthermore, prospective and imaging-focused studies are recommended to determine critical distance thresholds between the FL and key structures such as the FO or PC, which may pose potential risks during surgical approaches.

### Researcher Contribution Statement:

Idea and design: D.P., B.T.D., M.N.; Data collection and processing: D.P., S.E., B.T.D., M.N.; Analysis and interpretation of data: D.P., S.E., B.T.D.; Writing of significant parts of the article: D.P., S.E., B.T.D., M.N.

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The authors of the article have no conflict of interest declarations.

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