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MORPHOMETRIC ANALYSIS OF THE FORAMEN OVALE AND ITS CLINICAL AND SURGICAL IMPLICATIONS

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Abstract: Background: The foramen ovale (FO) is an opening at the posterior part of the greater wing of the sphenoid bone. Prior knowledge of the topography and possible variations in FO morphometry prevents possible injuries to the trigeminal nerve during such approaches. **Aim:** To analyze FO morphometry and its clinical and surgical implications. **Materials and methods:** 72 dry adult male and female human skulls were used. Skulls were measured bilaterally using a Stainless® digital caliper with a capacity of 150 millimeters. The following variables were analyzed: anteroposterior diameter (length); transverse diameter (width); distance from the FO center to the tubercle of the zygomatic root (d^1); and the distance from the FO center to the midline of the skull base (d^2). **Results:** The mean length in male skulls was 7.58 ± 1.05 mm on the right side and 7.77 ± 1.24 mm on the left side, whereas in females it was 7.56 ± 1.79 mm and 7 .97 ± 1.58 mm, respectively. Regarding the mean width values, it was observed that the measurements in males were predominantly higher when compared to females. The distance from the FO center to the tubercle of the zygomatic root (d^1) presented higher mean values in male skulls, whereas the distance from the FO center to the midline of the skull base (d^2) was predominantly greater in the right side when compared to the left side in females. **Conclusion:** Variations in FO size and shape are common findings, and they are likely related to fetal development. Thus, a thorough knowledge of FO morphological variants and morphometric details is greatly important for the diagnosis and treatment of several conditions, when microneurosurgical and microvascular approaches are necessary.
Keywords: Foramen ovale; Trigeminal nerve; Morphometry.

INTRODUCTION

The foramen ovale (FO) is an opening located in the posterior part of the greater wing of the sphenoid bone, responsible for the transmission of the sensorial part of the mandibular nerve together with the motor root of the trigeminal nerve, accessory meningeal artery, lesser petrosal nerve, emissary veins and, sometimes, the anterior trunk of the middle meningeal sinus (PRAKASH et al., 2019).

The FO is situated in the transition zone between intracranial and extracranial structures and, therefore, it is an important constituent of cranial anatomy with great significance for neurosurgery, as it allows access to the trigeminal nerve. Thus, knowledge of its position is clinically valuable during anesthesia procedures of the mandibular nerve, as well as in cases of assessment of skull base asymmetries, where measurements of these foramina become indispensable (SKRZAT et al., 2006).

Furthermore, understanding the exact location and dimensions of the foramen ovale plays a vital role during certain diagnostic procedures such as electroencephalographic analysis, microvascular decompression by percutaneous trigeminal rhizotomy, and percutaneous biopsy of cavernous sinus tumors. In this context, prior knowledge of the topography and possible variations in FO morphometry avoids possible injuries to the trigeminal nerve during such approaches (GUSMÃO et al., 2003).

Thus, this study aimed to analyze FO morphometry and its clinical and surgical implications.

MATERIALS AND METHOD

This is a study with a quantitative approach. Seventy-two (72) dry adult male and female human skulls were used. The skulls were collected from the Anatomy Departments of the Federal University of Paraíba (UFPB) and Unifacisa University Center. Morphometric measurements were performed by two researchers. Broken or damaged skulls that could influence measurements or results were excluded and only skulls in good condition were analyzed, measured and photographed. The data collection period was carried out from October to December 2019.

The skulls were measured bilaterally using a Stainless® digital caliper with a capacity of 150 (one hundred and fifty) millimeters. It was used for morphometric analysis and the following measurements: anteroposterior diameter (length); transverse diameter (width); distance from the FO center to the tubercle of the zygomatic root (d^1); and the distance from the FO center to the midline of the skull base (d^2).

Data obtained were analyzed using the statistical program GraphPad Prism version 5.0, GraphPad Software, Inc. San Diego CA. Descriptive statistics were used, measuring the mean and standard deviation. Inferential statistics were used to compare variables means regarding laterality and dimorphism, using t test. The Shapiro-Wilk test was previously used to verify data normality. To reject the null hypothesis, we adopted $p<0.05$. Data graphical representations were obtained from Microsoft Excel 2016.

RESULTS

This study was performed in 144 foramen ovale from 72 adult human skulls. The minimum and maximum length of the foramen ovale on the right and on the left sides in male skulls was 5.6 - 9.8 mm and 5.7 - 10.3 mm, and in female skulls 4.4 - 12.3 mm and 5.7 – 13.6 mm, respectively. The mean length in male skulls was 7.58 ± 1.05 mm on the right side and 7.77 ± 1.24 mm on the left side, whereas the mean values obtained for this variable in females were 7. 56 ± 1.79 mm and 7.97 ± 1.58 mm, respectively.

Regarding width average values, it was observed that the measures of the right and left sides in males were predominantly bigger when compared to females, the same happened for the mean values obtained for the area.

Distance from the FO center to the tubercle of the zygomatic root (d^1) presented higher mean values in male skulls, however, they were symmetrical in both sexes when comparing right and left sides. The distance from the FO center to the midline of the skull base (d^2) was predominantly greater on the right side when compared to the left side in females, although it presented symmetry on both sides in males. These were the only variables showing a statistically significant difference.

The different FO shapes were observed and compared in terms of laterality and sex difference (Table 2). Regarding the shape, the oval type was the most found in both sexes, 40% on the right side and 35% on the left side of male skulls and 53.84% and 33.33% in female skulls, respectively.

The D-shaped type was the second most frequently found, especially on the right side of male skulls, followed by the round shape mainly in male skulls. On the other hand, the longitudinal type was found more frequently in female skulls on the left side. The almond type was seen more consistently on the left side of the skulls in both sexes, while the irregular type was seen on only 5.12% of the right and left sides of female skulls. The shape and identification of FO types were identified in Figure 1.

Our results were compared with studies from different locations for a better data analysis, and then summarized in the table below (Table 3).

DISCUSSION

Several studies on the morphometric and

VARIABLES	MALE Mean ± SD	MALE V min – max	FEMALE Mean ± SD	FEMALE V min - max	p value
Length R	7.58 ± 1.05	5.6 -9.8	7.56 ± 1.79	4.4 – 12.3	0.54
Length L	7.77 ± 1.24	5.7 – 10.3	7.97 ± 1.58	5.7 – 13.6	0.54
p value	0.47		0.55		
Width R	4.73 ± 1.02	2.4 – 6.7	4.55 ± 1.09	2.7 – 8.9	0.47
Width L	5.0 ± 0.95	3.4 – 7.3	4.81 ± 0.86	3.6 – 7.5	0.38
p value	0.24		0.27		
Area R	28.48 ± 1.4	11.1 – 45.2	27.98 ± 1.6	9.3 – 62.8	0.41
Area L	30.88 ± 1.49	18.1 – 56.5	30.21 ± 1.7	18.7 – 62.4	0.50
p value	0.72		0.83		
d^1 R	33.56 ± 3.25	25.3 – 40.3	31.21 ± 2.3	23.4 – 36.0	0.0007*
d^1 L	33.4 ± 3.37	24.0 – 39.4	31.63 ± 2.5	23.8 – 38.5	0.014*
p value	0.87		0.47		
d^2 R	24.28 ± 1.88	20.2 – 28.1	23.17 ± 2.09	18.5 – 26.3	0.02*
d^2 L	24.24 ± 1.77	20.5 – 27.5	22.68 ± 1.47	19.2 – 25.6	0.0001*
p value	0.93		0.26		

R- right, L- left, d^1 - distance from the FO center to the tubercle of the zygomatic root, d^2 - the distance from FO the center to the midline of the skull base. Vmin – Minimum value; Vmax – Maximum value. SD – Standard Deviation.

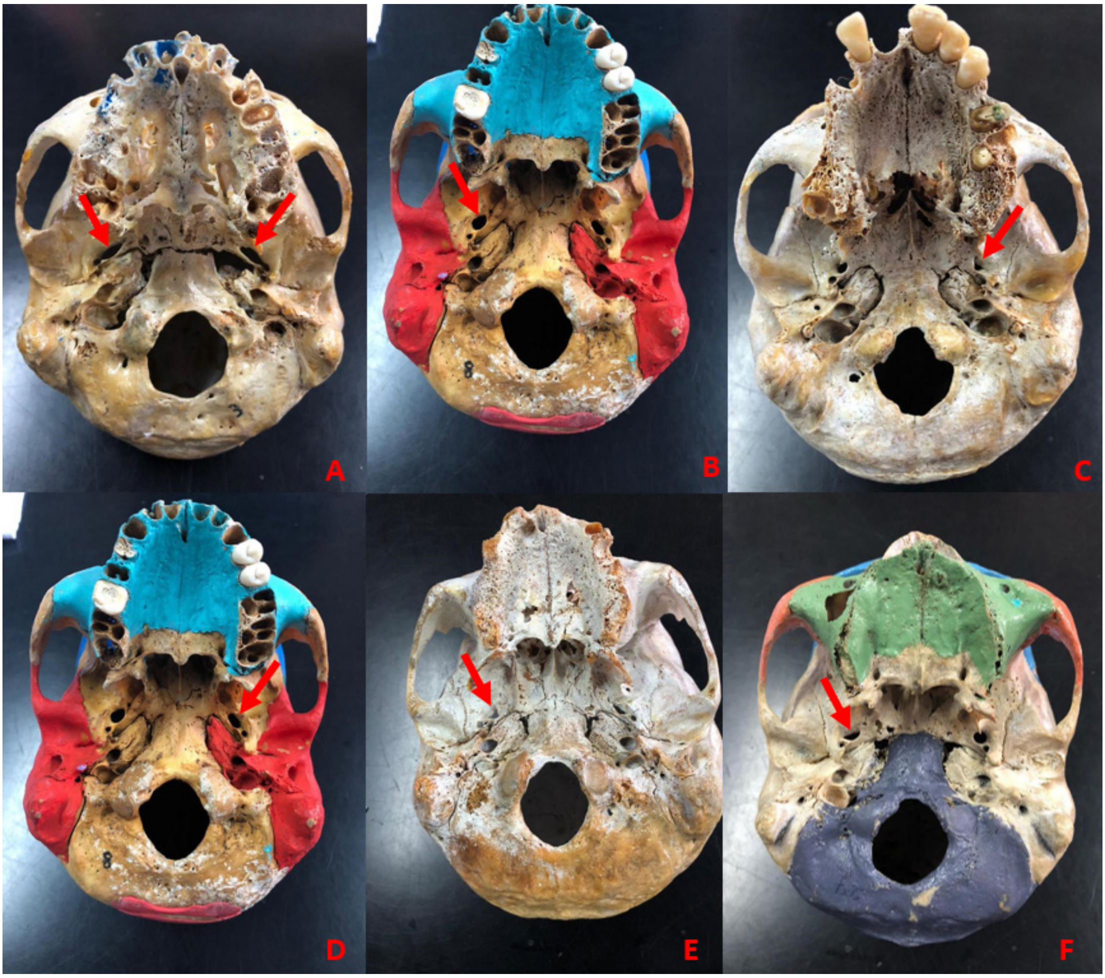
* P<0.05 when compared to dimorphic means between the same variables.

Table 1. Comparative morphometric analysis between the means of the investigated variables between bilateral foramina ovale of female and male human dry skulls in Paraíba.

Types of foramen ovale	MALE Right	*f*	Left	*f*	FEMALE Right	*f*	Left	*f*
Oval	16	40%	14	35%	21	53.84%	13	33.33%
D-shape	14	35%	11	27.5%	10	25.64%	10	25.64%
Almond	0	0%	3	7.5%	1	2.56%	2	5.12%
Longitudinal	2	5%	2	5%	1	2.56%	5	12.82%
Round	8	20%	10	25%	4	10.25%	7	17.94%
Irregular	0	0%	0	0%	2	5.12%	2	5.12%

Table 2. Comparative analysis between types of foramen ovale stratified by sex.

F – absolute frequency



A – Longitudinal type; B – Round type; C – Almond type; D – Oval type; E – Irregular type; F – D-shaped type.

Figure 1. FO identification and shape types in dried human skulls.

Studies	Location	Mean area		Mean length		Mean width	
		Right	Left	Right	Left	Right	Left
Hwang et al. (2005)	Korea	-	-	8.11 ± 0.97	8.24 ± 0.63	4.12 ± 0.99	4.01 ± 0.72
Patil et al. (2013)	South of India	-	-	7.0 ± 2.17	6.8 ± 1.40	5.0 ± 0.42	4.70 ± 0.91
Desai et al. (2012)	India	31.56 ± 9.82	32.08 ± 9.08	8.14 ± 1.42	7.98 ± 1.89	5.26 + 0.93	5.88 ± 1.01
Somesh et al. (2011)	India	30.808 ± 7.545	31.310 ± 8.262	7.64 ± 1.194	7.561 ± 1.123	5.128 ± 0.827	5.244 ± 0.950
Daimi et al. (2011)	West of India	-	-	6.60 ± 1.06	6.26 ± 1.23	3.70 ± 0.81	3.34 ± 0.77
Ray et al. (2005)	Nepal	-	-	7.46 ± 1.41	7.01 ± 1.41	3.21 ± 1.02	3.29 ± 0.85
Patil et al. (2014)	Kerala	-	-	7.80 ± 1.24	7.26 ± 1.18	4.0 ± 1.14	4.05 ± 1.16
Prakash et al. (2019)	India	31.07 ± 9.57	32.54 ± 7.54	7.74 ±1.94	7.60 ±1.25	5.18 ± 0.98	5.4 ± 0.94
Osunwoke et al. (2010)	Nigeria	-	-	7.01±0.1	6.89±0.09	3.37±0.07	3.33±0.07
This study	Brazil	28.48 ± 1.4 (M) 27.98 ± 1.6 (F)	30.88 ± 1.49 (M) 30.21 ± 1.7 (F)	7.58 ± 1.05 (M) 7.56 ± 1.79 (F)	7.77 ± 1.24 (M) 7.97 ± 1.58 (F)	4.73 ± 1.02 (M) 4.55 ± 1.09 (F)	5.0 ± 0.95 (M) 4.81 ± 0.86 (F)

F – Female; M – Male.

Table 3. Summary of studies on FO morphometry.

developmental aspect of the foramen ovale have been carried out worldwide (Hwang et al., 2005; Patil et al., 2013; Desai et al., 2012; Somesh et al., 2011; Daimi et al., 2011; Ray et al., 2005; Patil et al., 2014; Prakash et al., 2019; Osunwoke et al., 2010).

Mean values ranging from 4.70 to 5.88 mm were observed for FO width in studies carried out in India (Prakash et al., 2019; Patil et al., 2013; Desai et al., 2012; Somesh et al., 2011), although a study by Daimi et al. (2011), developed in West India, has shown lower mean values, 3.34 mm for the left side and 3.70 mm for the right side, results which are also similar to those found by Osunwoke et al. (2010) and Ray et al. (2005) in Nigeria and Nepal, respectively. The mean values found in our study for this variable were close to those of the study developed in the South Indian population (Patil et al., 2013).

On the other hand, the mean FO length in our study was 7.56 mm to 7.77 mm, also similar to the results observed by Patil et al. (2013), as well as by Daimi et al. (2011) in West India; Ray et al. (2005) in Nepal; Patil et al. (2014) in Kerala; Prakash et al. (2019) and Somesh et al. (2011) in India. Values above this average were seen in the Korean population by Hwang et al. (2005), while lower values were observed in the Nigerian population (Osunwoke et al., 2010).

The FO mean area of the skulls evaluated in our study was 28.48 ± 1.4 mm for males and 27.98 ± 1.6 mm for females on the right side and 30.88 ± 1.49 mm and 30.21 ± 1.7 mm, respectively for the left side, these findings are similar to two studies from India developed by Desai et al. (2012) and Somesh et al. (2011).

However, the distance from the FO center to the tubercle of the zygomatic root (d^1) presented higher mean values in male skulls, although they showed symmetry in both sexes when comparing right and left sides. The most likely reason our values were statistically higher in men is the fact that the male skull is generally larger and more robust than the female ones. Skull size can also vary with height and/or race of the individual, with change resulting from measurements of relevant landmarks, although this was not analyzed in the current study, that could also explain the significant differences observed in reference measurements of the skull (Nafte, 2000; White; Folkens, 2005).

Furthermore, although Ray et al. (2005) did not find statistically significant differences between men and women in terms of size or shape after analyzing FO morphology, in our study it was observed that the distance from the FO center to the midline of the skull base (d^2), was predominantly greater on the right side when compared to the left side in females. The asymmetry of the FO in size, shape and distance from the midline was also a finding reported by Patil et al. (2013).

The most frequent FO shape was the oval and the least common was the irregular type. Such results corroborate data found in previous studies (Prakash et al. 2019; Chimmalgi et al., 2007; Wadhwa et al., 2012). However, authors believe that this difference is unlikely to be explained by any sex difference regarding FO shape itself (Ray et al., 2005).

For this reason, a thorough understanding of fetal growth and development is the key to understanding both the complete normal anatomical structure and variations in FO size and shape. It is known that the sphenoid bone develops from both intramembranous and endochondral ossification with presphenoid and postsphenoid centers. On the other hand, both centers contribute to the basephenoidal part (body) and lesser wing, the post-sphenoid center forms the greater wing and the pterygoid process of the sphenoid bone. In this context, when the mandibular nerve is involved by cartilage, the FO is then formed. However, in the initial phase of embryogenesis during the

22nd week, this foramen can be demonstrated as a discrete ring-shaped opening in the area of the non-ossified cartilaginous part, becoming a definitive foramen only after the third year of life (Karthiga; Thenmozhi, 2016; Yanagi, 1987).

Thus, bone overgrowth during its developmental process is often evidenced by the appearance of tubercles, bone spurs, and bone plate around the FO. Furthermore, the occasional presence of an accessory foramen next to the ovale is probably due to the interaction of different parts of the bone membrane and the venous plexus, from the middle meningeal veins to the pterygoid venous plexus (James et al., 1980).

Knowledge of the three-dimensional topographic anatomy of the structures of the skull and their morphometric values is necessary, but not sufficient to carry out a safe treatment. Therefore, the detailed study of morphological variants and morphometric details of the FO in adult human skulls is essential for performing diagnostic procedures, such as electroencephalographic analysis of the seizure for patients undergoing selective amygdalohippocampectomy, microvascular decompression by percutaneous trigeminal rhizotomy for trigeminal neuralgia and percutaneous biopsy of cavernous sinus tumors (Prakash et al., 2019; Sindou et al., 1997; Barakos and Dillon, 1992).

Computed Tomography (CT) guided transfacial fine needle aspiration technique through FO is used to diagnose squamous cell carcinoma, meningioma, Meckel, and others. In addition to the CT-guided transfacial fine-needle aspiration technique, several important landmarks can be used radiologically and surgically to guide an endoscopic, endonasal, transzygomatic, transmaxillary, and transpterygoid approach to the infratemporal fossa to access pathologies arising in and around the middle FO cranial fossa, helping to decrease patient morbidity and significantly decrease costs (Kantola et al., 2013).

CONCLUSION

Variations in FO size and shape are common findings, and they are likely related to fetal development, which can make it difficult to perform clinical and diagnostic procedures in the head and neck regions. Thus, a thorough knowledge of the FO morphological variants and morphometric details, as observed in this study, is greatly important for clinicians in the diagnosis and treatment of several conditions when microneurosurgical and microvascular approaches are necessary.

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