

ORIGINAL ARTICLE

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Morphometric measurements and morphology of foramen ovale in dry human skulls and its relations with neighboring osseous structures

 Ece Akcay¹,  Gkionoul Nteli Chatzioglou²,  Ozcan Gayretli²,  Ilke Ali Gurses²,  Adnan Ozturk²

¹Istanbul University Faculty of Medicine, Istanbul, Turkey²Istanbul University Faculty of Science, Department of Anatomy, Istanbul, Turkey

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Abstract

The importance of the location of the foramen ovale (FO) is particularly evident in external approaches to the skull base. Neighboring structures are of great importance in surgical interventions such as approaches used for trigeminal neuralgia (percutaneous trigeminal rhizotomy), transfacial fine needle aspiration in perineural spread of the tumor, and electroencephalographic analysis for seizures. This study aimed to investigate the morphometry, morphology and anatomical relations of the FO.

Eighty hemiscraniums of osteological collection of the Department of Anatomy, Faculty of Medicine, Istanbul University, in Turkey were investigated. In the study, the morphological features of the foramen ovale and their distance to the surrounding anatomical structures were measured.

Oval (70%), almond (18.75%), slit (6.25%), round (5%) shaped foramen ovale were observed. The average length of foramen ovale on the right side was 7.09+1.07mm and 7.06+1.01mm on the left side, while the width was 4.16+0.79mm and 4.15+0.5mm, right and left respectively. The transverse distance of posterolateral edge of foramen ovale to lateral edge of articular tubercle was 33.06+3.25mm, the transverse and vertical distances of foramen ovale to mastoid process were, 17.36+3.09mm and 32.40+3.43mm. Finally, measurements of foramen ovale to the carotid canal, the inferior orbital fissure, and the pterygopalatine fossa were 16.70+1.9mm, 27.94+3.2mm and 14.88+1.91mm, respectively. Regional differences in morphometric and morphological analysis of foramen ovale are of clinical and anatomical significance for medical practitioners in neurosurgical procedures, treatment of trigeminal neuralgia, and diagnostic detection of tumors.

Keywords: Cranium, foramen ovale, skull, trigeminal neuralgia

Introduction

Foramen ovale (FO) is an opening located in the greater wing of the sphenoid bone which connects the anterior cranial fossa to the infratemporal fossa. The mandibular nerve (V3) of the fifth cranial nerve (trigeminal nerve-V), the accessory (meningeal) artery, and sometimes the minor petrosal nerve (which arises from the tympanic plexus of the glossopharyngeal nerve) passes through it [1,2]. The mandibular nerve supplies substantial structures of the mouth (teeth, lower lip, gums of the mandible, the mucous membrane of the anterior part of the tongue and the floor of the mouth) and the face (lower part of the face, the skin of the temporal region, part of the auricle and the muscles of mastication) [1,2].

The morphometric and morphologic evaluation of FO, which is an significant anatomic structure of the skull anatomy, and its proximities with other osseous structures such as mastoid process (MP), zygomatic arch, pterygopalatine fossa (PPF) and inferior orbital fissure (IOF) are essential for surgical procedures. Topographic relationships between FO and the external opening of the carotid canal (EoCC) and adjacent structures are very valuable, due to its proximity with the internal carotid artery located in the carotid canal and which is mainly responsible for feeding the brain. Therefore, any treatment and diagnostic intervention for trigeminal neuralgia is also at risk for the internal carotid artery, which enters the carotid canal [3]. Especially during a percutaneous rhizotomy procedure for treatment of trigeminal neuralgia (trigeminal rhizotomy), the importance of FO and adjacent structures become even more obvious. The rhizotomy needle used by the surgeon during the trigeminal rhizotomy procedure, first reaches the FO by passing through the superficial structures (skin, fascia, masticatory muscles, etc.) of the face. However, in some cases the needle may bypass the FO and reach the PPF or IOF. In cases where it reaches IOF, the optic nerve may be injured. As a result, unwanted

*Corresponding Author: Gkionoul Nteli Chatzioglou, Istanbul University Faculty of Medicine, Istanbul, Turkey E-mail: gonul.anatomy@gmail.com

complications such as blindness may be seen in patients [4-6].

The morphological feature of FO, as its name suggests, is generally seen as an oval. However, according to previous research studies, a large number of variations have been reported [7-10].

The foramen is found on the lateral side of the lacerum foramen and anterior side of the Eustachian tube, EoCC and spinous foramen of the skull. In addition, the localization of the FO has an important place on the anterior side, due to its proximity with the PPF and the IOF.

In present work, we aimed to appreciate the morphological and morphometric features, the different diameters such as length (anteroposterior diameter) and width (mediolateral diameter) of FO and its variable shapes, the location, and the relationships and

proximities with other anatomical osseous structures of the FO and to estimate the approximate location of FO.

Material and Methods

This work was approved by the Istanbul University, Faculty of Medicine, Research Ethics Committee (date and number: 23.11.2020 and 201949). A total of 80 (40 right and 40 left) adult Anatolian dry human hemicrania evaluated from the Department of Anatomy of Istanbul University, Faculty of Medicine were used within this study. The dry human skulls of undetermined age and gender were subjected to the morphometric study.

The following parameters as described in Figure 1, Figure 2, Figure 3 and Table 1 were measured:

Table 1. Measurement values concerning the bony landmarks of FO (FO-Length: the anteroposterior diameter of FO, FO-Width: the mediolateral diameter of FO, FO-AT: the transverse distance between the posterior edge of FO and AT, FO-IOF: the vertical distance between the anterior edge of FO and IOF, FO-PPF: the transverse distance between the anterior edge of FO and PPF, FO-CCa: The vertical distance between the posterior edge of FO and anterior edge of EoCC, FO-CCp: The vertical distance between the posterior edge of FO and posterior edge of EoCC, FO-MPv: The vertical distance between the posterior edge of FO and MP, FO-MPt: The transverse distance between the posterior edge of FO and MP)

Parameters (mm)	Side	Mean	Standart Deviation (SD)	Minimum	Maximum
FO-Length	Right	7.09	1.07	5.12	10.59
	Left	7.06	1.01	4.77	8.90
FO-Width	Right	4.16	0.79	2.92	6.80
	Left	4.15	0.50	3.20	5.06
FO-AT	Right	29.83	3.41	15.75	34.5
	Left	29.94	3.13	23.40	36.70
FO-IOF	Right	29.82	3.40	21.60	35.40
	Left	30.76	2.97	24.05	36.00
FO-PPF	Right	14.61	1.91	10.00	18.10
	Left	15.08	1.92	10.57	18.66
FO-CCa	Right	13.05	2.07	7.25	19.70
	Left	12.80	1.73	9.62	17.55
FO-CCp	Right	18.89	2.03	14.36	25.60
	Left	18.82	1.74	15.55	22.13
FO-MPv	Right	37.62	3.23	26.42	43.50
	Left	37.42	3.64	29.92	46.02
FO-MPt	Right	20.37	3.65	4.14	25.00
	Left	21.66	2.27	18.10	27.00

Metric analysis

- 1- The anteroposterior diameter (length) of FO
- 2- The mediolateral diameter (width) of FO
- 3- The transverse distance between the posterior edge of FO and articular tubercle (AT)
- 4- The vertical distance between the anterior edge of FO and IOF
- 5- The vertical distance between the posterior edge of FO and anterior edge of EoCC
- 6- The vertical distance between the posterior edge of FO and posterior edge of EoCC
- 7- The vertical distance between the posterior edge of FO and MP
- 8- The transverse distance between the posterior edge of FO and MP
- 9- The transverse distance between the anterior edge of FO and PPF

Non-metric analysis

With macroscopic examination, the shape of the FO was classified as oval, almond, round and slit (Figure 2).

The hemicrania were photographed by placing a metric in order to measure the mentioned parameters. The photographs were transferred to the computer, and the calculations were made by using Image J software (<http://rsbweb.nih.gov/ij>) program (Figure 3).

Statistical analysis

All data were expressed as mean, standart deviation, minimum and maximum. IBM SPSS V23 (IBM corporation, Armonk, NY) was used for all data analyses. Since the hemicrania are not bilateral, no correlation was made between right and left.

Results

The present study was conducted on a total of 80 hemicrania of dry adult skulls. The anteroposterior diameter of the FO was between 4.77 ± 1.03 mm and 10.59 ± 1.03 mm (Table 1). Likewise, the mediolateral diameter (width) of FO was 2.92 ± 0.66 mm 6.80 ± 0.66 mm (Table 1).

The shape of FO was also observed. FO was typically oval in 56 sides, almond in 15 sides, round in 4 sides, and slit like in 5 sides. Incidences of oval, almond, slit, and round were 70%, 18.75%, 6.25%, 5% respectively (Table 2).

Table 2. The number and frequency of shape of foramen ovale

	Oval	Almond	Round	Split	TOTAL
RIGHT	28 (35%)	7 (8.75%)	2 (2.5%)	3 (3.75%)	40 (50%)
LEFT	28 (35%)	8 (10%)	2 (2.5%)	2 (2.5%)	40 (50%)
TOTAL	56 (70%)	15 (18.75%)	4 (5%)	5 (6.25%)	80 (100%)

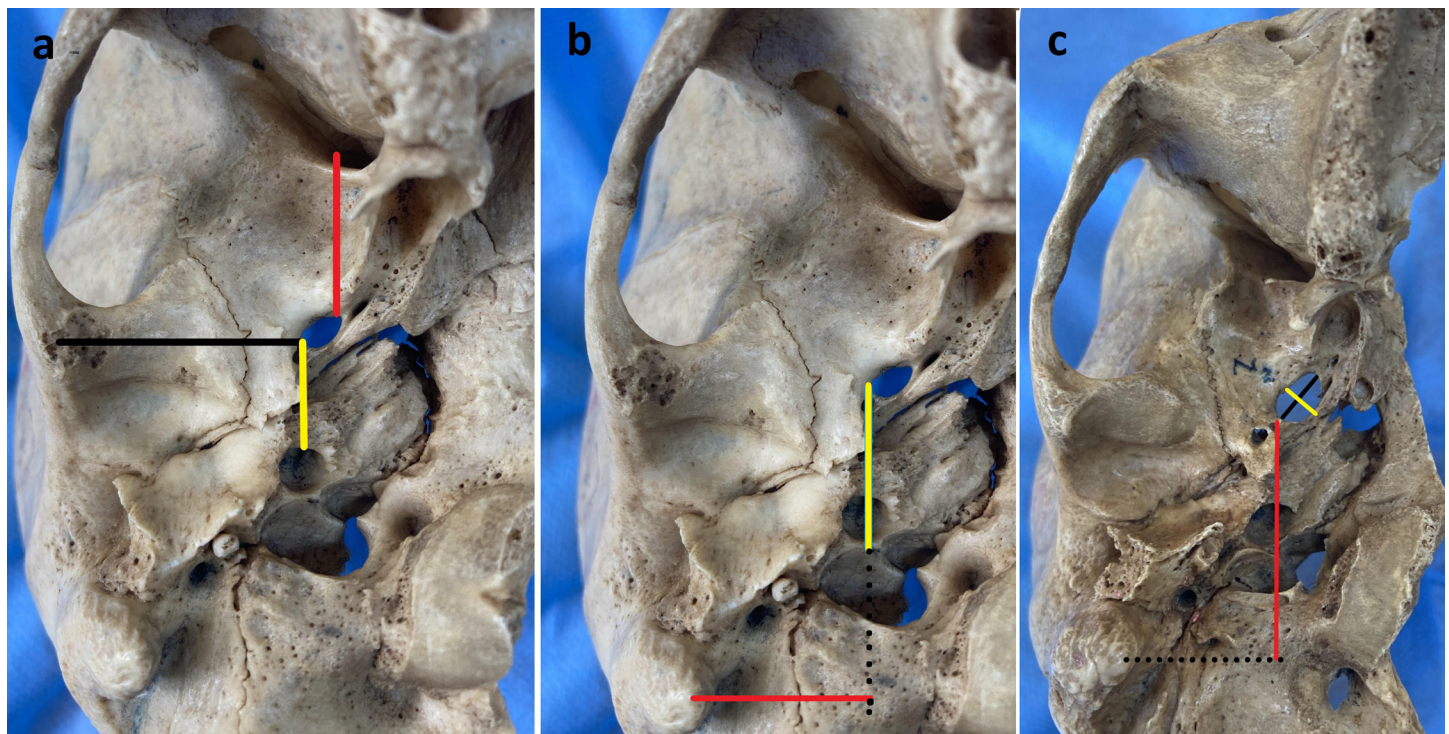


Figure 1. Measurement parameters. a, the transverse distance between the posterior edge of FO and AT (black line), the vertical distance between the anterior edge of FO and IOF (red line), distance between the posterior edge of FO and the anterior edge of EoCC (yellow line). b, distance between the posterior edge of FO and the posterior edge of EoCC (yellow line), transverse distance between the posterior edge of FO and MP (red line). c, anterolateral diameter of FO (black line), mediolateral diameter of FO (yellow line), the vertical distance between the posterior edge of FO and MP (red line)

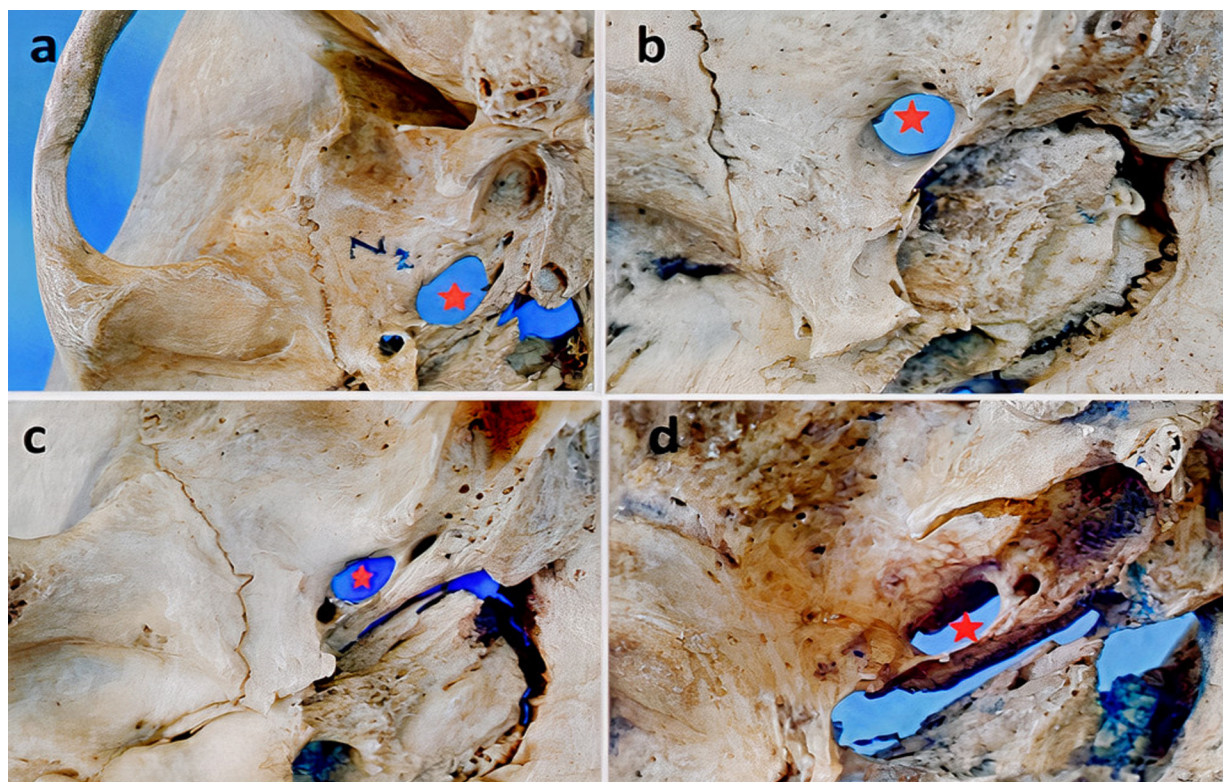


Figure 2. The types of FO shapes. a, almond (second most common (18.75%) foramen). b, round (fourth most common (5%) foramen). c, oval (most common (70%) foramen). d, slit (third most common (6.25%) foramen)



Figure 3. Figure 3. Calculation of distance between the anterior edge of FO and PPF using the image J program

Table 3. Comparison of data among various populations (N: numbers of specimens, SD: standart deviation, FO: foramen ovale)

Author, Year	Country	N	Length of FO (mm) mean±SD	Width of FO(mm) mean±SD	Shape of FO			
					Oval N(%)	Almond N(%)	Round N(%)	Split N(%)
Murugan M and Saheb H, 2014 (18)	India	7.09	Right	Right	345(69)	145(29)	10(2)	0
		7.06	8.9+1.67	3.9+0.98				
		4.16	Left	Left				
		4.15	8.5+1.31	3.7+1.03				
Ray B et al., 2005 (7)	Nepal	29.83	Right	Right	43(61.4)	24(34.2)	2(2.8)	1(1.4)
		29.94	7.46+1.41	3.21+1.02				
		29.82	Left	Left				
		30.76	7.01+1.41	3.29+0.85				
Osunwoke EA et al.,2010 (28)	Nigeria	14.61	Right	Right	-	-	-	-
		15.08	7.01+0.10	3.37+0.07				
		13.05	Left	Left				
		12.80	6.89+0.09	3.33+0.07				
Natsis K et al.,2017 (29)	Greece	18.89	Right	Right	-	-	-	-
		18.82	7.63+1.17	4.47+1.00				
		37.62	Left	Left				
		37.42	7.48+1.20	4.59+1.00				
Hwan SH et al.,2005 (19)	Korea		Right	Right				
		20.37	8.11+0.97	4.12+0.99				
		21.66	Left	Left				
Nagy AA et al., 2018 (30)	Egypt		Right	Right	58 (58)	33(33)	9 (9) other forms	
			6.90+1.13	5.58+1.18				
			Left	Left				
Kanyata D et al., 2015 (31)	Kenya		Right	Right				
			7.70+1.31	4.24+0.64				
			Left	Left				
Javed M et al., 2020 (16)	Pakistan		Right	Right	27(77.14)	5(14.28)	2(5.71)	1(2.86)
			7.64+1.19	5.12+0.82				
			Left	Left				
Somesh MS et al., 2011 (17)	India		Right	Right	93(56.70)	47(28.65)	18(10.97)	6(3.65)
			7.64+1.19	5.12+0.82				
			Left	Left				
Wadhwa A et al., 2012 (9)	India		Right	Right	42(70)	9(15)	6(10)	3(5)
			6.50	3.70				
			Left	Left				
Our study (Akçay E et al., 2021)	Turkey		Right	Right	56(70)	15(18.75)	4(5)	5(6.25)
			7.09±1.07	4.16+0.79				
			Left	Left				
				4.15+0.50				

Significant relationship between the FO and the EoCC, the PPF, the IOF, the MP, the lateral edge of articular tubercle (AT) were noticed and mentioned distances were measured. The vertical distance from the posterior edge of FO to the anterior edge of EoCC was 12.93 ± 1.90 mm (13.05 ± 2.07 mm right and 12.80 ± 1.73 mm left) and the distance between the FO and the posterior edge of EoCC was 18.86 ± 1.88 mm (18.89 ± 2.03 right and 18.82 ± 1.74 mm left). The distance between the anterior edge of FO and the PPF was measured as 14.84 ± 1.91 mm (14.61 ± 1.91 mm right and 15.08 ± 1.92 mm left). Another important distance was between the FO and IOF measured as 30.29 ± 3.20 mm (29.82 ± 3.40 mm right and 30.76 ± 2.97 mm left). The vertical and transverse distances of MP were 37.52 ± 3.43 mm and 21.02 ± 3.09 mm respectively. On the right side the transverse distance was 20.37 ± 3.65 mm and on

the left side 21.66 ± 2.27 mm was recorded. Likewise, on the right side the vertical distance was 37.62 ± 3.23 mm and on the left side was 37.42 ± 3.64 mm. Lastly, the transverse distance between the posterior edge of FO and the lateral edge of AT was 29.88 ± 3.22 mm (29.83 ± 3.41 mm right and 29.94 ± 3.13 mm left). Average, standard deviation (SD), minimum and maximum values of all measured metric values are presented in Table 1. It is important to note that the transverse distance measured from the posterior edge of FO to the AT varied regarding the position of the AT itself. The corresponding line drawn from the FO was above the AT in 4 (4 right, 0 left) cases, below it in 7 (2 right and 5 left) while the remaining measurements (34 right and 35 left) were at the level of the AT (Figure 4).

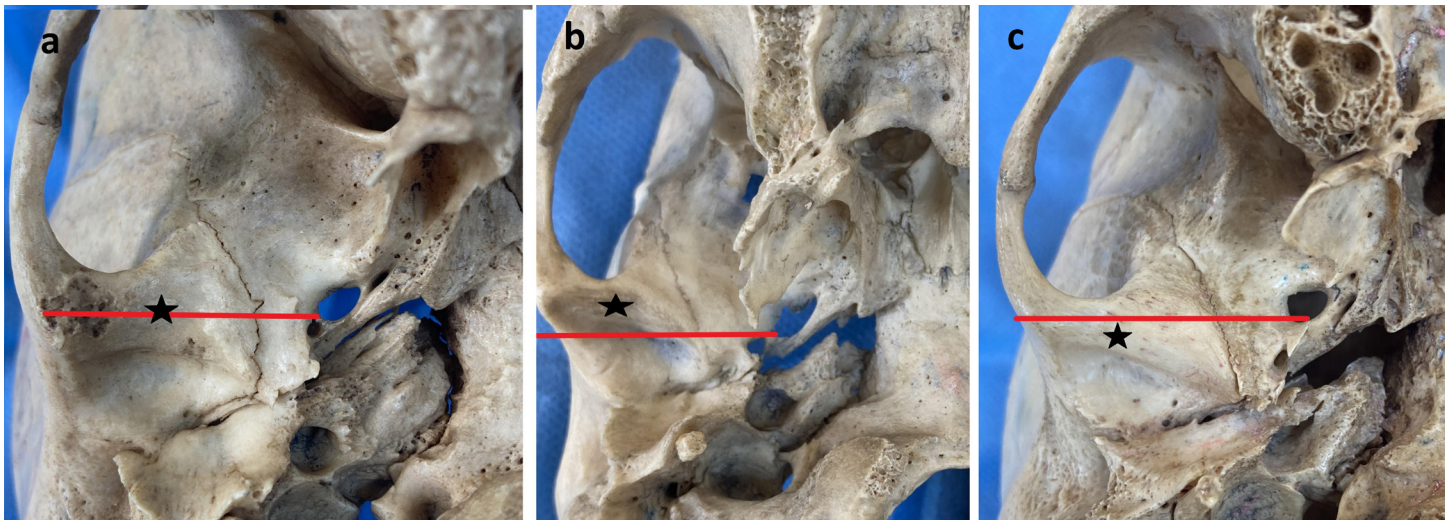


Figure 4. a, the transverse distance between the posterior edge of F and AT which is presented at the level of the AT (black mark). b, the transverse distance between the posterior edge of FO and AT which is presented below the AT (black mark). c, the transverse distance between the posterior edge of FO and AT which is presented above the AT (black mark).

Discussion

The location of the foramen ovale (FO) on the skull base is extremely important in preventing complications that can occur during the percutaneous approach to the FO in surgical procedures, since it contains the mandibular nerve of fifth cranial nerve [1,2,11-13]. Information on FO and its morphological diversity of the human skull base ensures understanding into the relationships between neurovascular (arteries, veins and nerves) structures and cranial morphology [11,14].

FO shows racial and ethnic differences in shape and size in different populations [15]. In the present study the FO is generally oval (70%) in shape. While the findings of shape of current study match some studies [9,16], differ from Somesh M.S's [17] study results. Also the results of length and width of FO differ from the results of Magi Murugan [18], Biswabina Ray [7] and SH Hwan [19]. We support that this difference may consist of a small number of studies which are carried out with bones whose demographic characteristics such as age and gender are unknown.

FO is used for surgical treatment and diagnostic procedures, such as electroencephalographic analysis, percutaneous trigeminal

rhizotomy and percutaneous biopsy of cavernous sinus tumors [11,20,21]. In addition, the morphology and morphometry of the FO is important, as well as its relationship with neighboring bone structures clinically. 9 cases that resulted in blindness have been described in the literature due to the close proximity of FO with the IOF. In reviewing the 9 reported cases in literature, it is described that the most common complication after a percutaneous trigeminal procedure is the acute blindness. During that operation, the used rhizotomy needle enters the IOF and reaches the optic nerve, resulting in blindness with nerve injury [4,21]. Since the proximity of FO to IOF and PPF poses a risk factor in refractory trigeminal neuralgia treatment. Nader A. et al. reported an other application via the PPF as an alternative that might reduce injury to the corneal reflex [3]. Taking this proximity issue into consideration the vertical distance between the anterior point of FO and IOF and the transverse distance between the anterior point of FO and PPF were measured and recorded. While the maximum value between the anterior point of FO and IOF was 36 mm on left, the minimum was 21.60 mm and on right side. Likewise, the maximum value between the anterior point of FO and PPF was 18.66 mm on the left and the minimum was 10.00 mm which is found on the right side. In our study, the distance between the anterior point of FO

and IOF was calculated and no results were obtained to match in literature were found to compare in literature. In the same way, although there is information in the literature about the lateral pterygoid plate height (21.0 ± 3.4 mm), no conclusions could be found about the distance between the FO and PPF [22].

Determining the exact position of the FO by measuring the distances from the posterior edge of FO and the lateral point of AT and MP become vital during penetration procedures from a lateral approach to reach the structures that pass through it [19,23,24]. Because any possible failure in this situation can often cause injury to the structures inside and around the foramina [12]. Therefore, these measurements for identifying the location of the FO, in combination with superficial skin marks, palpable- anthropometric landmarks, and imaging methods, can be utilized as a supplemental support for the surgical invasive procedures mentioned above. However, it should not be forgotten that these parameters are not similar in all population, as the morphology of the FO varies frequently in the Asian, African and European population [25,26]. The vertical and transverse distances between the posterior point of FO and MP was 37.52 ± 3.43 mm and 21.02 ± 3.09 mm respectively. Vertical values of the right side were recorded to be higher than the left side compared to the transverse where the measurements were higher on the left. The distance between the FO and MP was calculated, and no results were obtained to match in literature.

Due to the close proximity of the carotid canal with FO and the vital structures it contains, the distances between the FO and the anterior and posterior points of the EoCC were evaluated. The measurement between the anterior point of EoCC and FO was 13.05 ± 2.07 mm on the right and 12.80 ± 1.73 mm on the left side. The values between the posterior point of EoCC and FO was 18.89 ± 2.03 mm on the right and 18.82 ± 1.74 mm on the left side. Moreover Özalp et al. found that the mean distance between the FO and CC was 12.57 ± 1.56 mm in skulls and 12.45 ± 1.34 mm on CT images [27].

Conclusion

The FO is an important foramina of the skull base. In this study, we have provided average dimensions, all of which can be used as anatomical guidelines during the treatment of trigeminal neuralgia or diagnostic detection of variable osseous structures. Undoubtedly, taking a single bone or a point of a bone as a landmark is insufficient. Orientation waypoints are valuable information for physicians and surgeons. It is an incontestable fact that it can help easier access to the FO, reducing the risk of mandibular nerve injury. The success rate of the operation mainly relies on the practitioners' and surgeons' knowledge of the landmarks of the FO and gaining the right orientation in the skull base. The information maintained in this study along with the existing imaging can help surgeons provide a shorter surgery time and avoid complications.

Conflict of interests

The authors declare that they have no competing interests.

Financial Disclosure

All authors declare no financial support.

Ethical approval

The study was approved by research ethics committee of Istanbul University, Faculty of Medicine (date: 23.11.2020, number: 201949).

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