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ANATOMIC VARIATIONS

Incidence, morphology and morphometry of the foramen of Vesalius: complementary study for a safer planning and execution of the trigeminal rhizotomy technique

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Abstract
Background The foramen of Vesalius (FV) is located in the greater wing of the sphenoid bone between the foramen ovale (FO) and the foramen rotundum in an intracranial view. The FO allows the passage of the mandibular branch of trigeminal nerve, which is the target of the trigeminal radiofrequency rhizotomy.
Objective We analyzed its location, morphology, morphometry and interrelation among other foramina.
Materials and methods 400 macerated adult human skulls were examined. A digital microscope (Dino-Lite plus®) was used to capture images from the FV. A digital caliper was used to perform the measurements of the distance between the FV and other foramina (FO, foramen spinosum and the carotid canal) in an extracranial view of the skull base.
Results In the 400 analyzed skulls, the FV was identified in 135 skulls (33.75%) and absent on both sides in 265 skulls (66.25%). The FV was observed present bilaterally in 15.5% of the skulls. The incidence of unilateral foramen was 18.25% of the skulls of which 7.75% on right side and 10.5% on left side. The diameter of the FV was measured and we found an average value of 0.65 mm, on right side 0.63 mm and on the left side 0.67 mm. We verified that positive correlations were statistically significant among the three analyzed distances.
Conclusions This study intends to offer specific anatomical data with morphological patterns (macroscopic and mesoscopic) to increase the understanding of the FV features as frequency, incidence and important distances among adjacent foramina.

Keywords Foramen of Vesalius · Trigeminal rhizotomy and puncture

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Introduction

The sphenoid bone presents multiple foramina which allow the extracranial passage of nerves and venous plexuses, which enable the brain drainage [19]. The foramen of Vesalius (FV) can be found among these foramina. The FV connects the pterygoid plexus with the cavernous sinus, and transmits a small emissary vein, which drains the cavernous sinus [11]. The importance of this channel lies in the fact that it offers a path to the spread of an infection from an extracranial source to the cavernous sinus. The FV is a small and inconstant channel. It appears between the foramen ovale (FO) and the foramen rotundum (FR), and anteromedial to the FO in an intracranial view [12].

Although the FV is an independent structure, it has a close relationship with adjacent foramina of the middle cranial fossa as the FO, which serves as a passage for the mandibular nerve [10]. The nerve can suffer pathological changes that may lead to a severe disease characterized by shock-like pain. This pathology named trigeminal neuralgia (TN) is the most common neurological cause for facial pain [7], and it can affect the area supplied by the fifth cranial nerve. For treatment of the TN, the radiofrequency rhizotomy (RR) is a low risk, highly effective and minimally invasive procedure [6]. The RR can be described as a percutaneous intervention targeting the FO. During the RR, the professional is guided by many resources as computed tomography (CT) and magnetic resonance (MR) [15], but many punctures are performed until the surgeon finds the exact location of the FO [6]. In these attempts, the FV can be reached by a misplaced needle, resulting in severe complications, as an intracranial bleeding [23].

Based on the observed information, the goal of this descriptive study is to offer specific anatomical values, which aim to guide the surgeon to a better planning and a safer execution of the RR technique. Thus, professionals could avoid a technical error deriving from the unnoted anatomic inferences. The knowledge about the symmetry and incidence of FV is not only important from the anatomical point of view but is also essential for the operating surgeon [5].

Materials and methods

A total of 400 macerated adult human skulls were examined. The samples come from the Museum of Anatomy (FOB/USP/Bauru) and from the Anatomy Laboratory (UNIFESP/SP). Only the skull bases were used with a cross-section of the skullcap. This section provided the identification of the FV. When the FV was identified, we analyzed its location, morphology, morphometry and interrelation among other foramina. To prove the real communication between the middle cranial fossa and the infratemporal fossa by a patent FV, orthodontic wires with a thickness of 0.2 mm were used. These wires were carefully placed inside the FV. This procedure confirmed its trajectory and permeability. In some cases, the emissary foramen was a blind channel, which was recorded as absent.

In the skulls, where the FV was patent, a digital microscope (Dino-Lite plus®) was used to capture images from the foramen. This equipment was connected to a computer, and its software was used to calculate the diameter of the FV. The image was obtained from the skull base in an extracranial view.

The measurements of the distance between the FV and the FO, the distance between the FV and the foramen spinosum (FS) and the distance between the FV and the carotid canal (CC) were performed in an extracranial view of the skull base. Because of the irregular morphology of these foramina, the distances were measured from the closer margin of each foramen to avoid overestimated values. A digital caliper previously calibrated was used to perform the measurements. After the analysis of the 400 skulls, the values were statistically evaluated. The obtained data were compared to other previous studies presented in the literature.

Results

The FV is located anteriorly and medially to the FO, to the FS and to the CC (Fig. 1). In the 400 analyzed skulls, the FV was identified in 135 skulls (33.75%) and absent on both sides in 265 skulls (66.25%). The FV was observed present bilaterally in 15.5% of the skulls. The incidence of unilateral foramen in our study was 18.25% of the skulls of which 7.75% on right side and 10.5% on left side.

When the diameter of the FV was measured in the skulls, we found an average value of 0.65 mm. On right side, the mean diameter was 0.63 mm and on the left side, the mean value was 0.67 mm (Fig. 2).

In our research, the following distances were measured on both sides: distance between the FV and the FO, distance between the FV and the FS, distance between the FV and the CC. The values of the analyzed distances were variable, and the results of the measurements are displayed in Table 1.

Fig. 1 The foramen of Vesalius (FV) is located anteromedial to the foramen ovale (FO), to the foramen spinosum (FS) and to the carotid canal (CC)

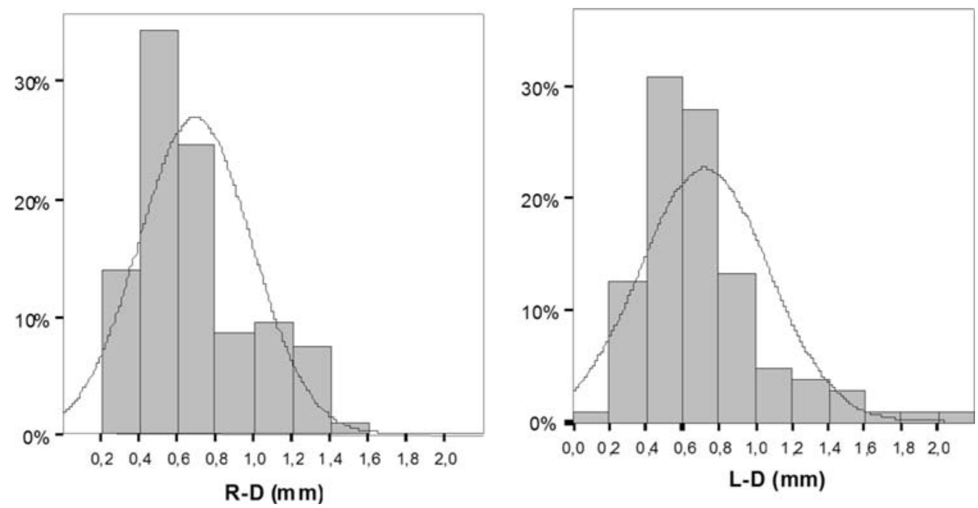

Fig. 2 Histogram of the FV diameter on both sides, diameter of the FV on *right side* (R-D) and on *left side* (L-D)

Table 1 Statistical description of the obtained measurements

Measurement (mm)	*n*	Mean	Median	Standard deviation	Minimum	Maximum
Right diameter (FV)	93	0.69	0.63	0.30	0.24	1.60
Left diameter (FV)	104	0.72	0.66	0.35	0.08	2.06
Distance FV–FO (right side)	93	2.55	2.34	0.90	0.98	5.45
Distance FV–FO (left side)	104	2.59	2.47	0.93	0.93	5.26
Distance FV–FS (right side)	93	11.52	11.39	1.72	7.31	16.85
Distance FV–FS (left side)	104	10.95	10.87	2.02	6.70	18.95
Distance FV–CC (right side)	93	18.77	18.70	1.79	14.54	24.57
Distance FV–CC (left side)	104	18.47	18.14	2.10	13.52	24.13

We performed a comparison between both sides for the values of distances and for the values of diameter. For the evaluation of these data, the paired *t* test was used (Table 2).

There was statistically significant difference between both sides in the measurement of the distance between the FV and the FS.

The Pearson's test was used to calculate correlations. We verified that positive correlations were statistically significant among the three analyzed distances: the distance between the FV and the FO, the distance between the FV and FS and the distance between the FV and the CC (Table 3).

The presence of a double foramen was noted in 7 of 400 analyzed skulls (Fig. 3).

The obtained results were compared with the data of other investigators, and they were reported in the discussion.

Discussion

The emissary foramen, originally noted by Andreas Vesalius, is described as a small and an inconstant aperture in the greater sphenoidal wing [21]. This foramen is classified

Table 2 Comparison between both sides for the values of distances and for the values of diameter

Measurement (mm)	Right side		Left side		*t*	*p*
	Mean	Standard deviation	Mean	Standard deviation		
Diameter	0.67	0.28	0.76	0.39	−1.790	0.078 ns
Distance FV–FO	2.61	0.94	2.73	0.93	−0.937	0.353 ns
Distance FV–FS	11.71	1.77	11.12	1.95	2.277	0.026 *
Distance FV–CC	18.73	2.06	18.68	2.15	0.182	0.856 ns

For the statistical analysis of these data the paired *t* test was used

ns no statistically significant difference

* Statistically significant difference ($p < 0.05$)

Table 3 Pearson's correlation coefficient was used to calculate correlations among the measurements

Correlation	Right side		Left side	
	r	*p*	*r*	*p*
Diameter × distance FV–FO	0.04	0.694 ns	0.09	0.376 ns
Diameter × distance FV–FS	−0.12	0.268 ns	0.03	0.774 ns
Diameter × distance FV–CC	−0.01	0.955 ns	−0.08	0.428 ns
Distance FV–FO × distance FV–FS	0.27	0.009*	0.37	<0.001*
Distance FV–FO × distance FV–CC	0.23	0.027*	0.20	0.045*
Distance FV–FS × distance FV–CC	0.39	<0.001*	0.45	<0.001*

ns no statistically significant correlation, *r* correlation coefficient

* Statistically significant correlation ($p < 0.05$)

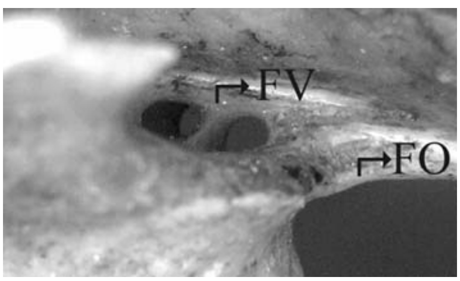

Fig. 3 A double foramen of Vesalius (FV) and the foramen ovale (FO)

as one of the smallest emissary foramen of the skull. When present, this foramen was noted as a structure located anteriorly and medially to the FO, to the FS and to the CC. Its location can also be confirmed in this work based on our observation. Although Vesalius described the presence of this foramen as a rare phenomenon, its importance cannot be denied as a surgical pitfall in the skull because of its variations. Recognition of the anatomical structures and their possible variations will help in distinguishing normal from potentially abnormal structures during the CT and MR imaging examinations [9].

Another procedure which is benefited with the CT images is the TR. The TR is described as a possible treatment for a severe facial pain caused by TN. This technique uses high-tech resources to perform the puncture of the FO. The TR is a low risk, highly effective and minimally invasive procedure in the treatment of the TN. The use of the CT-guided fluoroscopy turns FO's puncture easier, fast and precise [6]. In this surgical practice, a percutaneous intervention is performed targeting the FO. Imaging-guided techniques with CT fluoroscopy increase the efficacy and safety of several nerve block types, especially a trigeminal nerve block [20].

During this intervention, many puncture attempts are made, and the needle can be accidentally introduced in the inferior orbital fissure, in the lacerated foramen, in the jugular foramen, in the CC, and in the FV [6]. All these foramina are constant present in the skull base except the FV, a fact that highlights its importance as a variation into the middle cranial fossa. The needle used is most likely to cause direct damage particularly to the anastomosing venous structures between the cavernous sinus and the pterygoid plexus, which pass through the FO and the FV [8]. A needle insertion through the FV may occur and it can reach an emissary vein in the FV. This surgical complication was described in seven cases of 200 similar procedures [22]. This small emissary vein in the FV drains the cavernous sinus [11], and like the other emissary veins is an important agent in equalizing intracranial pressure, and in some conditions these veins can act as safety valves [3].

Therefore, with the increase of the use of high-tech equipments to analyze images, and the advancements in radiologic techniques, the knowledge about the symmetry and incidence of the foramina of the skull is extremely important for the operating surgeon [23]. Nowadays, the evaluation of these foramina is becoming an important part of diagnostic medicine [1]. Although we could not confirm the following statement, the presence of an asymmetric FV was described as a result of a pathologic process [14], and its asymmetry can be seen as a pathology that compromises the drainage through the emissary vein. Thus, the radiological importance of the FV and other foramina of the skull lies in the fact that pathologic processes involving the base of the skull may alter their size and shape [21]. The professional has to know data about these foramina to avoid a misinterpretation of some image which can lead to a lesion in the middle cranial fossa, as an intracranial hemorrhage in the case of the FV. So, information as the size, the occurrence, the incidence, the asymmetry can provide familiarity with important anatomical features and can show variations which may be clinically significant.

According to Vesalius [24], the FV "is rarely seen in one side of the skull, and much more rarely still on both sides", which disagrees with our results. In this study, the FV was demonstrated in 33.75% of the 400 analyzed skulls. The incidence rate of bilateral foramina was approximately 46%.

In every time the FV was present, it was identified as a single structure which defers from the results found by Shapiro and Robinson [21], who reported that on occasion the FO may coalesce anteromedial with the FV, or the anterior portion of the FO may be considered to be the FV.

Other investigators have reported the incidence of the FV in values which can really vary. The smaller values were found by Williams et al. [25] which mentioned that the FV appeared occasionally in 8.5% of the skulls, followed by Wysocki et al. [26] who found the FV in 17% of cases. According to Kodama et al. [12], 21.75% of the adult skulls had foramen Vesalius. Reymond [19] reported that the FV exists in 22% of cases. Gupta et al. [5] and Boyd [3] presented the closest result to our data, 32.85 and 36.5% respectively. According to Williams et al. [25], Bergman et al. [2] and Lang et al. [13], the foramen can be found in 40% of cases. Higher values were found by other researchers Ramalho et al. [18] and Kaplan et al. [8], whose values were 71.87 and 100%, respectively. The latest value could be explained by the fact that Kaplan et al. [8] had analyzed only ten skulls.

In the present evaluation, this structure was absent on both sides in 66.25%, which is similar to the value demonstrated by Boyd [3] (63.5% of the skulls).

In our study, the FV was present bilaterally in 15.5% of the skulls. Reymond et al. [19] mentioned a considerable lower frequency of the bilateral occurrence of this foramen (5% of the skulls). According to Boyd [3], the incidence rate was 12.5% for bilateral occurrence. Both Kodama et al. [12] and Gupta et al. [5] presented approximately 22% of bilateral foramina. Berge and Bergman [1] found 35% of bilateral presence, the highest incidence.

According to a famous book published by Andrea Vesalius [24] "De humani corporis fabrica", no significant difference in frequency of unilateral occurrence between the left and right sides was demonstrated. The incidence of unilateral foramen in our study was 18.25% of the skulls of which 7.75% on right side and 10.5% on left side. Our results were close to values found by Boyd [3] when the foramen was present on the right side only in 10.6% and on the left side only in 11.2%. According to Gupta et al. [5], it was present unilaterally in 20% of the skulls (7 out of 35 skulls) out of which 6 were on right and 1 on left side. Bergman et al. [2] reported the presence of this foramen unilaterally in 13% of cases. According to a study performed by Kodama et al. [12] in adult skulls, 5.5% presented unilateral foramina. Ginsberg et al. [4] observed unilateral presence of FV in 80% cases by high-resolution CT. Lang et al. [13] found the FV in 49% of the skulls on right side and 36% on left side. Though the FV was more observed on right side, no significant difference was found in both sides.

Based on our data, we can disagree with various previous reports, which reported that the incidence of bilateral foramen is bigger than unilateral foramen in individual skulls [5, 12].

The presence of a double foramen was noted in 7 of 400 analyzed skulls. This fact is noteworthy if compared to the number exposed by Boyd [3] who only found 1 double foramen in 1,000 analyzed skulls.

The diameter of the FV was also analyzed in this work. We found an average diameter of 0.7 mm. On right side, the average diameter was 0.69 mm (range 0.24–1.6 mm), and on the left side, the value was 0.72 mm (range 0.08–2.06 mm). In 29% of cases, the diameter value was below 0.5 mm, in 55% the FV had a value between 0.5 and 1 mm, and in 16% the value was above 1 mm. According to Boyd [3], in 65% of cases, the FV was 0.5 mm, in most of the others it was 1 mm, in only 5% it was over 1 mm, in three cases it was 2 mm and in one case it was 2.5 mm. The mean diameter found in the work of Kaplan et al. [8] was 1 mm (range 0.8–1.2 mm). Lanzieri et al. [14] studied 50 high-resolution CT and found well-formed foramina, 1–2 mm in size in 59% of the films. Lang et al. [13] observed FV as large as 2 mm.

The needles used in the TR have diameter between 0.7 and 1.27 mm [7, 16, 20], which could reach the FV. The mean diameter of the FV found in this work was 0.7 mm, and 44.1% of the diameters was values between 0.7 and 1.27 mm, which could be reached by the needles. This fact consists in one of the complications that result from the TR, the puncture of the FV [22, 23].

In our research, the following distances were measured on both sides: the distance between the FV and the FO, the distance between the FV and the FS and the distance between the FV and the CC. The average distance between the FV and the FO was 2.55 mm on the right side and 2.59 mm on the left side. The average distance between the FV and FS was 11.52 mm on the right side and 10.95 mm on the left side. In the distance between the FV and the CC, we found an average value of 18.77 mm on the right side and 18.47 mm on the left side. Kaplan et al. [8] reported the FV with a distance of 4 mm (range 3–5 mm) anteromedial to the FO. According to Ramalho et al. [18], this measurement is much greater than ours, they found 7 mm on the right side and 6 mm on the left side.

The veins are the anatomical structures that present the greater rate of variation in the human body. By the fact that the FV transmits an emissary vein, the presence or the absence of this vein could justify the presence of the FV.

The differences on the data found in some studies can be explained by the differences in methodology. Variations in the FV can be also explained by developmental reasons, because the sphenoid bone has a complex embryologic development, and the FV is one site of embryologic fusion in the sphenoid bone [5]. Development of the skull base begins after the spinal cord, cranial nerves, and blood vessels have formed [17]. Thus, the presence of the FV is closed related with the individual venous drainage organization. Therefore, we can expect some levels of variation in the data presented by many different authors.

In brief, the FV is an anatomical variation that has a high incidence (33.75%). This fact highlights its importance in the TR technique as described in the literature.

Finally, we can infer that the information provided with our study can help the surgeon and researchers to increase the knowledge about anatomy in the middle cranial fossa. In conclusion, we can also believe that these data can really be used to improve the operate condition allowing a safer TR execution by avoiding the FV puncture.

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