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ORIGINAL ARTICLE

Foramen venosum: a clinicoanatomic insight into its occurrence and morphometry

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Abstract

Purpose The present study aimed to evaluate the foramen venosum (FV) frequency, incidence, morphometry and relation with foramen ovale in an Indian population. The emissary vein passing through it may spread extracranial facial infections to the intracranial cavernous sinus. Due to its close proximity with the foramen ovale and its variable occurrence, awareness about its presence and anatomy is essential to neurosurgeons operating in this region.

Methods 62 dry adult human skulls were studied for the occurrence and morphometry of foramen venosum, both at the middle cranial fossa and extracranial base of the skull. Dimensions were taken using Java-based image processing program, IMAGE J. After collection of data, appropriate statistical analysis was done.

Results The foramen venosum was observed in 49.1% skulls. Its presence was noted more frequently at the extracranial skull base than in the middle cranial fossa. No significant difference was observed between the two sides. FV at the extracranial view of the skull base had a larger maximum diameter than in the middle cranial fossa; however, the distance between FV and the foramen ovale was found to be more at the middle cranial fossa than at the extracranial view of the skull base on both the right and left side. Variations in the shape of the foramen venosum were also observed.

Conclusion The present study is not only of great importance to anatomists, but also to radiologists and neurosurgeons for better planning and execution of the surgical approach to the middle cranial fossa through the foramen ovale to prevent iatrogenic injuries.

Keywords Morphometry · Foramen ovale · Foramen venosum · Emissary veins · Cavernous sinus thrombosis

Introduction

The skull base has multiple foramina, which allow passage to important nerves and blood vessels in and out of the cranium. The foramina present in the middle cranial fossa are of crucial importance to neurosurgeons and neurophysicians. Among various studies conducted on these foramina, very little attention has been paid to the foramen venosum (FV) that is small and infrequently present. Intracranially, FV opens in the middle cranial fossa, antero-medial to the foramen ovale, whereas extracranially, it opens near the scaphoid fossa of the skull base [1].

As the name suggests, FV was found by Andreus Vesalius [27] and is also known as sphenoidal emissary foramen, since it gives passage to a small vein (vein of Vesalius) that connects the pterygoid venous plexus with the cavernous venous sinus [7]. As the pterygoid venous plexus is further connected with the anterior facial vein, infection from the upper part of the face may easily travel to the cavernous sinus via the sphenoidal emissary vein. Also because of its close proximity to the foramen ovale, FV content may accidentally get damaged or infected during surgical intervention for trigeminal neuralgia performed through the foramen ovale. Hence, detailed knowledge of the anatomical variations of FV is essential for clinicians analyzing tomographic images of the region and performing various invasive procedures on the head and neck such as radiofrequency rhizotomy of the trigeminal nerve, temporal lobe electrode placement, balloon deployment to treat trigeminal neuralgia or cavernous sinus tumor biopsy [20].

The authors have analyzed the characteristics of FV in different population and reported variable incidence of this foramen around the world (Table 1) ranging from 10% [12] to

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Table 1 Distribution and dimensions of the foramen venosum reported by various authors

Author	Year	Country	Sample size/type	Frequency (%)			Mean maximum dimension (mm)		FV–FO distance (mm)	
				T	U/L	B/L	Right	Left	Right	Left
Chaisuksunt et al. [3]	2012	Thailand	377 dry skulls	17.2	12.7	4.5	1.71* 2.29**	2.22* 2.58**	3.15* 2.05**	2.53* 2.05**
Ozer et al. [19]	2014	Turkey	172 dry skulls	34.8	25.5	9.3	0.86	1.07	2.30	2.46
Toledo Junior et al. [30]	2016	Brazil	84 dry skulls	41.6	–	16.6	–	–	–	–
Bayrak et al. [1]	2018	Turkey	317 CBCT	28.1	21.1	6.9	2.66	2.82	2.31	2.21
Natsis et al. [15]	2018	Europe	195 dry skulls	40	18.5	21.5	2.63	2.79	2.40	2.22
Costa do Nascimento et al. [4]	2018	Brazil	194 skulls	18.5	12.4	6.1	3.23	2.59	2.90	2.55
Leonel et al. [9]	2019	Brazil	1000 CT 170 skulls, 50 cadavers	46.8 45.2 14	21.4 26.4 8	25.4 18.8 6	–	–	–	–
Görürgöz et al. [5]	2020	Turkey	260 CBCT	73.1	30.8	42.3	1.75	1.75	1.46	1.32
Maletin et al. [10]	2020	Serbia	26 dry skulls	61.5	12.5	87.5	–	–	–	–
Within Indian regions										
Gupta et al. [6]	2014	Central	200 Dry skulls	34	20	14	–	–	1.36	1.48
Nirmala et al. [18]	2014	Southern	180 Dry skulls	50	26.6	23.3	–	–	–	–
Raval et al. [24]	2015	Western	150 Dry skulls	60	35.6	32.2	0.98	1.12	0.98	1.12
Murlimanju et al. [14]	2015	Southern	78 Dry skulls	37.2	20.5	16.7	–	–	–	–
Prakash et al. [22]	2015	Southern	22 Dry skulls	40.9	14.3	28.6	2.36**	1.50**	1.45**	2.1**
Jadhav et al. [8]	2016	Western	250 Dry skull	28.8	17.6	11.2	–	–	–	–
Nayak et al. [16]	2018	Eastern	30 Dry skull	30	10	20	1.13	1.38	1.42	2.17
Mamatha et al. [11]	2019	Southern	100 Dry skull	10	10	0	–	–	–	–
Srivastava et al. [12]	2021	Central	30 Dry skull	10	6.6	3.4	0.9–1.1	1.41	4.2–3.9	2.1
Priya [23]	2022	Southern	100 Dry skull	45	25	20	–	–	–	–
Sthapak et al. [29]	2022	Central	200 CT scans	26	16	5	–	–	–	–
Present study	2022	Northern	62 dry skull	41.9	11.2	30.6	1.33* 1.84**	1.44* 1.44**	3.62* 2.2**	3.65* 2.35**

– Not informed

*Middle cranial fossa, **extracranial surface

73.1% [5]. Literature suggests that inconsistency during fusion between various parts of the developing sphenoid bone may be responsible for its variable occurrence. Ethnic differences and evolutionary processes may further influence this, signifying the need of having a local standard value in every region. Due to lack of studies on FV in India, especially in the north Indian population, knowledge of its topographic anatomy and morphometric values is still not sufficient for performing safe treatment in surgeries of middle cranial fossa The present study thus aimed to evaluate the foramen venosum frequency, morphometry, and relation with foramen ovale in the Indian population. The clinical implications and the embryological basis of its occurrence will be discussed.

Methods

The present study was done over a period of 3 months from October 2022 to December 2022 in the Department of Anatomy, Maulana Azad Medical College, New Delhi. 62 (30 skull bones, 32 sphenoid bones) dry adult human bones of unknown sex and ages procured from the dry bone repository of the department were used in the study. Only bones with regular shape and without evidence of dystrophy, deformities, and trauma, were selected. Bones that could not be evaluated bilaterally because of damage to surrounding bones were also excluded. The incidence of

FV was studied and variations in size, shape, duplication, laterality, patency, and distance of FV from the foramen ovale were noted both in the floor of the middle cranial fossa and at the extracranial skull base.

A thin wire of 0.1 mm was used to confirm the patency of the foramina by inserting it into the FV from the extracranial view of the skull base to the middle cranial fossa. A digital camera of 8 megapixel resolution, in auto ISO, was used to capture the photographs of FV from both the middle cranial fossa and at the extracranial skull base from a precise distance of 25 cm. Calibrated photographs were then analyzed for the measurement of maximum and minimum diameters of FV and the distance between FO and FV by processing the images in a Java-based program, IMAGE J 1.x (available in public domain) developed at the National Institutes of Health and the Laboratory for Optical and Computational Instrumentation (LOCI, University of Wisconsin) Bethesda, Maryland, USA (Fig. 1). Each measurement was performed two times and averaged. All measurements and frequencies of the data were tabulated and separated according to laterality, shape, patency, and side.

After data collection, entry was done in the Microsoft Excel spreadsheet and the final analysis was done with the use of Statistical Package for Social Sciences (SPSS) software, IBM manufacturer, Chicago, USA, ver. 25.0. The presentation of the categorical variables was done in the form of numbers and percentages (%), whereas quantitative data with normal distribution were presented as the means ± SD. The comparison of quantitative variables was analyzed using an independent t test, whereas qualitative variables were assessed using χ^2 test. For statistical significance, a p value of less than 0.05 was considered statistically significant.

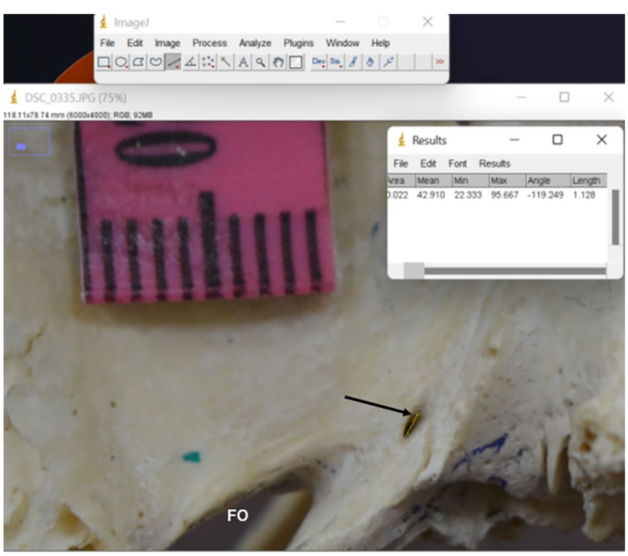

Fig. 1 Measurement of FV diameter using IMAGE J software1.x (available in public domain) developed at the National Institutes of Health and the Laboratory for Optical and Computational Instrumentation (LOCI, University of Wisconsin). Bethesda, Maryland, USA

Results

The present study demonstrated the total incidence of the foramen venosum as 41.9%. FV was noted more frequently on the extracranial view of the skull base (54.2%) than in the middle cranial fossa (45.7%). On being evaluated with respect to side, no significant difference was noted in the occurrence of foramina between the right and the left side at both the middle cranial fossa and skull base (Table 2) The foramen was found more bilaterally (73%) than unilaterally (Fig. 2). On checking the patency of FV, only 5.7% of FVs were non-patent, of which 4% were unilateral and 1.7% bilateral. Duplication of this foramen was observed in 7.5% skulls (Fig. 3).

When compared for shape, slit (35%) and round (34%) shape foramina were found to be most common, followed by oval (29%) shape, whereas in two cases FV was found to be directly open in the foramen ovale (Fig. 4).

Table 2 Comparison between the sides for distribution of the foramen venosum (FV) in dry skull bones using Chi-square test

	N	Intracranial	Extracranial (skull base)	P value
Total	105	48 (45.7%)	57 (54.2%)	–
Right side	51	23 (45%)	28 (55%)	0.902
Left side	54	25 (45.4%)	29 (53.7%)	0.902

χ^2 test

Statistically significant difference ($P < 0.05$)

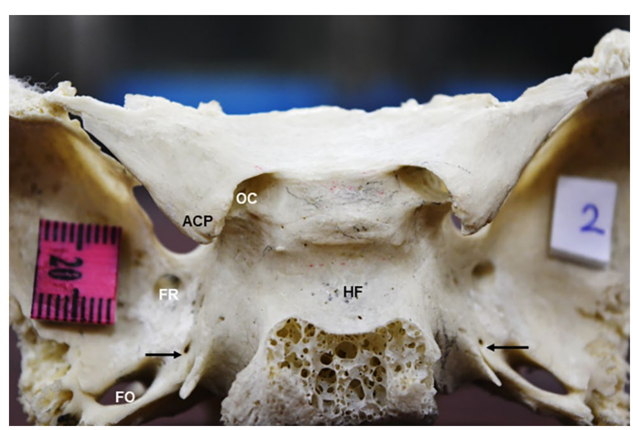

Fig. 2 Superior view of the sphenoid bone showing the bilateral presence (arrow marked) of the foramen venosum in the middle cranial fossa

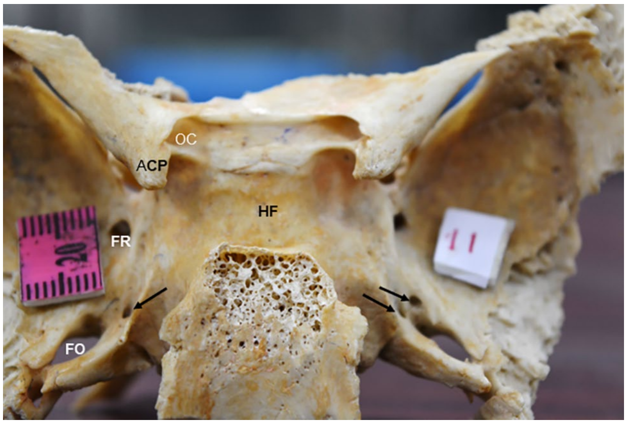

Fig. 3 Superior view of the sphenoid bone showing duplication of the foramen venosum on the right side of the middle cranial fossa

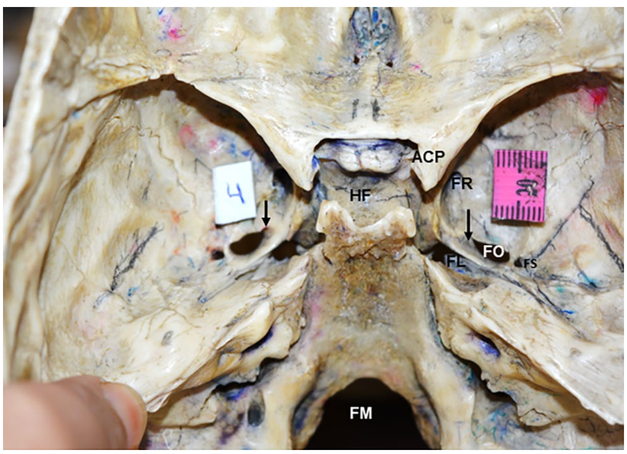

Fig. 4 Superior view of the skull showing bilateral opening of FV in the foramen ovale in the middle cranial fossa. *FO* foramen ovale, *FR* foramen rotundum, *FS* foramen spinosum, *FM* foramen magnum, *HF* hypophyseal fossa, *OC* optic canal, *ACP* anterior clinoid process

Comparatively, FV at the extracranial view of the skull base had a larger maximum and minimum diameter than in the middle cranial fossa. On comparing between the left and right side, larger diameter of FV was observed on the left side in the middle cranial fossa and on the right side at the extracranial skull base; however, the difference was not statistically significant (Table 3).

A larger distance was observed between FV and FO at the middle cranial fossa than at the extracranial skull base. When compared between the left and the right side, no significant difference was observed in both middle cranial fossa and extracranial skull base (Table 3).

Discussion

The FV is a small, variable foramen present in the middle cranial fossa within the bony plate of the greater wing of the sphenoid antero-medial to the foramen ovale and lateral to the foramen rotundum [26]. Morphological knowledge of FV is crucial for neurosurgeons while approaching the middle cranial fossa because of its variable presence and proximity to FO.

Inconsistency in the occurrence and morphology of FV can be explained by understanding its development. Embryologically, most of the central skull bones are formed majorly by endochondral ossification with only a small contribution from membranous bones [7]. Sphenoid bone develops from post-sphenoid and pre-sphenoid centers appearing at 14 weeks and 17 weeks and fusing in the 7th or 8th months of intrauterine life, respectively [13]. Ossification is also seen laterally in the orbito-sphenoid (16 weeks) and alisphenoid (15 weeks). The pre-sphenoid's cartilaginous ossifying center forms the body of the sphenoid anterior to the tuberculum sellae, whereas the post-sphenoid's part forms the basisphenoid including sella turcica and posterior part of the body of the sphenoid bone. Orbito-sphenoid and alisphenoid contribute to lesser wing and medial part

Table 3 Comparison between sides for the foramen venosum (FV) diameter and distance from the foramen ovale (FV–FO) using independent *t* test

Measurement (mm)	Total sides		Right side		Left side		*P* value
	N	Mean ± SD	*N* (%)	Mean ± SD	*N* (%)	Mean ± SD	
FV in the middle cranial fossa							
Maximum diameter	48	1.386 ± 0.68	23 (47.9)	1.326 ± 0.69	25 (52)	1.442 ± 0.68	0.561*
Minimum diameter	46	0.616 ± 0.43	22 (47.8)	0.606 ± 0.43	24 (52.1)	0.625 ± 0.43	0.883*
FV–FO distance	46	3.681 ± 1.55	22 (47.8)	3.622 ± 1.59	24 (52.1)	3.65 ± 1.52	0.952*
FV at the extracranial view of skull							
Maximum diameter	57	1.632 ± 0.91	28 (49%)	1.842 ± 0.92	29 (51%)	1.442 ± 0.68	0.120*
Minimum diameter	57	0.623 ± 0.41	28 (49%)	0.658 ± 0.49	29 (51%)	0.588 ± 0.34	0.532*
FV–FO distance	57	2.279 ± 1.36	28 (49%)	2.203 ± 1.35	29 (51%)	2.353 ± 1.38	0.680*

Independent *t* test

Statistically significant difference ($P < 0.05$)

of the greater wing containing the foramen rotundum, ovale and spinosum, respectively. The lateral part of the greater wing and the lateral pterygoid plate develop from intramembranous ossification. It has been suggested that the FV represents the site of fusion between developing sphenoid parts, which ossify in separate modes [7, 17]. Few authors have suggested that the FV may be a subdivided part of FO [8, 20].

Among various studies conducted, incidence of FV was found to be varying with race, topography, and environmental factors worldwide as well as within India (Table 1). In the present study, the overall incidence of FV was found to be 41.9% regardless of the side. Similar [15, 30], lower [1, 3, 4, 19], and higher incidences [5, 9, 10] have been reported in literature. Between imaging studies as well, varying incidence was observed worldwide ranging from 28.1% [1] to 73.1% [5]. Within India, the central [6, 12, 29] and eastern [16] regions reported a lower incidence in comparison to the present study, whereas the southern and western regions reported both higher [18, 23, 24] and lower [8, 11] occurrences of FV. India is a large country divided into 28 states, 8 union territories, and 5 geographic regions harboring more than 1 billion population with huge ethnic diversity in every region. These population groups resemble or differ from each other in terms of genetic traits and hence may report variable incidence. Further to the best of our knowledge, the present study is among the first few studies conducted in our region, and the only one showing similar incidence [22] had a very low sample size. Differences in the data detected from other studies can also be due to differences in the method of the study as well as the number and type of samples. Evolutionary processes, adaptive skeletal responses to local biomechanical stimuli, genetic drift, and migration frequency of the population may also add to these variations. Hence, a detailed study on the morphological characteristics of FV in every population is important.

The present study investigated the patency of FV and observed that only 5.7% of foramina were non-patent. FV was noted more frequently at the extracranial view of the skull base than in the middle cranial fossa, suggesting that few FVs seen in the extracranial view were blind channels. Leonel et al. [9] observed similar blind channels at the external surface of the cranial base in 9.5% of CTs and 21.1% of dry skulls, whereas Chaisuksunt et al. [3] observed them in 16.1% skulls. In contrast, few authors [3, 22] have reported lower number of patent foramina. Anatomical studies have revealed that FV may not be a thoroughfare channel, it may end at the diploe of the bone [28] or open into the pterygoid canal as observed in our study. Whenever FV is absent, the respective emissary vein traverses through FO. Literature suggests that though it is often absent, two or more diploic channels opening independently on the interior and exterior of the skull may take its place [2].

More bilateral foramina as seen in the current study are also observed in most recent studies [5, 9, 10, 15]. They further suggested that FV asymmetry could be due to invasion by diseases such as nasopharyngeal melanoma, angiofibroma or carotid-cavernous fistula draining into FV through the emissary vein. Therefore, knowledge about laterality is important in evaluating infratemporal pathology [22]. Few studies reporting more unilateral foramina are also documented in the literature [1, 3, 4, 19, 25]. In a meta-analysis by Piagkou et al. [21], FV prevalence is estimated at 38.1% and unilateral dominance was found to be associated with decrease in prevalence. Leonel et al. [9] in their study observed more bilateral foramina among imaging samples and more unilateral FVs among dry skull bone. Such contrasting results between the different sample types within the same study emphasize the importance of having imaging studies for assessing FV in every region. Among Indian research, only two authors other than the present study reported more bilateral foramina [16, 22]. In both these studies, however, the sample size was very low.

The present study did not observe any significant difference in the occurrence of FV between the left and right side. Contradictory to our findings, a few previous studies have reported a greater number of FVs on either the left [4, 15, 19] or right side [1, 25, 30]. Among Indian studies, the majority have reported more left [6, 18, 24] foramina than right [8, 11]. However, amid already limited studies conducted on FV in India, most lack comparison between the two antimeres.

Duplication of FV observed in the present study was also noted in a few other studies [5, 15, 19, 24]. However, the number of duplicated foramina reported by them was less as compared to the present study (7.5%). Variations among the shape and confluence of the FO with FV are also reported in the literature [1, 5, 24]. The present study reported the least number of oval shape foramina contrasting the findings of Bayrak et al. [1] and Görürgöz et al. [5] who observed irregular foramina as least common. The difference in the sample type may play a role in this, as the latter two studies were conducted on CBCT images. In the present study, 2 FV was found directly opening into the foramen ovale. A similar confluence was observed by Baryak et al. [1] and Görürgöz et al. [5] in 25.2 and 24.67% of the cases, respectively. Natsis [15], however, detected confluence in two skulls.

The present study reported a smaller diameter of FV in the middle cranial fossa than at the extracranial skull base. Similar findings were observed by Chaisuksunt et al. [3]. On comparing the sides with in the middle cranial fossa, literature reports a larger diameter on the left side [25]. However, at the extracranial skull base, a larger diameter was noted on the right side [4, 22]. The current study observed similar findings; however, the difference was not found to be statistically significant. In contrast, one study [19] reported a larger diameter on the left side at the extracranial skull base. The dimensions of FV observed by a few of these authors were either very small [19] or very large [22] in comparison to our findings on both the left and right side, thus emphasizing the importance of establishing the local value in every region. As observed in the current study, many other authors [5, 15, 16, 24] also did not observe any significant difference in the size of FV of the two sides, but most of them lack the assessment of measurements from both the extracranial surface and the middle cranial fossa.

As in the present study, few authors [3] observed greater distance between the FV and FO at the middle cranial fossa than at the extracranial view of the skull base on both right and left side. However, when comparing the distance at the middle cranial fossa and at the extracranial skull base we observed no significant difference in dimensions between the left and right sides. On the contrary, studies noting lesser FV–FO distance on the right [6, 16, 19, 22, 25] than on the left side [4, 5, 9, 15] have also been reported.

Emissary veins passing through these FV link the intracranial venous sinuses with extracranial veins and may carry infected thrombus to the interior of cranial cavity. This may result in the spreading of suppurative infection from the orbit, paranasal sinuses, upper half of the face, and even teeth resulting in thrombophlebitis or cavernous sinus thrombosis [5].

Knowledge of the cranial base morphology is vital for clinicians analyzing tomographic images of the region, while comparing normal findings with abnormal variations [10]. It is also essential for safely carrying out neurosurgical procedures such as percutaneous trigeminal rhizotomy or Gasserian ganglion compression for treating trigeminal neuralgia, percutaneous biopsy of parasellar lesions, and electroencephalographic analysis of the temporal lobe among patients undergoing selective amygdalohippocampectomy for treatment of epilepsy [15]. Previous studies have shown that needle displaced from FO could enter the FV and penetrate the emissary vein or make a puncture in the cavernous sinus, resulting in severe complications such as intracranial bleeding in the temporal lobe [1]. Ozer et al. [19] have suggested that the diameter of FV > 0.5 mm was highly risky for percutaneous techniques on the foramen ovale, as usually needles with a diameter between 0.7 and 1.27 mm are used in these procedures [5]. In the present study, the majority of FV diameters were more than this, suggesting the importance of our findings for neurosurgeons as the direction, angle, and position of any procedure in this region have to be modified according to measurements of FV. Authors [3, 22], including those of the present study, observed that with increase in the diameter of the FV, the distance between the FV and FO decreased. In such cases, inconsistent FV presence becomes more important for both radiologists and neurosurgeons. Tumors of nasopharyngeal origin are the most likely intracranial tumors to invade the middle portion of the skull base through the above-mentioned foramen [3].

Apart from being among the first few studies conducted in the northern part of India, the present study is also unique as the literature reports very limited studies assessing the FV from both extracranial and intracranial surfaces. However, one limitation of our study is that we used only dry skull samples. More research should be conducted using imaging techniques where the gender and age-specific estimates can also be correlated with the occurrence of FV.

Conclusion

The FV shows variations in incidence, size, and shapes in the present study. Usually, this foramen does not attract much attention of the surgeons, while performing the microneurosurgical procedures such as rhizotomy. The presence of FV near the foramen ovale, particularly at the extracranial view of the skull base, makes this foramen and its contents clinically unsafe. Prior detailed knowledge may prevent iatrogenic injuries, hemorrhages, and spread of infection to the cavernous sinus. Results of the present study can provide detailed knowledge on the anatomic characteristics of FV in the Indian population.

Author contributions NP: material preparation, data collection, analysis, and manuscript writing. SS: material preparation, data collection, analysis, and manuscript writing. SM: material preparation, analysis, and manuscript editing. All authors read and approved the final manuscript.

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Availability of data and materials All data and materials are available upon reasonable request.

Declarations

Conflict of interest The authors have no interests of financial, non-financial, or personal nature.

Ethical approval This declaration is not applicable.

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