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REVIEW

Morphology and morphometry of the foramen venosum: a radiographic study of CBCT images and literature review

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Abstract

Purpose The goal of this study was to assess the morphological variations, location, and morphometric measurements of the foramen venosum (FV) and analyse its interrelationships with other foramina on cone-beam computed tomography (CBCT) scans.

Methods A total of 269 individual CBCT scans were evaluated retrospectively. The presence or absence of FVs and their diameter, shape, and confluence to foramen ovale were recorded. The distances between anatomic structures and the FV were calculated. Appropriate statistical analysis was performed for the collected data.

Results Of the 269 cases studied, nine were excluded due to duplicate foramina that made statistical analysis difficult. In the 260 evaluated scans, the FV was identified in 190 individuals (73.1%). The incidence was 148 (56.9%) on the right side and 152 (58.5%) on the left side. The FV was present unilaterally in 80 (30.8%) and bilaterally in 110 (42.3%) out of the 260 individuals. The mean maximum diameter of FV was 1.75 ± 1.27 mm, and no significant differences related to gender and age were detected ($p < 0.05$). The most prevalent foramen shape was the oval type (45.9% on the right side and 40.8% on the left side).

Conclusion FV is a very frequent anatomical variation. This foramen can exist either bilaterally or unilaterally. No significant differences related to sex, side, or age could be found in the present study. The anatomic characteristics of FV should be considered during interventions in the middle cranial fossa. CBCT imaging with lower radiation doses and thin slices may prove useful before surgical skull-base procedures.

Keywords Anatomy · Cone-beam CT · Foramen Vesalius · Radiology · Sphenoid bone

Abbreviations

CBCT	Cone-beam computed tomography
CC	Carotid canal
CT	Computed tomography
ESFO	Emissary sinus of foramen ovale
FO	Foramen ovale
FOV	Field of view
FR	Foramen rotundum
FS	Foramen spinosum
FV	Foramen venosum
PPF	Pterygopalatine fossa
VC	Vidian canal

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Introduction

Foramina in the greater wing of the sphenoid bone allow extracranial passage of important structures, such as blood vessels, venous plexuses, and nerves, facilitating drainage of fluids from the brain [35]. The sphenoid bone typically contains the foramen ovale (FO), foramen rotundum (FR), and foramen spinosum (FS) and may also contain additional small foramina. Foramen venosum (FV) is one of these atypical foramina of the skull [34].

The FV is also known as the sphenoidal foramen, foramen Vesalii, foramen of Vesalius, canaliculus sphenoidalis, and sphenoidal canaliculus [17]. In 1543, Andreas Vesalius provided the first description of the FV. It transmits small emissary vein/veins (vein of Vesalius) that connect the pterygoid plexus with the dural venous sinus [14]. Embryologically, the FV represents the site of fusion of the membranous bone and medial cartilaginous ala temporalis [43].

The importance of the FV can be attributed to its role in the potential spread of infection from an extracranial space to the intracranial venous sinus [13]. FVs are usually detected anteromedial to the FO and lateral to the FR [35]. However, this foramen has a particularly close relationship with the FO; therefore, during percutaneous interventions to the FO in neurosurgery for the treatment of trigeminal neuralgia, a misplaced needle can produce severe complications, such as intracranial bleeding [43]. Moreover, knowledge of the FV is important during dental procedures, such as posterior superior alveolar nerve block [1].

In the literature, the anatomical characteristics and morphometry of the FV, especially in dry skulls, have been widely presented [8, 13, 34, 42]. However, imaging data for this foramen are limited [6, 39]. This descriptive retrospective study aimed to assess the variations in morphology and morphometry of the FV using CBCT. Furthermore, the influence of age and gender on these findings was analysed. The obtained results were compared with the findings of previous studies presented in the literature.

Materials and methods

Study design and sample selection

The CBCT records of 1491 patients who were referred to the Dentistry Faculty's Department of Dentomaxillofacial Radiology between Dec 2016 and Dec 2017 were reviewed. CBCT examinations were performed to evaluate cases with several dentomaxillofacial problems, such as impacted teeth, oral pathologies, orthognathic surgery, pre-orthodontic treatment, and dental implants. CBCT scans of 269 individuals (166 females and 103 males) were randomly selected by a dentomaxillofacial radiologist from the digital archive. The protocol of this study was approved by the local ethics board of the institution.

The inclusion criteria were as follows: (1) images of the skull base, especially of the mid-cranial fossa, covering the imaging field of view (FOV) and (2) CBCT images with good diagnostic quality. The exclusion criteria were as follows: (1) evidence of bone disease; (2) maxillofacial trauma history; (3) congenital abnormality; (4) history of surgery; (5) malignancy or facial fractures; and (6) presence of orthodontic expansion devices.

The age of the individuals in the study group was recorded on the basis of the date on which the CBCT scan was taken. Age groups were classified as follows: young group (< 20 years), young adult group (21–30 years), adult group (31–40 years), pre-elderly group (41–50 years), and elderly group (> 51 years). The gender of the individuals was recorded.

CBCT imaging

All CBCT scans were performed in compliance with a standardized scanning protocol and obtained using a Planmeca ProMax 3D Max (Helsinki, Finland) scanner with the following parameters: 96 kVp; 5.6–12 mA; 9–15 s scan time; FOVs of 13 × 9 cm, 23 × 16 cm; and voxel sizes of 200 or 400 µm. All data were reconstructed at 0.5-mm slice interval and thickness.

CBCT evaluations

All measurements and analyses were performed on CBCT images by the same oral radiologist using the Romexis 3.7 software (Planmeca Oy, Helsinki, Finland) on a 21.3-inch flat-panel monitor (NEC MultiSync; Munchen, Germany) with 2048 × 2560 pixel resolution, under dim-light conditions. The examiner could adjust the brightness and contrast of the images with the image-processing tool in the software to ensure ideal visual conditions for an accurate diagnosis. Images were evaluated from the sagittal, coronal, and axial planes to ensure a three-dimensional analytical approach.

This study started with the identification of the FV. To prove the patency of the FV, orthodontic wires (thickness 0.2 mm) were used in in vitro studies [8, 34, 42]. In this study, the continuity of the FV in CBCT images through the infratemporal fossa to the middle cranial fossa was determined as the criterion, and in cases showing blind endings of the channel, FV was recorded as absent.

After the FV was identified, its morphology, morphometry, and interrelationships with other foramina were analysed. The anatomical characteristics of the FV assessed included the laterality (unilateral or bilateral), presence or absence, and foramen duplication (Fig. 1). The FV shape was classified as round, oval, irregular, and pinhole in the extracranial view of the skull base. FV shape was evaluated in the first axial slice where the foramen was observed with a sclerotic rim and a radiolucent centre (Fig. 2).

Dimensional measurements of the FV and the distance between the FV and other foramina (FO and FS) and pterygopalatine fossa (PPF) were obtained in axial images (Fig. 3). The morphometric parameters were as follows:

1. The maximum diameter of the FV.
2. Distance from the FV to the FO (FV – FO).
3. Distance from the FV to the FS (FV – FS).
4. Distance from the FV to the PPF (FV – PPF).

Due to the irregular shape of these foramina, the distances were measured from the closest margin of each

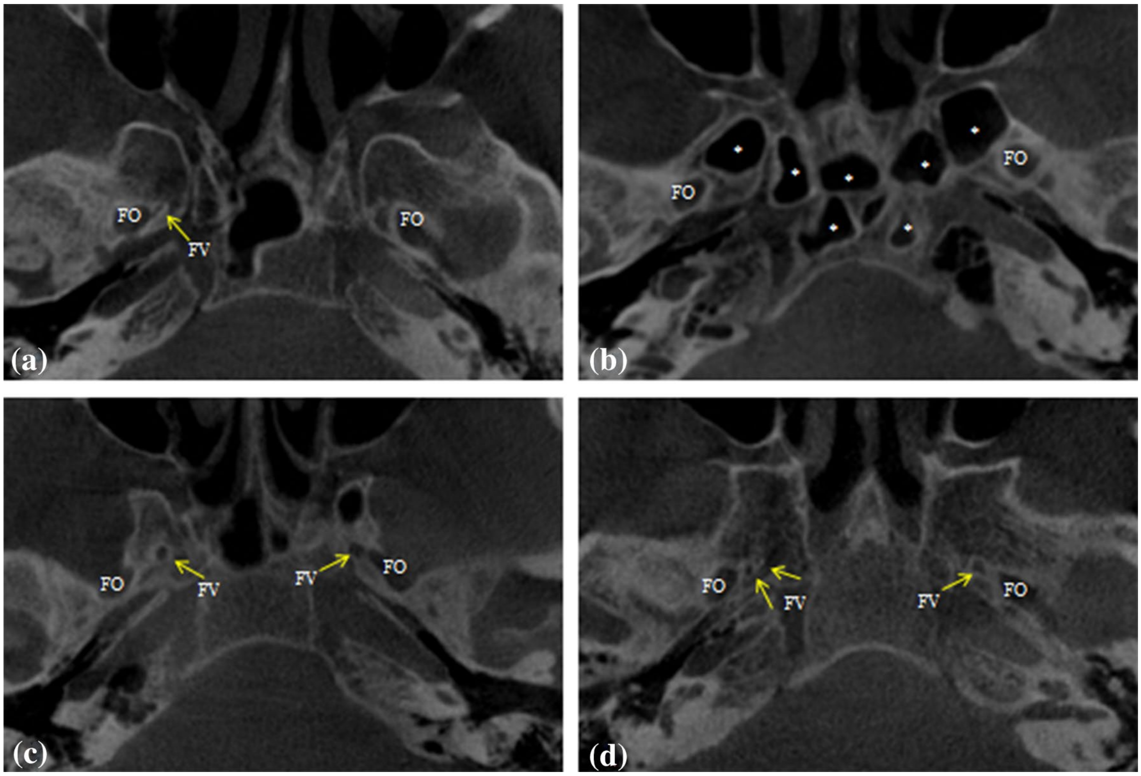


Fig. 1 Different types of the foramen venosum (FV). **a** The presence of unilateral opening, **b** the absence of bilateral opening, **c** bilateral openings, **d** a double opening on the right side and one on the left side. *FO* foramen ovale, *FV* foramen venosum. Asterisk indicates extensive pneumatization of the sphenoid sinus

foramen to prevent overestimated results. All measurements were performed twice and averaged.

In addition, the opening diameter of the FV was classified into five groups by adding two types to the classification described by Ozer et al. [31]: FV type 1, diameter < 0.5 mm; type 2, diameter 0.5–1 mm; type 3, diameter 1–1.5 mm; type 4, diameter 1.5–2 mm; and type 5, diameter > 2 mm.

Confluences, which are defined when bone separations between anatomical structures are completely invisible, with the FO were then evaluated (Fig. 4).

Statistical analysis

Data analysis was performed using the IBM SPSS Statistics 21.0 Statistical Analysis (Statistical Package for Social Sciences) program. Compliance with normal distribution of the data was tested with the Shapiro–Wilk test. When the variables did not show a normal distribution, the Mann–Whitney *U* test was used to examine intergroup differences. Fisher's exact test was used in cases where the expected values in the foramina did not have sufficient volume in 2 × 2 tables and Pearson Chi-squared analysis was performed in $R \times C$ tables with the Monte Carlo simulation. In addition, categorical variables were analysed using the Chi-squared test. A *p* value of less than 0.05 was considered significant.

Results

In the present study, a unilateral duplicated FV was present in 3.35% of the patients (nine patients). However, there were differences between the mean diameters and shapes of duplicate foramina, which made statistical analyses difficult. Thus, these images were excluded from this study. The final study sample consisted of 160 females (61.54%) and 100 males (38.46%) with a mean age of 41.16 years (age range, 8–82 years).

The FV was found in the posterior part of the greater wing of sphenoid, anterior, and medial to the FO, FS, and the carotid canal (CC). In the 260 analysed images, the FV was observed in 190 (73.1%) and absent on both sides in 70 images (26.9%). Unilateral, bilateral, and total distribution of FV according to sides and gender are presented in Table 1. In this study, bilateral FV was more prevalent, but the difference was not significant ($p > 0.05$). The distribution of FV occurrence on both sides across age groups is shown in Fig. 5. With respect to age groups, the incidence

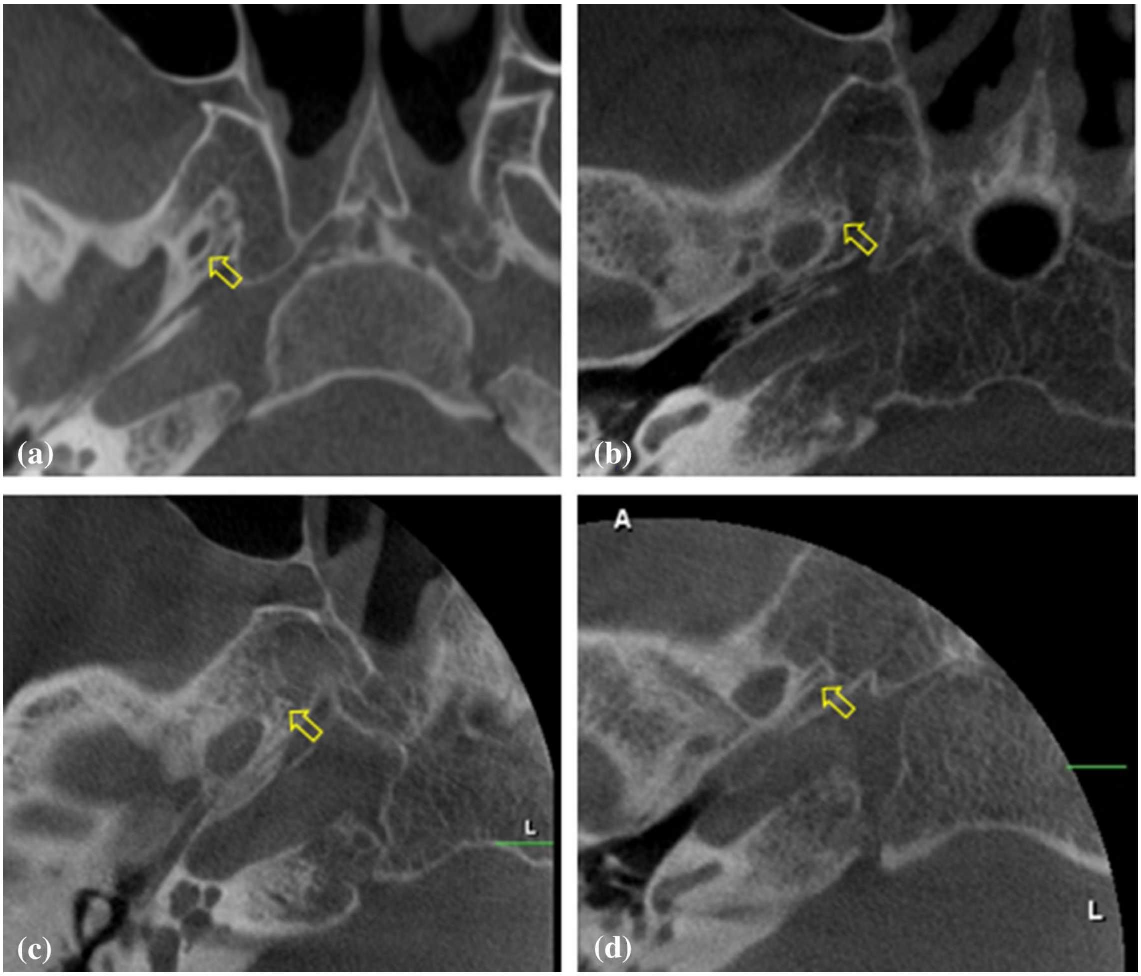
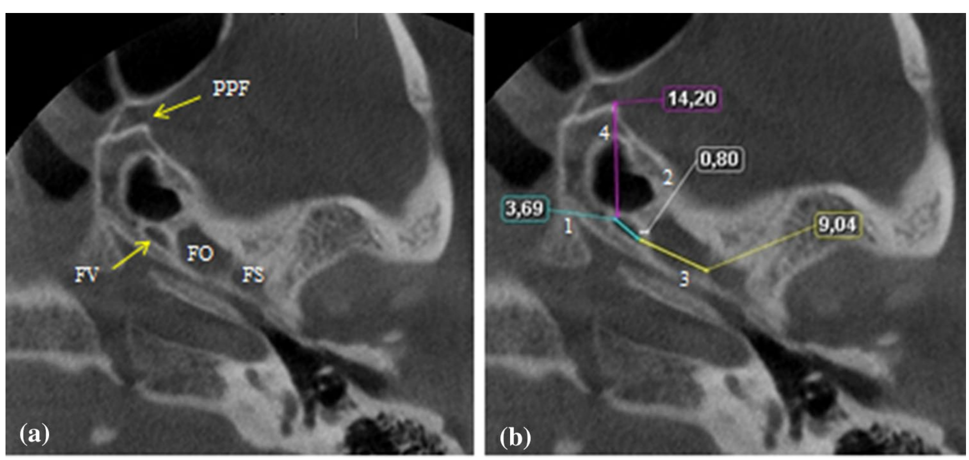


Fig. 2 The foramen venosum showing various shapes: oval (**a**), round (**b**), pinhole (**c**), irregular (**d**)

Fig. 3 The foramen venosum and surrounding anatomical structures in relation to the foramen **a** and **b**. *1* the diameter of the FV, *2* the distance between the FV and FO, *3* the distance between the FV and FS, *4* the distance between the FV and PPF, *FV* foramen venosum, *FO* foramen ovale, *FS* foramen spinosum, *PPF* pterygopalatine fossa



of FV on the right side was higher in the adult group (61.4%) and lower in the elderly group (51.9%) than that in other groups, but this difference was not statistically significant ($p=0.812$). On the left side, the prevalence of FV was higher in the young group (64.3%) and lower in the young adult group (51.9%); however, no significant difference was detected in comparison with other groups ($p=0.834$).

The most prevalent foramen shape was oval (130 cases; 43.3%), followed by round (71 cases; 23.7%), pinhole-shaped (52 cases; 17.3%), and irregular (47 cases; 15.7%).

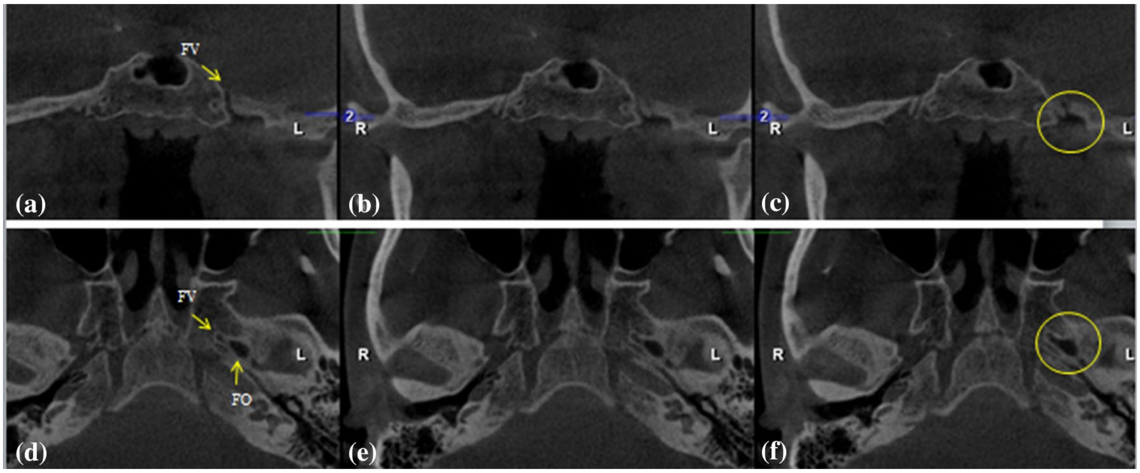


Fig. 4 Coronal and axial CBCT slices showing the middle cranial fossa (**a**–**f**). On the left side **c** and **f**, FV confluence into FO (yellow circles). *FO* foramen ovale, *FV* foramen venosum, *L* left, *R* right

Table 1 Distribution of foramen venosum found in analysed CBCT images according to sides and gender

Distribution	Right side	Left side	Total sides
Unilateral FV	38	42	80 (30.8%)
Male	18	24	42 (16.2%)
Female	20	18	38 (14.6%)
Bilateral FV			110 (42.3%)
Male			32 (12.3%)
Female			78 (30%)

FV foramen venosum

With respect to the variations in the shape of the FV, there was no statistically significant difference between females and males (p > 0.05). The prevalence of canal shapes according to sides and gender is also shown in Table 2. The incidence of pinhole foramina was higher in the elderly group (14/41 individuals on the right side and 12/47 individuals on the left side) than that in other groups, but the difference was not significant (p > 0.05).

Analysis of the dimensions revealed that the mean maximum diameter of the foramen was 1.75 mm (SD ± 1.27). The diameter of the FV was 1.75 ± 1.33 mm on the right side and 1.75 ± 1.2 mm on the left side (Table 3). Females showed a wider FV (mean diameter, 1.82 mm) than males (mean diameter, 1.62 mm), but the average diameter of the foramen did not differ significantly between genders (p > 0.05) (Table 4). On the right side, the distribution of mean FV diameters from the widest to the narrowest across age groups was as follows: young group (mean, 2.37 mm), pre-elderly group (mean, 1.869 mm), young adult group (mean, 1.865 mm), adult group (mean, 1.51 mm), and elderly group (mean, 1.47 mm). The corresponding distribution on the left side was as follows: young adult group (mean, 2.00 mm), adult group (mean, 1.81 mm), pre-elderly group (mean,

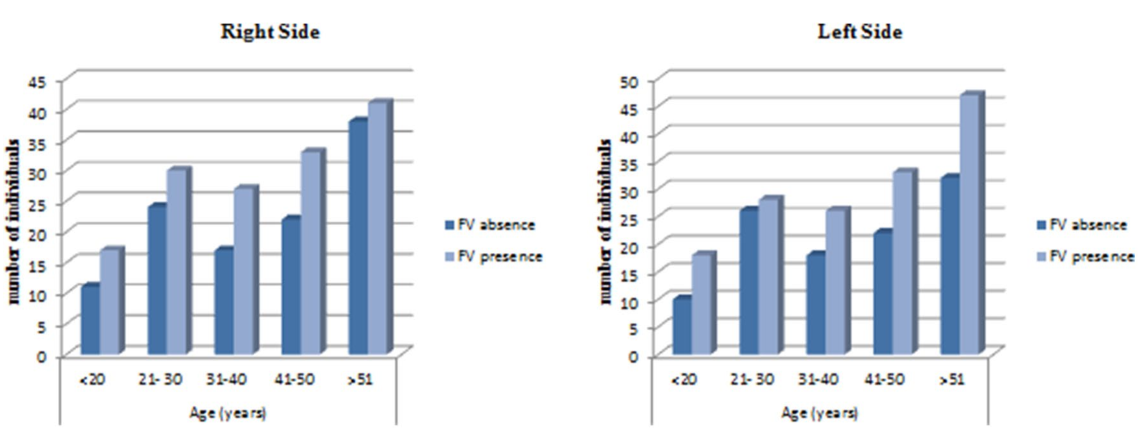


Fig. 5 Bar diagrams showing the age-wise distribution of the occurrence of the FV on both sides

Table 2 Variation in shape of foramen venosum according to sides and gender

Shape	Right						Left					
	Male		Female		Total		Male		Female		Total	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Oval	18	36	50	51	68	**45.9**	20	35.7	42	43.8	62	**40.8**
Round	12	24	22	22.4	34	23	16	28.6	21	21.9	37	24.3
Pinhole	13	26	15	15.3	28	18.9	12	21.4	12	12.5	24	**15.8**
Irregular	7	14	11	11.2	18	**12.2**	8	14.3	21	21.9	29	19.1
Total	50	100	98	100	148	100	56	100	96	100	152	100

The highest and least results for canal shapes according to the side were shown in bold

n number of individuals

Table 3 Statistical analyses and comparisons of the right and left measurements

	Right side				Left side				Total				*p* value
	Min	Max	Mean	sd	Min	Max	Mean	sd	Min	Max	Mean	sd	
#1	0.28	6.62	1.75	1.33	0.20	6.11	1.75	1.20	0.20	6.62	1.75	1.27	0.976
#2	0.20	7.35	1.46	0.97	0.20	3.96	1.32	0.87	0.40	7.35	1.39	0.93	0.081
#3	5.10	18.40	10.54	1.85	0.0	15.88	10.1	2.35	0.0	18.40	10.42	2.13	0.179
#4	2.83	13.69	7.10	1.65	3.49	14.41	7.2	1.83	2.83	14.41	7.15	1.74	0.805

Measurements #1–#4 correspond to distances shown in Fig. 3

sd standard deviation

Table 4 Analysis effect of gender on the dimensions (in mm) of foramen venosum, using reformatted axial slices from CBCT images

Measurements	Side	Gender	*n*	Mean	sd	*z*	*p* value
Diameter	Right	Female	98	1.77	1.13	−1.587	0.112
		Male	50	1.72	1.68		
	Left	Female	96	1.88	1.20	−1.902	0.057
		Male	56	1.54	1.18		
Distance FV – FO	Right	Female	98	1.41	0.96	−1.037	0.300
		Male	50	1.57	1.00		
	Left	Female	96	1.24	0.79	−0.756	0.450
		Male	56	1.45	0.99		
Distance FV – FS	Right	Female	98	10.20	1.77	−3.462	**0.001***
		Male	50	11.20	1.85		
	Left	Female	94**	10.03	2.34	−2.080	**0.038***
		Male	55**	10.77	2.32		
		Male	56	7.71	1.99		
Distance FV – PPF	Right	Female	98	13.07	1.88	−0.458	0.648
		Male	50	13.23	2.15		
	Left	Female	96	12.76	2.04	−0.604	0.547
		Male	56	12.96	1.71		

sd standard deviation, *n* number of individuals, *FV* foramen venosum, *FO* foramen ovale, *FS* foramen spinosum, *PPF* pterygopalatine fossa

*Statistically significant differences ($p<0.05$)

**Absence of foramen spinosum was detected in one male and in two females on the left side

1.75 mm), young group (mean, 1.65 mm), and elderly group (mean, 1.61 mm). However, there was no significant association between FV diameter and age group ($p > 0.05$).

In the categorization by opening diameter, the most prevalent group was type 5 (55 cases [37.2%] on the right side and 58 cases [38.2%] on the left side). On the right side, this was followed by type 1 (26 cases, 17.6%), type 2 (25 cases, 16.9%), type 3 (23 cases, 15.5%), and type 4 (19 cases, 12.8%). For the left side, the prevalence was as follows: type 1 (24 cases, 15.8%), type 2 (27 cases, 17.8%), type 3 (24 cases, 15.8%), and type 4 (19 cases, 12.5%).

The distances between the FV and the FO, FS, and PPF were analysed, and the results were presented according to both sides and gender (Tables 3, 4, respectively). There was no significant difference between the results for both sides ($p > 0.05$). (Table 3). Gender had a statistically significant influence on the FV – FS distance, with the mean values being generally greater for male subjects ($p < 0.05$). Although males showed longer FV – FO (mean, 1.51 mm) and FV – PPF distances (mean, 13.09 mm) than females (mean values, 1.33 mm and 12.92 mm, respectively), the difference was not significant ($p > 0.05$) (Table 4).

Pearson's test was used to assess correlations. The authors found statistically meaningful negative correlations between the diameter and the FV – FO distance (only left side) and the FV – FS distance (both sides). A statistically significant positive correlation was detected among FV – FO and FV – FS distances on both sides (Table 5).

Confluence of the FV with the FO was observed in 74 cases (24.67%) in the present study. Of these, 44 (30 in female, 14 in male; 59.46%) were in the left side and 30 (22 in female, eight in male; 40.54%) were in the right side. With respect to the presence of a confluence, there was no relevant difference between sexes ($p > 0.05$).

Discussion

Descriptions of anatomical structures and their possible variations, particularly involving neurovascular structures, play a significant role in surgical procedures [1, 31, 34]. Radiologic imaging is an important diagnostic instrument for surgical procedures and post-operative assessments. Technological developments in the use of 3-dimensional imaging have advanced the assessment of craniofacial structures [4, 42]. More recently, CBCT evaluations of the craniofacial region have been accepted as an alternative imaging modality comparable with CT due to the low radiation dose, low cost, easy access, and increased use [39].

The emissary veins build links between intracranial venous sinuses and extracranial veins [14, 31, 43]. The FV is defined as an emissary foramina in the skull. If present, the FV appears as a foramen positioned anteriorly and medially to the FO, FS, and CC [13, 14, 31]. Its location was verified in our investigations in the present study.

The FV has clinical importance since the emissary veins passing through it communicate between the pterygoid venous plexus and cavernous sinus. Thrombophlebitis or septic thrombosis may occur through spreading by adjacent structures, which is caused by supportive processes at the orbit, paranasal sinuses, or the upper half of the face level, sinusitis or otitis, boils, and rarely dental infections [1, 8, 43].

Trigeminal neuralgia is the most significant neuralgia of the craniofacial region. When medical procedures fail to control pain, microvascular decompression, glycerol rhizolysis, radiofrequency thermocoagulation, and percutaneous trigeminal microdecompression are attempted [31, 34, 42]. Skull radiographs, stereotaxic techniques, and imaging-guided techniques have been recommended to decrease complications during percutaneous interventions targeting the FO. This treatment procedure involves many punctures, and the needle may be accidentally inserted into other anatomical structures, such as the inferior orbital fissure, foramen lacerum, jugular foramen, CC, and FV [1, 14, 42]. Therefore, skull-base morphology, neurovascular anatomy, and the variations of these foramina must be considered to avoid complications [18].

Incidence and opening side

In his famous book 'De humani corporis fabrica', Andreas Vesalius noted that the FV 'is rarely seen unilaterally in the skull, and much more rarely bilaterally', which disagrees with our findings [14]. In this study, the incidence was 73.1%. Moreover, the incidence of bilateral FV was higher than that of unilateral FV, which is similar to the findings of various previous reports [12, 13, 17, 21].

Table 5 Pearson's correlation coefficient used to calculate correlations among the measurements

Correlation	Right side		Left side	
	r	*p*	*r*	*p*
Diameter × distance FV – FO	−0.16	0.051 ns	−0.24	0.003**
Diameter × distance FV – FS	−0.33	< 0.001**	−0.34	< 0.001**
Distance FV – FO × distance FV – FS	−0.46	< 0.001**	0.33	< 0.001**

FO foramen ovale, *FS* foramen spinosum, *FV* foramen venosum, *ns* no statistically significant correlation, *r* correlation coefficient

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

According to Shapiro and Robinson [41], who identified the FV as a single structure that was present in every cases, the FO may occasionally coalesce anteromedially with the FV, or the anterior portion of the FO may be considered to be the FV.

Many studies have noted the presence of the FV with variable prevalence rates (5–100%). The overall distribution of the foramen in this study was higher than that in previous studies (except the studies by Kaplan et al. [18] and Ginsberg et al. [12]) (Table 6). Srimani et al. [44] and Williams et al. [46] have reported smaller values for the prevalence of the FV (5% and 8.5%, respectively). Higher prevalence values were reported by Ramalho et al. [33], Ginsberg et al. [12], and Kaplan et al. [18], who observed FVs in 71.87%, 80%, and 100% of their cases, respectively. The 100% incidence can be explained by the fact that these researchers had analysed only ten skulls. Kodama et al. [21] mentioned a statistically significant difference based on gender. Gupta et al. [13] and Rossi et al. [36] noted that FV was significantly more common in females. In the present evaluation, though the foramen was more frequently detected in females, no remarkable difference was found between sexes.

The findings for the unilateral and bilateral presence of FV were compared with those of previous studies as shown in Table 6. Previous studies have reported the incidence of bilateral foramina to range from 5 to 48.8%. According to Reymond et al. [35], the incidence of bilateral foramina was 5%, while a CBCT study by Bayrak et al. [4] found the incidence to be 6.9%. In the present study, the foramen was present bilaterally in 42.3% of the cases, which is similar to

Table 6 Incidence of foramen venosum presented by various studies

Name of author	Year	Specimens examined	Total distribution (%)	Bilateral distribution (%)	Unilateral distribution (%)
Alves et al. [2]	2017	172 dry skulls	34.8	9.3	25.5
Berlis [6]	1992	60 dry skulls	36	15	21
Boyd [7]	1930	1500 skulls	36.5	14.7	21.8
Chaisuksunt et al. [8]	2012	377 dry skulls	10.9	12.7	4.5
Dogan et al. [11]	2014	44 skulls + 18 cadavers	32.3	8.06	16.12
Gupta et al. [13]	2005	35 dry skulls	32.85	22.85	20
Gupta et al. [14]	2014	200 dry skulls	34	14	20
Jadhav et al. [16]	2016	250 dry skulls	28.8	11.2	17.6
Kale et al. [17]	2009	347 skulls	45	25.1	19.9
Kodama et al. [21]	1997	20 juvenil skulls, 400 adult skulls	21.75	–	–
Lazarus et al. [23]	2015	100 skulls	5	–	–
Murlimanju et al. [27]	2015	78 dry skulls	37.2	16.7	20.5
Nascimento et al. [10]	2018	194 macerated skulls	18.5	6.1	3.1
Nirmala et al. [30]	2014	180 dry skulls	50	23.3	26.67
Ozer and Govsa [31]	2014	172 dry skulls	34.8	9.3	25.5
Ramalho et al. [33]	2007	64 skulls	71.87	Not found	Not found
Raval et al. [34]	2014	150 dry skulls	60	32.23	35.56
Reymond et al. [35]	2005	100 skulls	17	5	6
Rossi et al. [36]	2010	80 dry skulls	40	13.75	26.25
Shaik et al. [40]	2012	125 dry skulls	36	24	16
Shinohara et al. [42]	2010	400 macerated skulls	33.75	15.5	18.25
Singh et al. [43]	2011	103 dry skulls	51	–	20
Srimani et al. [44]	2014	40 skulls	5	–	–
Lanzieri [22]	1988	50 CT scans of the skull base	64	–	–
Ginsberg [12]	1994	123 CT	80	48.8	30.8
Kim and Kim [19]	1995	305 temporal bone CT	47.5	26.2	21.3
Kim et al. [20]	1997	163 CT	54.6	20.9	33.7
Bayrak et al. [4]	2018	317 CBCT	28.1	6.9	21.1
Leonel et al. [25]	2019	1000 CT	46.8	25.4	21.4
		170 skulls	45.2	18.8	26.4
		50 cadavers	14	6	8
Present study	2019	260 CBCT	73.1	42.3	30.8

CBCT cone-beam computed tomography, *CT* computed tomography the rate mentioned by Ginsberg et al. [12] (48.8% of high-resolution CT images).

In the previous studies, the incidence of unilateral FV was reported to range from 3.1 to 30.8%. According to Kodama et al. [21], the incidence was 5.5%. Our values were equal to the results found by Ginsberg et al. [12]. Unilateral FV was found in 80 individuals (30.8% of the CBCT images) in this study, of which 38 FVs were in the right side and 42 were in the left side. Although the foramen was more frequently detected on the left side, no significant difference was detected in relation to the sides ($p=0.738$).

Diameter

In addition to the incidence of the FV, its diameter is also important in neurosurgical procedures. In most of the previous studies, only the presence of the FV was analysed [12, 17, 21, 30, 33]. The findings for mean maximum diameter of FV in this study were different from those in other studies [8, 31, 36, 42, 43]. In the literature, different measurement techniques were used to determine the diameter. While several authors calculated the diameter of the foramen by callipers or metric, some did not provide any information regarding the methodology used for measurements. However, Ozer and Govsa [31] used digital photogrammetry instead of conventional measurement methods. In the present radiological study, the measurements were performed using the CBCT machine's software. These morphometric findings are shown in Table 7. In the study by Bayrak et al. [4], the mean maximum diameter of FV was higher than that in the other studies. In this study, the mean maximum diameter of the foramen did not show any significant difference between both sides, which is similar to the findings of most previous studies.

The high rate of prevalence of FV alone cannot sufficiently evaluate the risk of surgical interventions, because needles with diameter between 0.7 and 1.27 mm are used in trigeminal rhizotomy [15, 26, 37]. The diameter of the foramen detected in this study was 1.75 mm, and approximately 80% of the diameters were between 0.5 and 2 mm or more (type 2, type 3, type 4, and type 5), which could be a potential pitfall for percutaneous interventions. In this regard, surgical procedures were safer in cases with type 1 FVs.

In a dry skull study, Raval et al. [34] reported the shapes of foramina as round in 72% of the cases, oval in 24% of the cases, and irregular in 4% of the cases. According to Bayrak et al. [4], the shape of FVs on CBCT scans was oval in 68.5%, round in 25.2%, and irregular in 6.3% of the total foramina.

Lanzieri et al. [22] suggested that the FV are usually bilaterally symmetrical, and asymmetrical FVs may be attributable to pathologic conditions, such as nasopharyngeal melanoma, neurofibromatosis, and angiofibroma. In contrast, Prakash and Viveka [32] showed that such asymmetry of the foramen is a normal finding in their study.

Measurements

The distances between FV and other foramina in the skull base were analysed and compared with those reported in other studies (Table 8). Kaplan et al. [18] mentioned the FV was 4 mm (range: 3–5 mm) anteromedial to the FO. In the study by Ramalho et al. [33], this value was higher than ours, with the distances being 7 mm on the right side and 6 mm on the left side. In this study, the mean FV–FS distance was similar to that in previous studies [31, 42]. With respect to the FV – FS distances, there was a significant difference between females and males ($p < 0.05$). The greater values in males may be related to the relatively larger craniocaudal dimensions in males as compared to those in females.

In the current study, they compared the FVs between genders and across age groups. Although a few previous studies have assessed gender-related differences [4, 13, 21, 36], to our knowledge, no previous study has assessed FV characteristics across age groups. Although the age group had no statistically important influence on the variations and morphometric measurements of the FV ($p > 0.05$), the results in the elderly age group require attention. Half of

Table 7 Mean maximum dimension of foramen venosum shown by various studies

Name of author	Year	Mean maximum dimension (mm) (right side)	Mean maximum dimension (mm) (left side)
Bayrak et al. [4]	2018	2.66 ± 0.76	2.82 ± 0.96
Chaisuksunt et al. [8]	2012	1.71 ± 0.58	2.22 ± 1.05
Ozer et al. [31]	2014	0.86 ± 0.21	1.07 ± 0.37
Raval et al. [34]	2014	0.98 ± 0.67	1.12 ± 0.73
Rossi et al. [36]	2010	1.457 ± 1.043	1.592 ± 0.938
Shinohara et al. [42]	2010	0.67 ± 0.28	0.76 ± 0.39
Singh et al. [43]	2011	0.79	0.96
Present study	2019	1.75 ± 1.33	1.75 ± 1.20

Table 8 Mean values (in millimetres) for the FV – FO and FV – FS distances reported in other studies

Name of author	Year	Distance FV – FO		Distance FV – FS	
		Right	Left	Right	Left
Aviles-Solis et al. [3]	2011	2.51	2.46	–	–
Bayrak et al. [4]	2018	2.31	2.21	11.32	11.26
Chaisuksunt et al. [8]	2012	2.05	2.05	–	–
Dogan et al. [11]	2014	4.42	2.80	–	–
Gupta et al. [14]	2014	1.36	1.48	–	–
Lazarus et al. [23]	2015	2.83	2.42	–	–
Ozer and Govsa [31]	2014	2.30	2.46	10.76	10.42
Rossi et al. [36]	2010	1.85	2.46	–	–
Shinohara et al. [42]	2010	2.55	2.59	11.52	10.95
Present study	2019	1.46	1.32	10.54	10.1

FO foramen ovale, *FS* foramen spinosum, *FV* foramen venosum

the individuals showing pinhole foramina belonged to the elderly group. The mean maximum diameter of the FV value was also the lowest in this age group. This result may be explained by the changes in bone remodeling with aging, but the literature does not contain any information pertaining to these findings. According to Crockett et al., structural changes in the skull shape with age may be a physiological response to mechanical forces [9]. Local pressure changes due to changing venous outflow may cause localized mechanical forces, contributing to bone remodeling. However, this hypothesis is not conclusive. FV showed a smaller surface area (1.6–2.86 mm^2 depending on the gender and side) compared to the jugular foramen (51.11–59.84 mm^2 depending on the gender and side) and hypoglossal canal (17.96–19.16 mm^2 depending on the gender and side), which are the two large venous foramina in the skull [48]. Further studies are needed on this issue.

The differences in the data detected from other studies can be explained by the differences in methods and the number of samples. They can be also attributed to ethnic differences and to differences in development since the sphenoid bone follows a complex course of embryologic development [13]. Development of the skull base begins after the spinal cord, cranial nerves, and blood vessels have formed [29]. Thus, the presence of the FV is closely related to the individual's venous drainage system. As a result, some levels of variation can be expected in the studies presented by different authors.

In the literature, the confluence of the FO with the FV, which reduces the chances of surgical success, has been reported in many studies [4, 5, 7, 13, 19, 21, 22]. The FV content and its location prompted Wood-Jones [47] to hypothesize that the FV is an extension of the FO. The author deduced that the FV may either replace the FO venous part, resulting in a smaller FO, or it is possibly related to the FO, or that it provides an additional venous pathway to the FO [47]. In addition, Schalfuss and Camp [38] concluded that the FV – FO confluence and the course of the vein of Vesalius via the FO in the absence of the bilateral FV are a possible explanation for the FO asymmetry. However, Berge and Bergman [5] observed no alteration in FO size with unilateral FV. Natsis et al. [28] found that the occurrence of the vein of Vesalius does not change the FO venous component and that this is an additional venous outlet.

The vein of Vesalius is considered to depend directly on the presence of the FV [25]. Some researchers have reported that the FO is an alternative path between the cavernous sinus and the pterygoid plexus when the FV is not present [32, 41]. Leonel et al. [24] verified an additional pathway for blood drainage that was termed the emissary sinus of the foramen ovale (ESFO). This is a typical structure, and its existence does not depend on the presence of the FV. Moreover, the ESFO and the vein of Vesalius have been defined as emissary veins classically. However, Leonel et al. [25] reported that the wall structure of the vein of Vesalius is similar to that of the dural sinuses as described for the ESFO [24].

Clinical implications

The FV is a very frequently observed anatomical variation (73.1%) located anteromedial to the FO, and its position at the transition zone between intracranial and extracranial structures makes it important for surgical interventions and diagnostic procedures. Knowledge of the anatomy and variations of the middle cranial fossa which can be detected in CBCT scans is important for clinicians during transovale procedures. The presence of the FV, the FV diameter, and the FV – FO confluence may affect the outcomes of FO cannulation. In the current study, the foramina were categorized into five types on the basis of diameter, and all types except type 1 (diameter smaller than 0.5 mm) might cause problems in terms of orientation since the percutaneous approach surface is quite narrow. According to our results, individuals under 50 years of age constitute the majority of the population with large FV diameters (77.9% on the right side and 71.9% on the left side), which shows narrow surgical resonance areas that necessitate additional caution during interventions. Moreover, the clinicians should be aware of the proximity of FV – FO, which could be as close as 1.46 mm (right side) and 1.32 mm (left side).

In addition, the vidian canal is generally found in the skull base along the fusion line of the pterygoid process and the body of the sphenoid bone. It is a bony canal from the middle cranial fossa to the pterygopalatine fossa and carries a neurovascular bundle with variable pathways. Its relationship with other foramina and fissures can be affected by this variability, together with the pneumatized sphenoid sinus

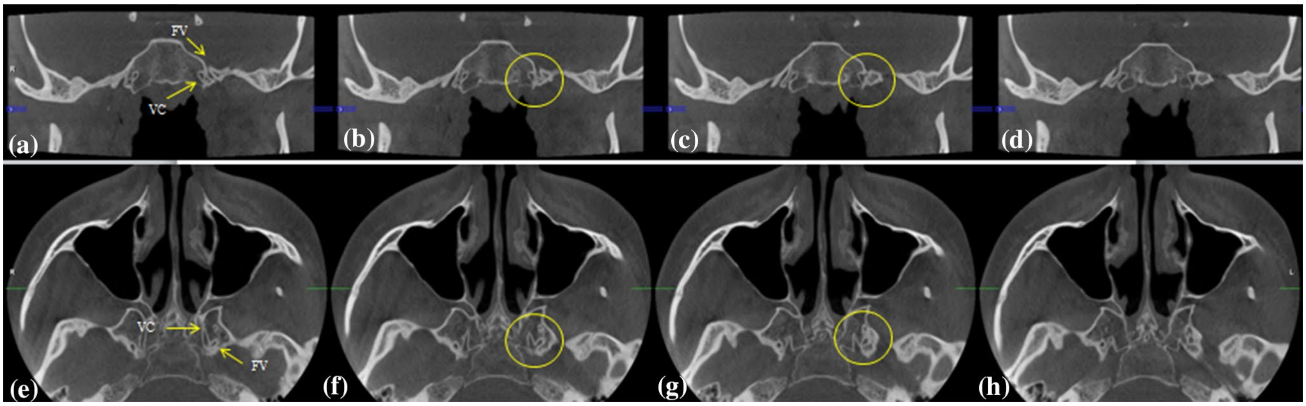


Fig. 6 Coronal and axial CBCT slices showing the middle cranial fossa (**a**–**h**). This case shows the FV communicating with the VC (yellow circles) on the left side, **c** and **f**. *FV* foramen venosum, *VC* vidian canal, *L* left, *R* right

[45]. This study suggested that there was a communication between the FV and vidian canal (26 individuals on the left side and 11 individuals on the right side) (Fig. 6), but they could find only one study that includes this knowledge in the literature [25]. Further studies are necessary in this field.

Study limitations

The present study had some limitations. This study sample consisted of CBCT scans with free pathological images. Evaluations of images with other parameters which could affect the FV's topographic relationships with other foramina and fissures in the cranial base, such as pterygoid canal variability together with pneumatization of the sphenoidal sinus, would be useful for better understanding the presence of the FV. A further limitation of this study was that all evaluations were performed by one observer only.

Conclusion

The present radiological study evaluated FVs with detailed morphometric parameters and compared the findings according to gender and age. The present study highlights an important variability in the anatomy and morphology of the FV. In this study, the incidence of the foramina was 73.1%, which is considerably higher than that in most of the previous studies. No specific age- and gender-related differences were observed in FV distribution. The diameter of the foramen and its confluence with and proximity to FO should remind surgeons to be careful when performing the surgical approach through FO. CBCT imaging with lower radiation doses and thin slices can be a useful technique before skull-base surgical procedures.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was performed in accordance with the Institutional Ethical Review Board of Ankara University, Faculty of Dentistry approved the study with decision number: 13/11 (Ref: 36290600/03), and the study followed the Declaration of Helsinki on medical protocol and ethics.

Informed consent For this type of study, formal consent is not required.

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