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Anatomical Variability of Foramen Vesalius Using Cone Beam Computed Tomography

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ABSTRACT

Purpose: This study aims to provide a detailed morphometric analysis of the foramen Vesalius (FV) using Cone Beam Computed Tomography (CBCT) to understand its anatomical variations and clinical implications.

Material and Methods: A retrospective study was conducted at JSS Dental College and Hospital, analyzing 140 CBCT scans (68 males, 72 females) of subjects aged 11-70 years. Inclusion criteria were diagnostic-quality images showing the skull base with clear FV views.

Exclusion criteria included partial images, artifacts, pathologies, or previous surgeries. Prevalence of FV, unilateral/bilateral presentation, and distances to foramen Ovale (FO) and foramen Spinosum (FS) were measured using Planmeca Romexis 5.3 software. Statistical analysis was performed using SPSS version 23.

Results: AFV prevalence varied significantly by sex, with bilateral occurrences being more common (44.64%) than unilateral (18.72%) or absent (37.44%). Males had higher bilateral FV (25.92%) and lower absent FV (17.28%) compared to females (18.72% and 20.16%, respectively).

Mean distances between FV and FO were 3.176 mm (right) and 4.689 mm (left) in females, and 3.922 mm (right) and 4.699 mm (left) in males. Distances between FV and FS were 11.966 mm (right) and 14.028 mm (left) in females, and 13.063 mm (right) and 14.206 mm (left) in males.

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Age-related variations were observed, with the highest bilateral FV prevalence in the 21-30 and 51-60 age groups.

Conclusions: The morphometric analysis of FV highlights significant anatomical variations by sex and age, emphasizing the need for precise surgical planning. Understanding these variations can minimize procedural risks and optimize treatment outcomes in neurosurgical and radiological interventions.

Keywords: : Foramen vesalius, Cone beam computed tomography, Foramen ovale, Foramen spinosum, Anatomical variation

Introduction

The skull base, divided into the anterior, middle, and posterior fossae, contains numerous foramina, with the middle fossa housing critical neurovascular structures. Within the intricate structure of the sphenoid bone, the foramen rotundum, foramen ovale (FO), and foramen spinosum (FS) serve as permanent apertures. Additionally, two foramina are non-permanent: the meningo orbital (Hyrtl's channel) and the Vesalius foramina, also known as sphenoidal emissary foramen, foramen venosus, or canaliculus sphenoidal. These foramina, with their diverse functions and characteristics, contribute significantly to the intricate network of passages and channels within the skull base, facilitating crucial neuro-vascular interactions and pathways [1].

The foramen of Vesalius is a tiny, variable foramen in the middle cranial fossa, posterolateral to the foramen rotundum and anteromedial to the foramen ovale (FO), and it transmits emissary veins that connect the pterygoid plexus and the cavernous sinus. The anatomist Andreas Vesalius was the one who initially described and depicted the FV. The FV may be bilateral, unilateral, or absent at times [2].

Regarded as a promising modality for the analysis of the foramen Vesalius, CBCT provides three-dimensional, high-resolution imaging. CBCT facilitates precise evaluation of the dimensions, configuration, and fluctuations of the foramen Vesalius through the provision of distinct and accurate visualisations of anatomical structures.

This technology allows for non-invasive evaluation, aiding in the diagnosis of anomalies or pathologies associated with the foramen Vesalius. Furthermore, CBCT facilitates an enhanced understanding of the spatial relationships between the foramen Vesalius and neighboring structures, offering valuable insights for surgical planning and interventional procedures. Its ability to provide comprehensive imaging data makes CBCT a valuable tool in the analysis of foramen Vesalius morphology and pathology [3].

By employing CBCT technology, this study aimed to provide precise measurements and detailed three-dimensional reconstructions of the foramen Vesalius, elucidating any population-specific anatomical variations. This study was also aimed to contribute to the understanding of cranial anatomy, potentially informing clinical practice, surgical interventions, and diagnostic approaches related to neuro-vascular conditions involving the foramen Vesalius.

Material and Methods

This monocentric, descriptive retrospective study was conducted at JSS Dental College and Hospital and approved by the institutional ethics committee (reference number 22/2023). A convenient sampling technique was used, assuming an absolute precision of 5% and a confidence level of 95%. 140 CBCT scans, 68 males and 72 females, were estimated for the sample size and were utilized between June 2022 and June 2023, which fulfilled the following criteria.

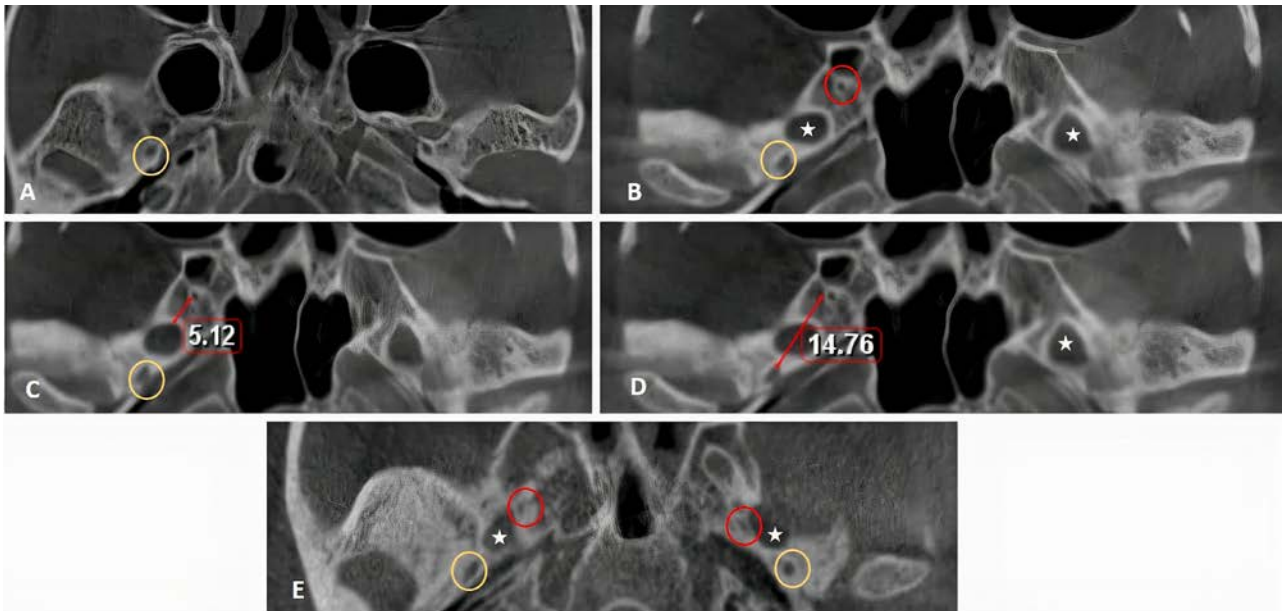
Inclusion Criteria

- CBCT images of male and female subjects aged between 11 and 70 years.
- CBCT images of diagnostic quality.

Exclusion Criteria

- CBCT images with artifacts or subpar diagnostic quality.
- CBCT images that do not reveal the base of the skull with a clear view of the expected location of the foramen Vesalius (FV).
- Partial images or the presence of artifacts in the skull's base.
- CBCT images with any pathology or developmental defects of the base of the skull.
- Images with any evidence of previous surgery, fracture, or healed fracture in the base of the skull.

Radiographic images satisfying the inclusion criteria were subjected to analysis for the following landmarks in the axial section in 3D-rendered images of Planmeca Romexis 5.3 (3D software) for the prevalence of FV, uni-



(CBCT of axial images; *Fig A- Showing absence of FV, B- Showing unilateral presence of FV, C- Showing distance between FV to FO, D- Showing distance between FV to FS, E- showing bilateral presentation of FV).*

(Note: red circle- denotes Foramen Vesalius, Yellow circle- denotes Foramen Spinosum, Asterisk denotes Foramen Ovale)

lateral (Fig. B) or bilateral (Fig. E) presentation among different age groups and genders. If it exists, the distance between FV to FO (Fig. C) and FV to Foramen Spinosum (FS) (Fig. D) was evaluated.

Statistical Analysis

Descriptive statistics were done to establish the mean and median for all the demographic and quantitative data. Mean differences between the left and right sides were evaluated using a paired sample t-test. Age and gender were also analyzed qualitatively with the chi-square test to determine the presence of FV.

A p-value of less than 0.05 was considered significant. The statistical analysis software employed was SPSS version 23.

Results

There was a notable disparity in the distribution of foramen Vesalius variations between males and females. While bilateral occurrences were more prevalent in both sexes compared to unilateral or absent occurrences, there were distinct differences in their frequencies. Females demonstrated a slightly higher incidence of absent foramen Vesalius (Fig. A), but lower bilateral occurrences compared to males. Conversely, males exhibited a higher prevalence of bilateral occurrences and lower rates of absent occurrences. Additionally, unilateral occurrences were substantially higher in males than in females. Although the p-value of 0.059 indicated a trend towards significance, further investigation with a larger sample size is warranted to confirm these findings and elucidate any potential sex-based differences in foramen Vesalius morphology (Table 1).

Table 1. Prevalence of Unilateral or Bilateral Foramen Vesalius.

Sex	Absent (in %)	Bilateral (in %)	Unilateral (in %)	p-value
Female	20.16	18.72	12.96	0.059
Male	17.28	25.92	5.76	
Total	37.44	44.64	18.72	

The analysis of the frequency distribution of foramen Vesalius variations among various age groups revealed that bilateral occurrences of foramen Vesalius are more prevalent than unilateral or absent occurrences across all age groups. The highest prevalence of bilateral occurrences was observed in the 21-30 and 51-60 age groups, while absent occurrences are most prominent in the 11-20 age group. Unilateral occurrences

varied across age groups, with notable percentages in the 21-30 and 11-20 age groups. Although the result approaches statistical significance, it is not statistically significant under the conventional threshold of $p < 0.05$. (Table 2).

Table 2. Prevalence of Foramen Vesalius Among Different Age Groups.

Age group (in years)	Absent (in %)	Bilateral (in %)	Unilateral (in %)	p-value
11-20	1.44	2.88	4.32	0.091
21-30	11.52	14.92	5.76	
31-40	8.64	8.64	2.88	
41-50	5.76	5.76	4.32	
51-60	4.32	10.72	1.44	
61-70	5.76	5.76	0	

Bilateral prevalence of FV relative to nearby structures by gender and side is summarized in Table 3. Females generally have slightly smaller mean distances compared to males. For instance, between FV and FO, females average 3.176 mm (right) and 4.689 mm (left), while males average 3.922 mm (right) and 4.699 mm (left). Standard deviations suggest variability, providing insights into gender and side-based anatomical differences.

Table 3. Bilateral Prevalence of Foramen Vesalius Based on Gender and Side.

Parameters	Sex	Mean (in mm)	Standard Deviation (in mm)	Minimum (in mm)	Maximum (in mm)
Right FV-FO	Female	3.176	1.114	2.00	5.90
	Male	3.922	1.858	1.70	7.9
Left FV-FO	Female	4.689	1.390	2.04	7.8
	Male	4.699	1.727	2.00	8.5
Right FV-FS	Female	11.966	2.500	6.50	16.4
	Male	13.063	2.573	8.80	18.9
Left FV-FS	Female	14.028	1.654	11.60	17.8
	Male	14.206	2.400	10.90	18.9

Morphometric measurements related to foramen Vesalius morphology across age groups revealed that the mean distances between foramen Vesalius and foramen Ovale (FV-FO) and foramen Spinosum (FV-FS) ranged from approximately 3.218 mm to 5.345 mm and 11.851 mm to 15.285 mm, respectively. Standard deviations indicate variability around these means, with values ranging from 0.239 mm to 3.844 mm. Minimum and maximum distances vary across age groups, reflecting morphological differences (Table 4).

Table 4. Descriptive statistics of Foramen Vesalius based on different age groups.

Parameters	Age (in years)	Mean (in mm)	Standard Deviation (in mm)	Minimum (in mm)	Maximum (in mm)
Right FV-FO	11-20	3.755	1.241	2.680	4.830
	21-30	3.218	1.699	1.700	7.690
	31-40	3.263	0.884	2.150	4.560
	41-50	3.192	1.011	2.560	4.820
	51-60	4.946	2.301	2.530	7.850
	61-70	3.777	1.379	2.680	5.910
Left FV-FO	11-20	3.690	1.951	2.00	5.380
	21-30	4.218	1.880	2.00	8.410
	31-40	4.600	0.883	3.690	6.250
	41-50	6.002	1.761	4.120	8.540
	51-60	4.598	0.239	4.250	4.820
	61-70	5.345	1.580	3.770	7.770
Right FV-FS	11-20	12.520	1.062	11.600	13.440
	21-30	11.851	2.902	6.510	18.420
	31-40	12.420	1.242	11.030	14.700
	41-50	13.295	1.052	11.760	14.340
	51-60	14.032	3.844	8.780	18.970
	61-70	12.323	2.628	10.000	16.420
Left FV-FS	11-20	15.285	2.950	12.730	17.840
	21-30	14.261	1.803	11.560	18.180
	31-40	13.097	1.582	10.920	14.750
	41-50	14.755	2.878	12.320	18.930
	51-60	13.828	1.991	12.270	17.550
	61-70	14.476	2.334	11.560	17.760

The results indicate a statistically significant difference between the distances of the right and left sides for both the foramen Vesalius to foramen Ovale (FV-FO) and foramen Vesalius to foramen Spinosum (FV-FS) measurements. The t-values of -4.823 and -5.345, with degrees of freedom (df) at 61 for both comparisons, suggest a substantial difference between the mean distances of the right and left sides. Additionally, the p-values of less than 0.001 signify a highly significant finding, indicating that the observed differences are unlikely to be due to random chance (Table 5).

Table 5. Paired t-test for Bilateral Prevalence.

Parameters	t	df	p-value
Right-Left FV-FO	-4.823	61	**<0.001**
Right-Left FV-FS	-5.345	61	**<0.001**

Distances between the foramen Vesalius (FV) and neighboring structures, foramen Ovale (FO) and foramen Spinosum (FS), by sex. Females exhibit a mean FV-FO distance of 4.362 mm (SD 1.916 mm), males 4.777 mm (SD 1.995 mm). FV-FS distances for females average 13.429 mm (SD 1.913 mm), males 14.107 mm (SD 1.727 mm). Minimum and maximum distances show comparable ranges across sexes for both measurements (Table 6).

Table 6. Descriptive Statistics of Unilateral Prevalence of FV Based on Gender.

Parameters	Sex	Mean (in mm)	Standard Deviation (in mm)	Minimum (in mm)	Maximum (in mm)
FV-FO	Female	4.362	1.916	2.680	8.770
	Male	4.777	1.995	2.830	7.770
FV-FS	Female	13.429	1.913	10.810	17.120
	Male	14.107	1.727	12.350	16.560

Unilateral FV measurements across age groups are presented in Table 7. Mean FV-FO measurements rise from 3.777 mm (11-20 age group) to 6.995 mm (31-40), then decrease to 2.830 mm (51-60). Similarly, mean FV-FS measurements peak at 13.897 mm (11-20) and decline to 12.350 mm (51-60), indicating age-related variations.

Table 7. Descriptive statistics of unilateral Foramen Vesalius based on different age groups.

Parameters	Age (in years)	Mean (in mm)	Standard Deviation (in mm)	Minimum (in mm)	Maximum (in mm)	P Value
FV-FO	11-20	3.777	1.547	2.680	5.770	0.619
	21-30	4.790	1.873	3.390	7.770	
	31-40	6.995	2.050	5.220	8.770	
	41-50	3.687	0.878	3.120	4.820	
	51-60	2.830	0.000	2.830	2.830	
FV-FS	11-20	13.897	2.824	10.810	17.120	0.399
	21-30	14.055	1.891	11.890	16.560	
	31-40	13.635	1.819	12.060	15.210	
	41-50	13.253	0.979	12.450	14.500	
	51-60	12.350	0.000	12.350	12.350	

Discussion

The greater wing of the sphenoid bone has an inconstant aperture known as the FV. An emissary vein travels through the foramen and interacts with the cavernous sinus with the help of the pterygoid plexus. The embryonic development of these foramina begins with the alisphenoid cartilage and obturator membrane. During the formation of the cranial base, nerves and arteries create orifices at the intersection of several embryonic components. Hence, radiologic imaging is a crucial diagnostic tool for presurgical, intrasurgical, and postoperative evaluations, focusing on anatomical features, variations, and neurovascular structures [4].

The FV carries a small emissary vein that connects the cavernous sinus to the pterygoid plexus, which helps to regulate intracranial and extracranial pressure. The emissary veins have minimal blood flow during normal physiological settings, but when intracranial pressure rises, these veins play a significant role in blood drainage [5]. This vein may transfer an infected thrombus from the extracranial region to the cavernous sinus. Because this foramen is inconstant, it can complicate a surgical procedure in this area if the practitioner lacks solid anatomical conceptualization [6,7].

Maletin et al. reviewed 500 CT images of adults and observed that the FV was present in 67.7% of instances [8]; similarly, our study shows 63.36%. These findings are consistent with those reported by Görürgöz et al. [9], Lanzieri et al. [10], and Raval et al. [11], who found FV of about 73.1%, 61.54% and 64% of those surveyed, respectively. In contrast to our study, Shinohara et al. [12] and Shaik et al. [13] reported that foramen prevalence is 33.75% and 36%, respectively, which is considerably lower than the current study's results. They claimed that the lower incidence rate could be due to the different methodology, where they evaluated the dry skull; another reason suggested was that impairment in the development of venous drainage organization would lead to the existence of FV [12]. As a result, we could anticipate some degree of heterogeneity in the information provided by numerous authors.

Maletin found that bilateral FV was significantly more common in males and unilateral in females [8], which is in accordance with the current study, where bilateral FV in males shows 25.92% and unilateral FV in females shows 12.96%. When different age groups were analyzed, the second and third decades show higher prevalence rates, yet there were no statistically significant differences between age groups and genders.

The FV is situated anteromedially to the FO at a mean distance of 3.54±1.48mm on the right side and 4.69±1.55mm on the left side, which shows statistical significance between the right and left sides. Similarly, the study by Rossi et al. showed that the FV-FO distance on the right side of the skull was less than that on the left side [14]. However, the study by Shinohara et al. showed no significant difference in the average FV-FO distance between the left and right sides [12]. It could be due to the low prevalence rate of FV observed in their study, as well as the ethnic variances. In such cases larger sample size was advised to analyze between the right and left sides.

The foramen ovale serves as the entry point for the surgical treatment of trigeminal neuralgia. However, when approaching this foramen, one may misplace the needle for microvascular decompression inside the foramen Vesalius. This proximity can lead to a puncture of the cavernous sinus, potentially causing serious complications such as intracranial bleeding [15]. Thus, the distance between FV and FO plays a crucial role.

The other structure in close proximity to the FV is the foramen spinosum, located posterolateral to the FO and anteromedial to the spine of the sphenoid bone. Crucial blood vessels that permeate the dura mater emerge from the FS [1]. In the current study, the average distance between FV-FS in males is 13.63±2.48mm, and in females it is 12.51±2.07mm, which is statistically insignificant between sexes. Shinohara found 11.52mm on the right side and 10.95mm on the left side; contrarily, our study shows 12.51±2.5mm on the right side and 14.11±2.02mm on the left side, showing statistically significant differences among sides ($P<0.001$) [12]. This can be explained by the fact that the higher values in men are due to their comparatively bigger craniocaudal dimensions than those in women.

Conclusion

The morphometric analysis of the foramen Vesalius reveals clinically critical findings, shedding light on its anatomical variations and potential implications. Variations in distances between the foramen Vesalius and adjacent structures, such as the foramen Ovale and the foramen Spinosum, underscore the importance of precise surgical planning and intervention. Understanding these morphometric characteristics aids in minimizing procedural risks and optimizing treatment outcomes, particularly in

neurosurgical and radiological interventions. Moreover, recognizing sex-based differences in these measurements emphasizes the need for tailored approaches in patient care. Overall, this study emphasizes the critical role of foramen Vesalius morphology in clinical practice, guiding more effective patient management strategies. **R**

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