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Original Article

Volumetric analysis of maxillary sinus, sphenod sinus and pterygopalatin fossa in different skeletal malocclusions

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ABSTRACT

Purpose: This study aimed to examine the changes in maxillary sinus volume (MSV), sphenoid sinus volume (SSV), and pterygopalatine fossa volume (PPFV) in different skeletal malocclusions using cone beam computed tomography (CBCT) images.

Methods: CBCT images of 600 patients (318 females and 282 males) aged between 18 and 73 years (mean: 31.3 ± 12.9 years) were evaluated. Firstly, all patients were divided into classes according to their skeletal malocclusion. A threshold range between −1024 HU and −526 HU was applied for making paranasal sinuses. In all sections in all three planes, it was checked that MS, SS, and PPF were separated from other anatomical landmarks and the airway.

Results: All MSV, SSV, and PPFV values were found to be significantly higher in males than in females ($p > 0.05$). MSV was statistically significantly higher in Class III malocclusion than in Class I and II malocclusion ($p < 0.05$), whereas there was no significant difference between Class I and II malocclusion ($p > 0.05$). No statistically significant correlation was found between SSV and skeletal malocclusion classes ($p > 0.05$). PPFV had the highest value in Class I malocclusion, followed by Class III and Class II, and there was a statistically significant difference between them ($p < 0.05$).

Conclusion: MSV, SSV, and PPFV have been observed to show significant changes depending on sexual dimorphism; MSV in Class III skeletal malocclusion, and PPFV in Class I skeletal malocclusion. Knowing the dimensions of the anatomy and anatomical structures specific to the individual before surgical interventions in these regions will also reduce the risk of complications.

1. Introduction

The maxillary sinus (MS), which significantly contributes to facial structure development, is the earliest to form and the largest of the four paranasal sinuses. The development of the maxillary sinus (MS) starts during the third month of fetal life, and its pneumatization process extends up to the ages of 15 to 18. The average maxillary sinus volume (MSV) in adults ranges from 14 to 18 cm³ and decreases with age after the period of maximum growth, regardless of sex [1]. According to the literature, the maxillary sinus (MS) has a significant influence on the configuration of facial characteristics [2]. Due to its location, size, and proximity to important craniofacial structures such as the nasal cavity, tooth roots, and zygomatic bone, variations in an individual's craniofacial growth pattern and respiratory patterns may affect the MS morphometry [3]. Understanding the relationship between the volume of these sinuses and the surrounding craniofacial structures provides valuable insights into various clinical aspects, such as orthodontic treatment planning, dental implant placement, and the management of sinus pathologies [4]. However, three-dimensional volumetric studies examining the relationship between MSV and skeletal malocclusion are limited and lack consensus.

The sphenoid sinuses (SS) are bilateral, air-filled spaces within the sphenoid bone. They are present as small cavities at birth and extend backward into the presellar area. They then expand below and behind the sella turcica, reaching their full size during puberty [5]. The SS are critical in determining surgical approaches owing to their close relationship with important neurovascular and endocrine structures such as the pituitary gland, Vidian nerve, and cavernous sinus [6]. Enlargement of the sinuses may increase the risk of iatrogenic lesions due to the potential for damage to these vital structures [7]. Several studies have examined the influence of factors such as ethnicity, sex, and age on SS development and craniofacial growth [8]. However, only one study in the literature has evaluated sphenoid sinus volume (SSV) concerning different skeletal malocclusion classes [5].

The pterygopalatine fossa (PPF), located along the virtual line separating the viscerocranium and neurocranium, is a clinically,

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radiologically, and anatomically important transition zone. It hosts numerous neurovascular structures that connect various intracranial and extracranial spaces [9]. The PPF is a bilaterally symmetrical, pyramidal-shaped anatomical structure [10]. Its location between the middle cranial fossa, nasal chamber, orbital region, and oral space makes it a critical anatomical and clinical region for nerves and blood vessels [11]. The maxillary nerve and its branches, maxillary artery, and the pterygopalatine ganglion with its branches are located within the PPF. These structures may contribute to treatment failure and clinical complications, including intravascular or intracranial injection, infraorbital nerve injury, transient nerve tissue damage, intracranial infections, and even blindness [12]. Severe complications such as sudden-onset headache or brainstem anesthesia have been reported when the volume of anesthetic exceeds the capacity of the PPF. Consequently, volumetric analysis has made the PPF a subject of various scientific studies [13]. The PPF volume (PPFV) plays a crucial role in defining and limiting the space available to surgeons during endoscopic procedures [14]. When the studies so far are examined, there is currently no study that has explored whether a connection exists between PPFV and skeletal malocclusions.

The morphology and size of the paranasal sinuses were initially determined through anatomical measurements obtained by injecting different substances into cadavers or by using plain radiographs. More recently, the introduction of multiplanar reconstruction computed tomography has enabled a more reliable assessment of these structures [15]. Nowadays, cone beam computed tomography (CBCT) is preferred over conventional computed tomography as the primary imaging method for the craniofacial region due to its well-defined images, lower radiation dose, and shorter procedure time [1].

This study aimed to investigate changes in MSV, SSV, and PPFV according to skeletal malocclusion classification.

2. Material and methods

2.1. Ethical approval

This study was approved by the Local Ethics Committee of the Hatay Mustafa Kemal University (Date:20.11.2024, Decision no:36), and the study protocol was carried out in accordance with the principles outlined in the Declaration of Helsinki.

2.2. Study design

In this retrospective study, the CBCT of 2000 patients who applied to Hatay Mustafa Kemal University Faculty of Dentistry, Department of Dentomaxillofacial Radiology between 2021 and 2024 and whose radiography was taken for various reasons was retrospectively evaluated. Images that did not have sufficient diagnostic quality and CBCTs of patients with pathology, cysts and tumors (inflammation or sinusitis) in the MS, SS, and PPF, craniofacial anomalies, cleft lip and palate, maxillofacial surgery, trauma, growth retardation, facial asymmetry, mouth-breathing individuals and participants with missing teeth in the posterior maxilla were excluded from the study. The study included CBCT images of 600 patients (318 female and 282 male) who met these criteria and were aged between 18 and 73 (mean:31.3 ± 12.9 years).

After recording the age and sex information of all selected patients, the patients were first divided into skeletal malocclusion classes according to the ANB angulation determined by Stainer analysis [16]. Those with an ANB angle between 1° and 4° degrees were included in Class I skeletal malocclusion, those with ANB > 4° were included in Class II skeletal malocclusion, and those with ANB < 1° were included in Class III skeletal malocclusion. The number of females and males in each skeletal malocclusion group was kept close. All scans were saved in the DICOM (Digital Imaging and Communications in Medicine) format. CBCT scans were uploaded to a computer, where the volume was measured using ITK-SNAP v.4.0. open-source software. A threshold range between −1024 HU and −526 HU was applied for marking the paranasal sinuses.

- Each coronal image was used to evaluate the MS, the surrounding bone structure, and the narrowest part of the ostium located between the infundibulum and the processus uncinatus were cropped according to the border structures [17] (Fig. 1).
- The SS was cropped anterior, posterior, lateral, medial, superior, and inferior walls and defined the region of interest for segmentation on axial section [5] (Fig. 2).
- The PPF was clipped along the following borders: The anterolateral and medial borders were the perpendicular plate of the palatine bone with the pterygomaxillary fissure and the sphenopalatine foramen, respectively. The anterior and posterior segmentation borders were determined on the posterior wall of the MS and the pterygoid process of the sphenoid bone and foramen rotundum. The lower boundary was identified at the upper opening of the greater palatine canal. The pterygomaxillary fissure, vidian canal and greater palatine canal were excluded [14] (Fig. 3).

In all sections in all three planes (axial, coronal, sagittal), it was checked that MS, SS and PPF were separated from other anatomical landmarks and the airway. Then, volume measurement was performed in cubic millimeters via the program. All segmentation and volume measurement were done the right and left sides were analyzed independently.

2.3. Imaging parameters and display features

All CBCT scans (Kavo 3D Op Pro, Biberach, Germany) were obtained with a 380 μm voxel size,13 × 15 cm FOV, and 0.38 mm slice thickness, and the images were evaluated in the axial, coronal, and sagittal planes.

The first two hundred radiographs for the calibration of observers were evaluated and discussed under the supervision of a senior dentomaxillofacial radiologist (C.A.B.) With a professional background spanning >10 years. After that, one dentomaxillofacial radiology research assistant (M.K., with one year of clinical experience) evaluated all CBCTs. Inconsistent findings were resolved by consensus. At 3-week intervals, the observer (M.K.) separately re-performed their measurements to test for intra-observer reliability. The average of both measurements was used as the basis for statistical analysis. To more clearly define the presence and classification of anatomical variations in the measurements, image contrast, brightness, and zoom settings were allowed and the same 359 × 258 pixel liquid crystal monitor was used for standardization and to rule our differences in image resolution (Dell 15.6 inc.; Dell. Round Rock. Texas. USA).

2.4. Statistical analysis

Mean, standard deviation, frequency, median, maximum value, minimum value, and percentages were applied in the descriptive statistical analysis. The distribution of variables is measured by Kolmogorov Smirnov and Shapiro-Wilk tests. Kruskal-Wallis was used in the analysis of independent quantitative data with non-normal distribution. The Wilcoxon test was applied to analyze repeated measurements. SPSS v.28.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analyses. Statistical significance was set at the level of $p < 0.05$.

3. Results

CBCT images of a total of 600 patients (318 females and 282 males) aged between 18 and 73 years (mean: 31.3 ± 12.9 years) were applied throughout the study. The mean age and sex of the patients according to all three skeletal malocclusions are given in Table 1.

The mean values of right and left MSV, SSV, and PPFV according to skeletal malocclusion classes are shown in Table 2. MSV, SSV, and PPV

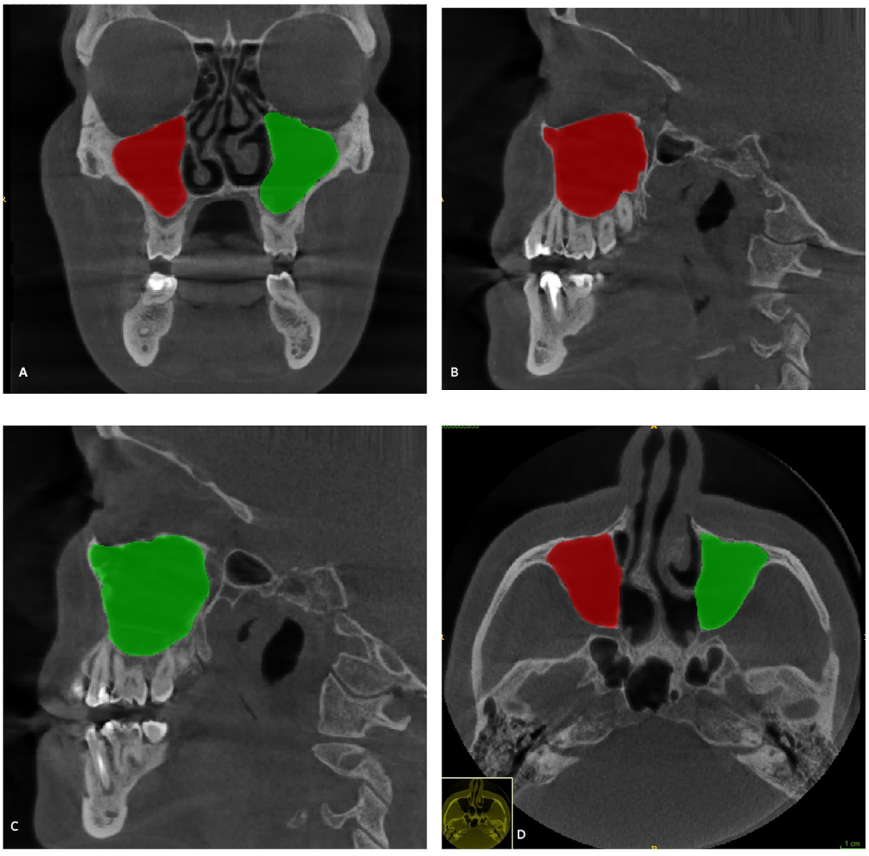


Fig. 1. Right and left maxillary sinus volume measurement in CBCT. A: coronal section, B: Right maxillary sinus volume measurement in sagittal section, C: Left maxillary sinus volume measurement in sagittal section, D: Axial section.

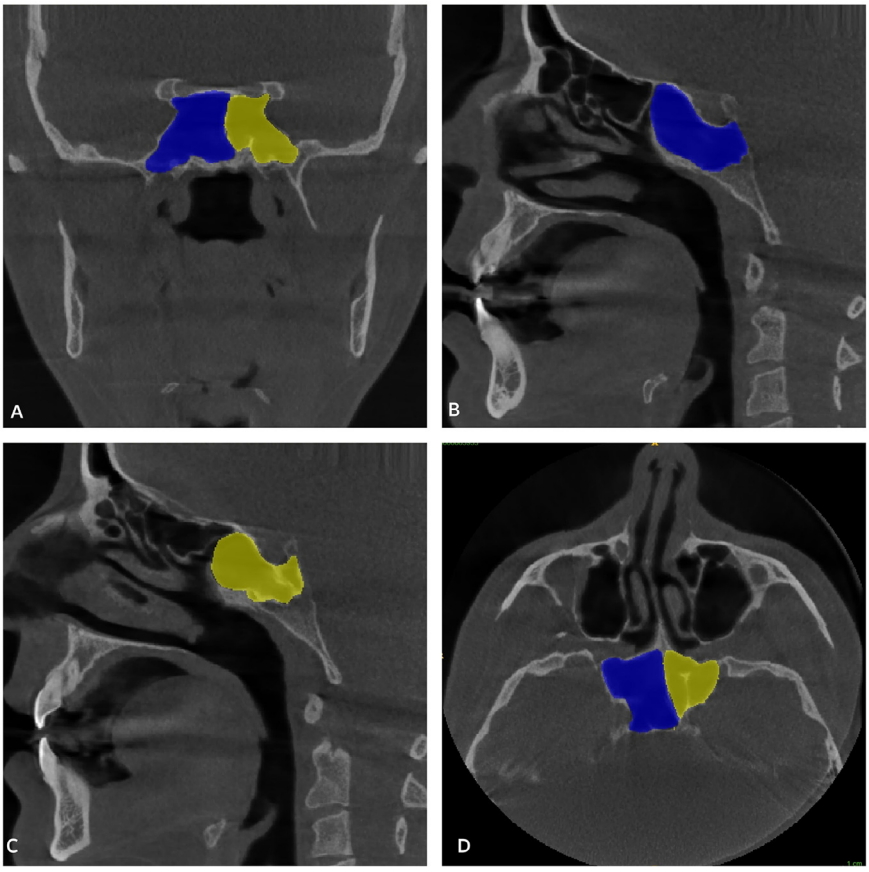


Fig. 2. Right and left sphenoid sinus volume measurement in CBCT. A: coronal section, B: Right sphenoid sinus volume measurement in sagittal section, C: Left sphenoid sinus volume measurement in sagittal section, D: Axial section.

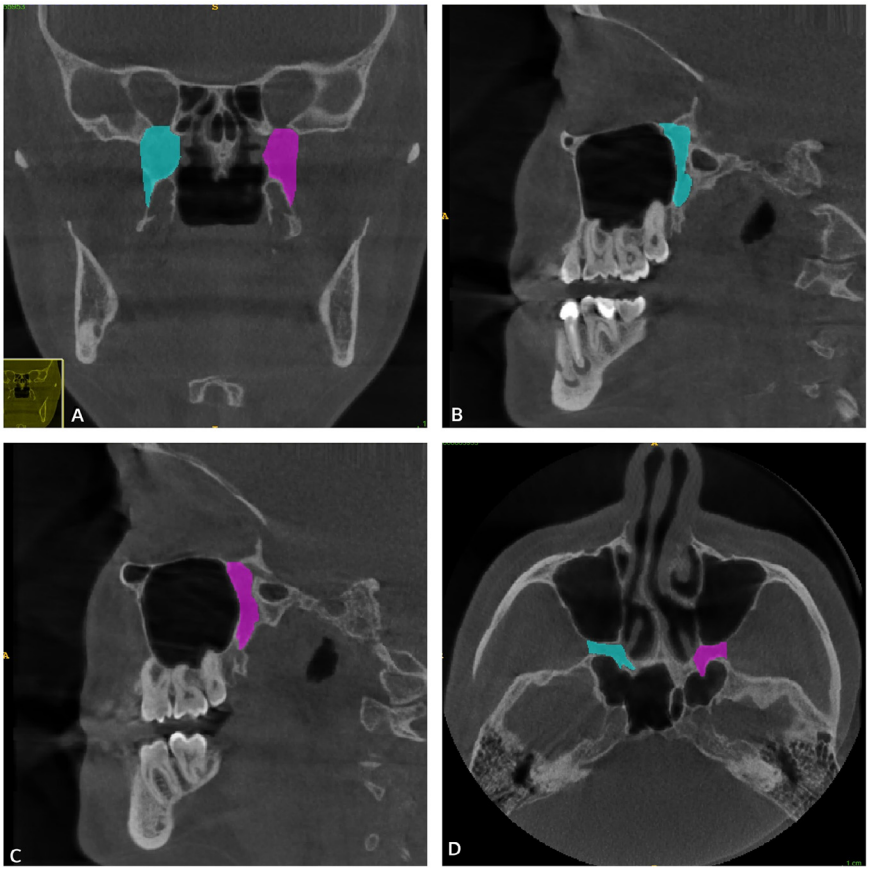


Fig. 3. Right and left pterygopalatine fossa volume measurement in CBCT. A: coronal section, B: Right pterygopalatine fossa volume measurement in sagittal section, C: Left pterygopalatine fossa volume measurement in sagittal section, D: Axial section.

was not found any significant statistical difference between the sides in the three classes ($p > 0.05$) (Table 2).

The MSV in females and males was calculated as 17,590.5 ± 3.974 mm^3 and 18,003.2 ± 3.982 mm^3, respectively. The MSV males showed a significantly higher value than females ($p < 0.05$). MSV was statistically significantly higher in Class III malocclusion than in Class I and II malocclusion ($p < 0.05$), while no statistically significant difference was observed between Class I and II malocclusion ($p > 0.05$) (Table 2).

The SSV in females and males was calculated as 5696.5 ± 1058.3 mm^3 and 5803.2 ± 1055.9 mm^3, respectively. The SSV value in males was significantly greater than that in females ($p < 0.05$). No significant statistical correlation was detected between SSV and skeletal malocclusion classes ($p > 0.05$) (Table 2).

Significantly larger PPFV was found in males (819.2 ± 206.5 mm^3) than in females (808.2 ± 273.5 mm^3) ($p < 0.05$). PPFV had the highest value in Class I malocclusion, followed by Class III and Class II, and a statistically significant difference was observed between the two ($p < 0.05$) (Table 2).

Table 1
Distribution of sample according to sex and age to all three skeletal malocclusions.

			Class-I (n:200)	Class-II (n:200)	Class-III (n:200)
Age	Mean ± SD		31.3 ± 12.6	30.7 ± 12.6	32.1 ± 13.6
	Median		26.5	25.0	28.0
Sex	Female	*n*- %	110 (55 %)	102 (51 %)	106 (53 %)
	Male	*n*- %	90 (45 %)	98 (49 %)	94 (47 %)

SD: standard deviation. N: number.

4. Discussion

The correlation between MSV and craniofacial morphology has been a subject of great interest and research in the fields of dentistry, otolaryngology and anthropology. One of the important points here is that MS development continues until approximately the age of 15–18 [1]. Therefore, CBCT images of participants who were 18 years old or older were preferred in our study. In dentistry, the clinical importance of MSV stands out in implant planning, sinus lifting procedures, maxillary posterior tooth extractions, orthognathic surgery or skeletal anchorage procedures. In orthodontics; in cases of extraction, in the mesio-distal movements of the teeth, in the intrusion of maxillary premolars/molars, during the angulation of impacted maxillary teeth, since the impacted depth is affected by the dimensions of the maxillary sinus, it should be evaluated in treatment planning [18,19]. Although there are many studies evaluating MSV in the literature, three-dimensional studies examining its relationship with skeletal malocclusion relationships are limited and their results are variable [20]. In their study investigating the changes in MSV in different malocclusions, Oruç et al. [20] showed that the MSVs among individuals diagnosed with Class II malocclusion were statistically significantly greater than those with other malocclusions. They also reported no statistically significant difference between the right and left sides MSV and that MSV was significantly greater in men. In their study, Oktay et al. [21] showed that the MSVs of patients with Class II malocclusion were statistically significantly greater than those with other malocclusions. Magat et al. [1] stated that the MSV values among individuals diagnosed with Class III malocclusion were greater than those of individuals with other malocclusions, however, this difference did not reach statistical significance. They also stated that MSV did not show significant change according to sex. It was observed in this study that MSV of patients with Class III malocclusion was statistically significantly greater than those with other malocclusions, with no

Table 2
MSV, SSV and PPFV values according to skeletal malocclusion classes.

		Class-I	Class-II	Class-III	
MSV					*p*
Right	Mean ± SD	17.5 ± 5.0	17.0 ± 5.9	18.4 ± 5.3	*0.010*^{K}
	Median	17.1 [1]	16.4 [1]	18.2	
Left	Mean ± SD	17.6 ± 5.0	17.0 ± 5.8	18.3 ± 5.0	*0.027*^{K}
	Median	17.3 [1]	16.5 [1]	18.0	
Right/Left Difference p		0.776^{W}	0.795^{W}	0.774^{W}	
SSV					
Right	Mean ± SD	5.4 ± 2.8	5.6 ± 3.0	5.9 ± 2.8	0.235^{K}
	Median	5.0	4.8	5.7	
Left	Mean ± SD	5.5 ± 2.9	5.8 ± 2.8	5.8 ± 2.6	0.328^{K}
	Median	5.5	5.4	5.3	
Right/Left Difference p		0.991^{W}	0.582^{W}	0.591^{W}	
PPFV					
Right	Mean ± SD	0.99 ± 0.34	0.73 ± 0.24	0.82 ± 0.26	*0.000*^{K}
	Median	1.01	0.69	0.81	
Left	Mean ± SD	0.90 ± 0.32	0.75 ± 0.24	0.74 ± 0.21	*0.000*^{K}
	Median	0.85	0.70	0.71	
Right/Left Difference p		0.216^{W}	0.810^{W}	0.314^{W}	

K: Kruskal-wallis (Mann-whitney u test) / w: Wilcoxon test. [1]: Difference With Class-III Group $p < 0.05$. Significant differences are indicated in bold.

statistically significant difference observed between Class I and Class II. Furthermore, it was determined that MSV was significantly greater in men, consistent with the literature, and there was no significant difference between right/left MSV. Although we reached a conclusion similar to the studies of Magat et al. [1], the differences from other results in the literature are thought to be due to the different methodology used, different angular classifications, and the inclusion of different numbers of individuals and ethnic origins in the study.

The SS is cavities located beneath the sella turcica and in the body of the sphenoid bone. Due to their location within the skull, these sinuses are at low risk of traumatic and pathological injuries. Since the SS is very important in the surgical management of the pituitary gland and provides connection to different regions of the cranial base, its volume evaluation is important in patients with different craniofacial morphology. It reaches adult size at approximately 12 years of age [22]. When the studies evaluating the relationship between skeletal malocclusion and SSV were analyzed, and it was observed that there was only one study on this subject in the literature. Nejaim et al. [5] detected that the SSVs from patients diagnosed with Class II malocclusion were statistically significantly larger than the SSVs of patients with other malocclusions, and that the difference was not statistically significant in SSVs between patients with Class I and Class III malocclusions. As another finding of their study, they stated that SSV did not show significant change with sex and direction. Our study revealed no statistically significant correlation between malocclusion and SSV. The literature includes research focusing on the relationship between SSV and age and sex. Cohen et al. [23] was found no statistically meaningful difference between the right and left sides SSV in their study evaluating the paranasal sinus volumes in different ages and sexes, while Oliveria et al. [24] reported that the right SSV was statistically significantly larger than the left SSV. When we look at the articles evaluating SSV between sexes, Cohen et al. [25] and Oliveria et al. [24] reported in their studies that SSV was found to be significantly higher in men compared to SSV in women. As a result of our examinations, showing no statistically significant difference between the right and left SSV, but SSV was significantly larger in men than in women.

The PPF connects to the middle cranial fossa via the foramen rotundum, through which the maxillary nerve passes on its posterior wall, and the pterygoid canal, which carries the Vidian nerve. The PPF is an important structure whose position and volume must be known surgically because it contains the maxillary artery, maxillary nerve, and pterygopalatine ganglion. Additionally, knowing the anatomy of this region may increase the success of anesthesia or maxillary nerve block in patients with trigeminal neuralgia [25]. It is known that PPFV is influenced by variables like posterior tooth deficiency and posture changes. It has been stated that PPF expands relatively in the direction of gravity due to downward hyperpneumatization of the maxillary sinus in maxillary posterior tooth deficiency [25]. Therefore, patients with maxillary posterior tooth deficiency were excluded from our study. Another clinical significance of PPFV is that in patients with maxillary sinus pathology, there is a regression in sinus development due to impaired sinus pneumatization [25], supporting the functional matrix hypothesis of Moss and Salentijn [23]. According to the literature, wall thickening occurs as a result of hyperostosis associated with chronic rhinosinusitis and mucosal thickening in the sphenoid sinus reduces the sinus volume and the increase in PPF volume in these patients may be attributed to the same underlying mechanism [26]. It is known that skeletal malocclusions that remain untreated for a long time can lead to postural changes, and it has been stated that PPFV can be affected by these postural changes [25]. In most cases of Class II malocclusion, mandibular retrognathism, open bite, elongated face and hunchback appearance are extraoral symptoms [27]. Another clinically significant PPF is the complication of pterygoid plate fracture in Le Fort I surgeries. Obata et al. [28] reported that patients with short and poorly fused pterygomaxillary junctions have a lower risk of pterygoid plate fracture during Le Fort I osteotomy and a lower likelihood of injury to structures passing through the PPF. They added that clinicians should pay attention to PPF dimensions to avoid complications such as damage to the optic and other cranial nerves or branches of the internal carotid artery. When the literature was evaluated, there were a limited number of studies examining the changes in PPFV according to age, sex and direction, but no study was found examining whether there was a relationship between skeletal malocclusions. Lentzen et al. [29] reported that the right PPFV was statistically significantly greater than the left PPFV and no statistically significant difference was found between sexes. Hwang et al. [13] reported in their study that PPFV was statistically greater in males compared to females. In our study, it was found that PPFV in patients with Class I malocclusion was statistically significantly greater than in patients with other malocclusions. In addition, although there was no notable difference in PPFV values between the parties, it was determined that PPFV the value was found to be statistically significantly higher in men compared to women. If all these results are to be interpreted clinically, it can be considered that the larger PPFV volume in patients with Class I malocclusion may increase the risk of complications in surgical interventions to the relevant region.

Today, CBCT scans are widely used for diagnostic and imaging purposes in all areas of dentistry due to the significantly lower radiation dose compared to CT scans. Medical image processing technologies make it possible to use three-dimensional reconstructed images of the skull obtained from CBCT scans. With these technologies, measurements regarding the anatomical configuration of the head and volume measurements of various anatomical structures can be made [19]. Monsour et al. [30] stated that the highest, widest and longest measurements of the sinus can be calculated when drawing the sinus borders and calculating its volume. Nevertheless, it is believed that this will give different results than the real anatomical values. Because the sinuses do not have a uniform structure. They are a complex and limited anatomical structure. Przystanska et al. [31] stated in their study that volumetric measurements depend on the skill and experience of the observer and therefore, any incorrect mapping while drawing the sinus border will affect the automatically calculated volume. However, they stated that there is an excellent correlation between manual and automatic methods for volumetric assessment of the maxillary sinus. It has been stated that automatic volume calculation is the most accurate method after manually determining the sinus borders. In another study, Kauke et al. [32] stated that the combination of semi-automatic and manual segmentation can be used on CBCT datasets and for better and more precise volume measurements of pathological structures in the cranio and maxillofacial regions. Another issue that should be considered in volume calculations is surface rendering. For the most precise volume measurement, it is important to identify the correct threshold ranges when performing surface rendering. Because excessive adjustment of the upper threshold leads to the inclusion of mucosa in the sinus and overestimation of the sinus volume, while setting the upper threshold too low leads to failure to recognize small cells and underestimation of the volume [33]. In our study, the boundaries of anatomical structures were determined manually by paying attention to all issues in accordance with the literature, volume calculation was made automatically and threshold values were selected in accordance with the literature.

One limitation of this study may be the fact that the ethnic diversity in our sample group may affect the results. In addition, if the sample size is increased, more realistic results can be obtained. In our study, patients with no systemic disease in their anamnesis records were preferred. However, since the volumetric values of the structures we examined may vary with various metabolic and bone diseases, this study can be repeated in patient populations with different metabolic diseases in future studies. Another point is that the ANB angle in the Stainer analysis [16] was taken into account in the classification of skeletal malocclusion. Although Endo et al. [34] and Dhiman et al. [35] reported that the SNA and SNB angles did not affect MS dimensions, they did not present a study that included the SS and PPF. We believe that this issue could be improved by comparing groups with different craniofacial features and cephalometric analyses, and that more general conclusions could be reached by excluding variations due to individual differences.

5. Conclusion

MSV, SSV and PPFV have been observed to show significant changes depending on sexual dimorphism; MSV in Class III skeletal malocclusion, and PPFV in Class I skeletal malocclusion. Knowing the dimensions of the anatomy and anatomical structures specific to the individual before surgical interventions to these regions will also reduce the risk of complications.

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Data availability

No datasets were generated or analyzed during the current study.

Declarations

Ethical approval

This study was approved by the Local Ethics Committee of the Hatay Mustafa Kemal University (Date:20.11.2024, Decision no:36).

Informed consent

Approval from the Institutional Review Board was obtained and in keeping with the policies for a retrospective review, informed consent was not required.

Declaration of competing interest

The authors declare no competing interests.

CRediT authorship contribution statement

Merve Kucuk Kurtgoz: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Zarif Ece Hammudioglu:** Writing – original draft, Methodology, Investigation, Conceptualization. **Ceren Aktuna Belgin:** Writing – review & editing, Supervision, Methodology, Investigation, Data curation, Conceptualization.

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