ONLINE FIRST

This is a provisional PDF only. Copyedited and fully formatted version will be made available soon.

ISSN: 0015-5659

e-ISSN: 1644-3284

Relation between orthodontic malocculusion and maxillary sinus volume

Authors: Kamile Keskin, Atılım Akkurt, Mehmet Cudi Tuncer

DOI: 10.5603/fm.100054

Article type: Original article

Submitted: 2024-04-01

Accepted: 2024-05-22

Published online: 2024-05-27

ORIGINAL ARTICLE

Relation between orthodontic malocculusion and maxillary sinus volume

Kamile Keskin[1], Atılım Akkurt[1], Mehmet Cudi Tuncer[2]

[1]Faculty of Dentistry, Department of Orthodontics, Dicle University, Diyarbakir, Türkiye

[2]Faculty of Medicine, Department of Anatomy, Dicle University, Diyarbakir, Türkiye

Address for correspondence: Kamile ORUÇ, Assistant Professor, Ph.D, Faculty of Dentistry, Department of Orthodontics, Dicle University, Diyarbakir, Türkiye; e-mail: kamile.keskin@gmail.com, tel. +90 533 7157405

ABSTRACT

Background: This study aimed to determine maxillary sinus volume (MSV) in different skeletal malocclusion classes and the correlation between MSV and craniofacial morphology on Cone Beam Computed Tomography (CBCT).

Materials and methods: The study was performed retrospectively on CBCT images of individuals aged 12–24 years. A total of 129 patients (70 females, 59 males) with a normal vertical growth pattern (27° ≤ SNGoMe ≤ 38°) were divided into three groups according to malocclusion. Group 1 consisted of Class I (1 ≤ ANB ≤ 4) (n = 46) patients, Group 2 consisted of Class II (ANB > 4) (n = 47) patients, and Group 3 consisted of Class III (ANB < 1) (n = 36) patients. Four angular (SNA, SNB, ANB, SNGoMe) and linear (S-N, ANS-PNS, S-Ar, N-ANS) parameters were measured to evaluate craniofacial morphology. Right and left MSV were measured using Dolphin 11.0 (Dolphin Imaging, Chatsworth, CA, USA) Imaging software. Pearson's correlation analysis was performed to assess statistical correlation.

Results: MSV was larger in males than females (male AMSV = 14244.1 ± 4735.8, female AMSV = 12778.2 ± 4606.9 p = 0.011) in the general population, but just the Class II group showed this (male AMSV = 16089.6 ± 4330.4, female AMSV= 12705.9 ± 3210.2, p = 0.008). RMSV and LMSV were similar (female p = 0.181 male p = 0.097), and MSV showed no significant differences between the different malocclusion classes in both sex (female p = 0.315, male p = 0.118). In the Class III group, SNB was positively correlated with RMSV (r = 416, p = 0.012). MSV showed significant positive correlation with N-ANS in all groups (Class I r = 0.359, p = 0.014, Class II r = 0.336, p = 0.021, Cl III r = 0.387, p = 0.02). In the Class II and Cl III groups, there is a statistically significant correlation between MSV and the S-N parameter (Class II r = 0.304, p = 0.038, Class III r = 0.412, p = 0.013). ANS-PNS parameter was measured at the lowest statistically significant level (female 43.1 ± 3.9[a], p < 0.001, male 43.1 ± 4.3[a], p < 0.001) in the Class III group but no correlation was found with MSV. Only Class II group showed a weak positive correlation between MSV and ANS-PNS (r = 0.314, p = 0.032).

Conclusions: There was no difference regarding MSV between malocclusion classes. Class II males exhibit significantly larger MSV compared to females. There is a correlation between MSV and SNB, S-N, N-ANS and ANS-PNS parameters for various orthodontic skeletal patterns. Further studies are needed to understand the relationship between MSV and different skeletal structures.

Keywords: maxillary sinus, craniofacial anatomy, sinus morphology, malocclusion, CBCT

INTRODUCTION

The correlation between maxillary sinus volume (MSV) and craniofacial morphology represents a significant area of interest within the field of anatomy and craniofacial biology. Maxillary sinuses (MS), situated in the maxilla, play a crucial role in the structural integrity and function of the craniofacial complex. Understanding the relationship between the volume of these sinuses and the surrounding craniofacial structures offers valuable insights into various clinical aspects, including orthodontic treatment planning, dental implant placement, and the management of sinus pathologies. This correlation reflects the intricate interplay between skeletal development, functional adaptation, and anatomical variations within the craniofacial region. By elucidating these connections, researchs aim to enhance diagnostic accuracy, treatment efficacy, and overall patient care in the realm of oral and maxillofacial health. In this article, we delve into the current understanding of the correlation between MSV and craniofacial morphology, exploring its implications for clinical practice and highlighting avenues for future research.

The paranasal sinuses are spaces within the skull and facial bones. The largest paranasal sinus is the MS, located bilaterally inferior to the eyes inside each maxillary bone [1, 2]. Postnatally, they grow according to a biphasic pattern, in which the first phase occurs between 0-3 years, and the second phase occurs during years 6–12. The MS is nearly developed to adult size between 12 and 15 years of age [3–5]. However, some studies have indicated that the MS's development continues until the third decade in males and the second decade in females, and after that, their size decreases [6, 7]. The earliest phase of pneumatization is directed horizontally and posteriorly, whereas the later stage proceeds inferiorly toward the maxillary teeth. Some other early researchers reported that MS serves many functions [8–14]. However, the function of the MS and the underlying patterns governing its form remain elusive [15].

The shape of the MS is a pyramid, with the base along the nasal wall and the apex pointing laterally toward the zygoma. The MS's anatomy is directly related to the palate, posterior alveolar bone, and teeth. Because of its large volume, some researchers have reported that MS plays an essential role in the formation of facial contours [6, 7, 16, 17]. The relationships between the structures that make up the craniofacial complex are based on the structural and functional balance between MS and these structures [18]. Some 2D radiographic studies tried to explain the MS size in different malocclusion groups and the correlation between MS size and dentofacial morphology [19–21]. It has been observed that malocclusions and sex factors do not appear to affect the size of the maxillary sinuses. However, it seems that sex may be a significant factor in Angle Class II malocclusions [19]. The study utilized cephalometric radiographs to identify significant correlations between maxillary sinus measurements and various dentofacial morphologic measurements. While no significant differences in maxillary sinus size were observed between different malocclusion classes and genders, correlations with a big cranial base and nasomaxillary complex were identified. [20].

A research shows that variations in maxillary sinus volume are linked to variations in maxillary sinus shape, particularly height and width dimensions, rather than length [22]. In addition, there is a correlation between maxillary sinus volume and maxillary arch width, with a stronger relationship observed compared to other linear measurements of the sinuses [23]. The maxillary sinus acts as a compliance zone within the midface, covarying with midface and nasal cavity structures, affecting height and width relationships and lateral expansion toward the zygoma [24]. Furthermore, larger maxillary sinus volumes predict displaced zygomatic bone fractures, and greater sinus height indicates a larger zygomaticomaxillary support surface area

[25] Gender affects MSV, men generally having larger sinuses than women, while skeletal malocclusion, facial type and breathing pattern do not significantly affect sinus volume [26].

The correlation between MSV and craniofacial morphology represents a significant area of interest in anatomy and craniofacial biology [27]. MS, situated in the maxilla, plays a crucial role in the structural integrity and function of the craniofacial complex. Understanding the relationship between the volume of these sinuses and the surrounding craniofacial structures offers valuable insights into various clinical aspects, including orthodontic treatment planning, dental implant placement, and the management of sinus pathologies. This correlation reflects the intricate interplay between skeletal development, functional adaptation, and anatomical variations within the craniofacial region. By elucidating these connections, researchers aim to enhance diagnostic accuracy, treatment efficacy, and overall patient care in the realm of oral and maxillofacial health [28–30].

However, 3D volumetric research on MSV and skeletal jaw relationship is limited, and there is no consensus among them [31–34]. Additionally, limited specific Cone Beam Computed Tomography (CBCT) studies report a correlation between MSV and cephalometric data according to sagittal jaw relationships. This study aimed to determine MSV in different skeletal malocclusion classes and the correlation between MSV and craniofacial morphology on CBCT.

MATERIALs AND METHODS

Review group and ethics approval detail

The local Ethics Committee of the Dicle University Faculty of Dentistry approved the study. A total of 982 CBCT scans of patients were reviewed as a retrospective study from the archive of the Oral and Maxillofacial Radiology Department, Dicle University (Diyarbakır, Turkey). The study was performed on CBCT images of individuals aged 12–24. The CBCTs were excluded if they showed indications of MS pathology such as inflammation or sinusitis, MS cysts or tumors, subjects with craniofacial anomalies, cleft lip, or palate, those who had undergone jaw surgery, facial trauma, growth delay, extracted posterior tooth, tooth agenesis, or cases with severe facial asymmetry, where jaws were not at maximum interception. The subjects of this study were individuals with bilateral healthy MS.

Radiological examination

All CBCT images were acquired using the i-CAT® (Model 17–19; Imaging Sciences International, Hatfield, PA, USA). Exposures were made at 5.0 mA and 120 kVp for 8.9

seconds, and the axial slice thickness was 0.3 mm. As a routine image exposure protocol, patients were asked to bite but not to swallow or move their head or tongue while the CBCT was taken. All scans were acquired with the patient sitting upright, with the Frankfort Horizontal Plane (FHP) parallel to the floor.

Cephalometric analyses

The Digital Imaging and Communications in Medicine (DICOM) format of each CBCT was transferred to analyze into Dolphin 11.0 3D (Dolphin Imaging, Chatsworth, CA, USA) software. After a careful orientation in axial, sagittal, and horizontal planes, cephalometric radiographs were derived from CBCT's. Cephalometric evaluation of the radiographs was made by Dolphin imaging software (version 11.0). In the evaluation of craniofacial morphology, four angular (SNA, SNB, ANB, SN-Go-Me) and four linear (S-N, ANS-PNS, S-Ar, N-ANS) measurements were selected from the parameters of Steiner [35], McNamara et al. [36] and Ricketts [37] cephalometric analysis (Table 1). Finally, a total of 129 patients (70 females, 59 males) with normal vertical growth pattern (27° ≤ SNGoMe ≤ 38°) who met the inclusion criteria were divided into three groups according to the malocclusion. The groups were established in accordance with the ANB parameter, as determined by the Steiner analysis [35]. Group 1 consisted of Class I (1 ≤ ANB ≤ 4) patients (n = 46: 26 female, 20 male), Group 2 consisted of Class II (ANB > 4) patients (n = 47: 27 female, 20 male), and Group 3 consisted of Class III (ANB < 1) patients (n = 36: 17 female 19 male) were selected.

Anatomical landmarks: S. Midpoint of sella turcica, **N.** The most anterior point of intersection of internasal suture with nasofrontal suture in midsagittal plane, **A.** The deepest midline point on the anterior outer contour of the maxillary alveolar process, **B**. The deepest point on the outer contour of the mandible, **Go.** Gonion, a point at the intersection of lines tangent to the posterior border of the ramus and the lower border of the mandible, **Me.** Menton, the most inferior point of the outline of the symphysis in the midsagittal plane, **Ar.** Articulare, a point at the intersection of the image of the posterior margin of the ramus and the outer margin of the cranial base, **PNS.** Posterior nasal spine, **ANS.** Anterior nasal spine; ***Lines:*** **S–N.** Anterior cranial base length, distance from sella turcica (S) (midpoint of sella turcica) to nasion (N) (intersection of internasal suture with nasofrontal suture in midsagittal plane), **N–A.** Upper face lengt, distance from nasion (N) and A point (deepest midline point on anterior maxilla between anterior nasal spine and prosthion, **N–B.** Line, between nasion

(N) and B point (the deepest midline point on the outer contour of the mandible), ***Planes:*** **S–N,** Anterior cranial base length, distance from sella turcica (S) (midpoint of sella turcica) to nasion (N) (intersection of internasal suture with nasofrontal suture in midsagittal plane), **Go–Me.** Line between Go and Me**, SAr:** Posterior cranial base length, distance from S to Ar, **N–ANS.** Anterior upper facial length, distance from N to ANS, **ANS-PNS.** Maxillary length, distance from ANS to PNS; ***Angles:*** **SNA.** Prognathism of maxillary alveolar bone, S–N to N–A angle**, SNB.** Prognathism of the mandibular alveolar bone, S-N to N-B angle, **ANB.** Sagittal jaw relationship angle, N-A to NB angle, **SNGoMe.** Angle between cranial base (S–N) and mandibular plane (Go-Me).

Table 1. Defination of the Parameters used for the evaluation of craniofacial morphology

Parameters	Definations
SNA (°)	Prognathism of maxillary alveolar bone, S–N to N–A angle
SNB (°)	Prognathism of the mandibular alveolar bone, S–N to N–B angle
ANB (°)	Sagittal jaw relationship angle, NA to N–B angle
SNGoMe (°)	Skeletal vertical growth patern angle, between S–N plane and Go–Me plane
S–N [mm]	Anterior cranial base length, distance from S to N
SAr [mm]	Posterior cranial base length, distance from S to Ar
ANS–PNS [mm]	Maxillary length, distance from ANS to PNS
N–ANS [mm]	Anterior upper facial length, distance from N to ANS

Volumetric measurements

For the evaluation of MSV, DICOM files obtained from the CBCT scans were exported to the Dolphin 11.0 (Dolphin Imaging, Chatsworth, CA, USA) Imaging software. After careful identification of the borders of MS in axial, sagittal, and coronal views (Fig. 1), all CBCT images were carefully scanned slice by slice, and the evaluation of each right and left MSVs were accomplished by adding the seeds to the unmarked areas by using the 3D module of the software (Fig. 2). The same observer made all measurements.

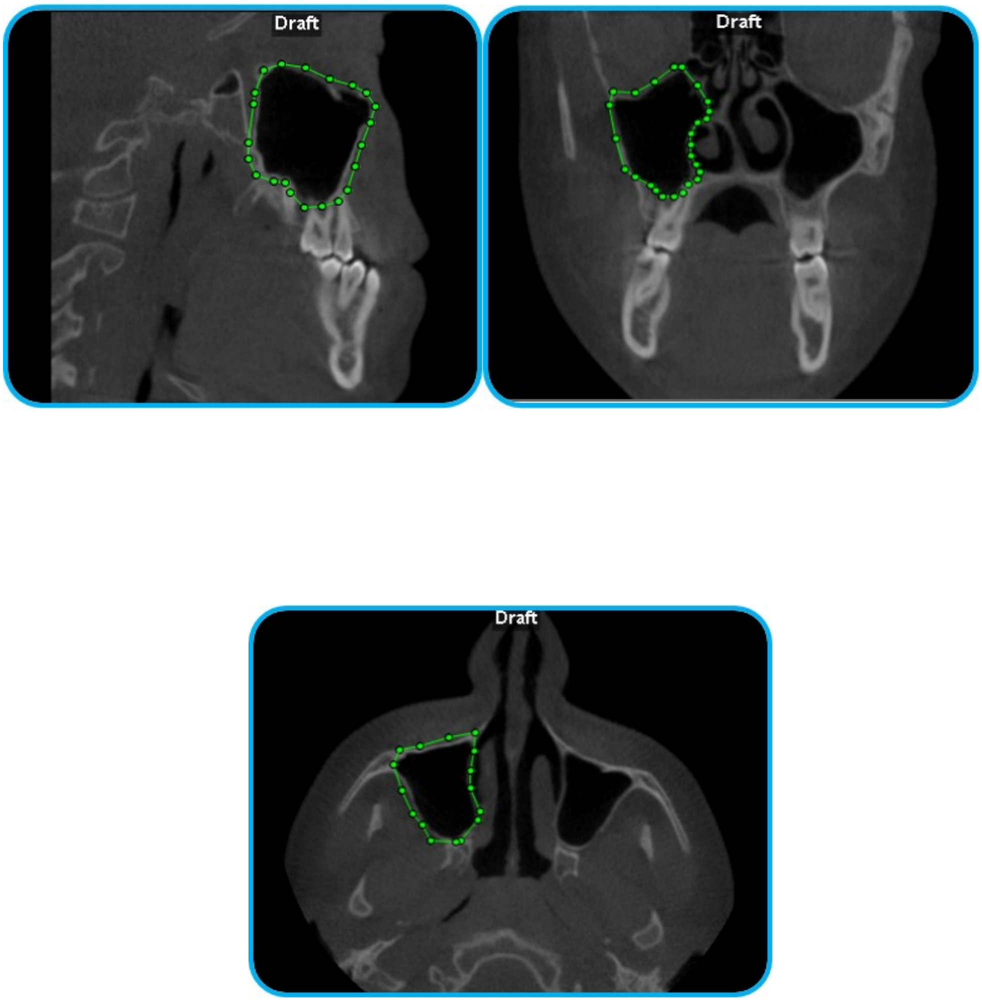

Figure 1. Borders of MS in axial, sagittal, and coronal views

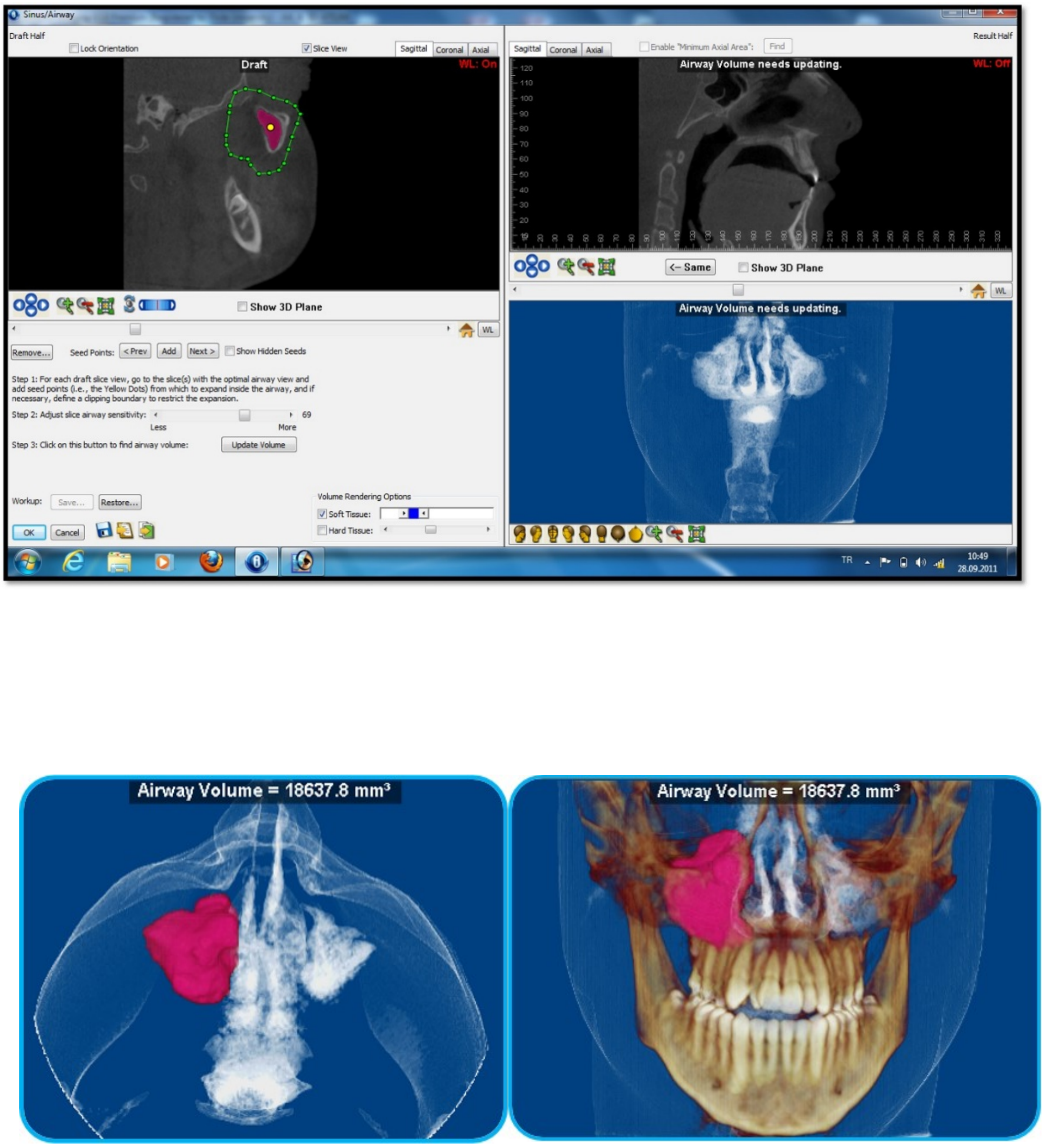

Figure 2. All CBCT images were carefully scanned slice by slice, and the evaluation of each right and left MSVs were accomplished by adding the seeds.

Method error

To assess method error, the same observer repeated measurements of twenty-four subjects at one-month intervals. Wilcoxon matched-pairs signed rank test was used to detect the differences between repeated measures with the significance level set at $p<.05$.

Statistical analysis

The data were analyzed using IBM SPSS V23. The normality of the distribution was assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests. Independent two-sample t-tests were employed to compare normally distributed data between two groups, while the Mann-

Whitney U test was used for comparing non-normally distributed data between two groups. One-way ANOVA was utilized to compare normally distributed data among different classes, and multiple comparisons were conducted using the Duncan test. For non-normally distributed data among classes, comparisons were performed using the Kruskal-Wallis test, and post-hoc multiple comparisons were carried out using the Dunn test. The Wilcoxon test was employed to compare the intragroup mean square variance values for non-normally distributed right and left data. To investigate relationships between non-normally distributed variables, the Spearman's rho correlation coefficient was used. Analysis results were presented in the form of mean ± standard deviation (SD) and median (m) (minimum–maximum). A significance level of $p < 0.050$ was considered.

RESULTS

The study was conducted on 129 individuals (70 female, 59 male). Age distribution of the groups according to gender were as follows: Group 1 was female 16 ± 3.1, male 15 ± 2.4, Group 2 was female 14 ± 2.1, male 15 ± 1.9, Group 3 was female 15 ± 2.2, male 15 ± 3.3. There is no significant difference in the mean ages of Class I, Class II, and Class III groups by gender ($p = 0.236$, $p = 0.974$, $p = 0.549$). In the intergroup comparison, no statistically significant difference was observed between the mean ages of females and males ($p = 0.255$, $p = 0.909$).

Evaluation of cephalometric data within groups

The results of the cephalometric measurements for different groups, categorized by gender, are presented in Table 2. In Class I group, only the S-N parameter was found to be significantly larger in males compared to females ($p = 0.005$). In the Class II group, males exhibited significantly larger values than females for the S–N, S–Ar, and N–ANS parameters ($p < 0.001$, $p = 0.008$, $p < 0.001$). In the Class III group, there was no significant difference in cephalometric parameters between genders.

Comparison of cephalometric data between groups

In terms of the groups, there is no statistically significant difference in the mean SNA values among females ($p = 0.088$). However, among males, there is a statistically significant difference in the mean SNA values ($p = 0.038$). By groups, there was a statistically significant difference in the mean SNB values among females (p < 0.001) and males (p < 0.001). Among females and males, there is a statistically significant difference in the mean ANB values among the groups respectively (p < 0.001). Among females there is a statistically significant difference in the mean ANS–PNS values among the groups (p < 0.001). Similarly, among males, there is a statistically significant difference in the mean ANS–PNS values among the groups (p < 0.001).

Table 2. Comparison of cephalometric parameters according to gender and groups

		Class I			**Class II**			**Class III**			**Test statistic**	**p**
		n	**Mean ± SD m (min–max)**		**n**	**Mean ± SD m (min–max)**		**n**	**Mean ± SD m (min–max)**			
SNA	**Female**	26	81.6 ± 2.5	81.8 (75.6–85.7)	27	81.8 ± 3.5	81.4 (75.1–89.2)	17	79.2 ± 4	79.7 (70.9–84.4)	χ^2 4.87	0.088
	Male	20	80.7 ± 3.4	81.5 (73.7–87.1)[ab]	20	82.3 ± 3.9	81.9 (75.6–89.8)[a]	19	79.6 ± 2.8	79.4 (75.4–88.3)[b]	χ^2 6.563	**0.038**
	Test statistic		U = 219.5			U = 245			U = 151			
	p		0.369			0.591			0.754			
SNB	**Female**	26	78.9 ± 2.7	79.2 (72.3–83.7)[b]	27	75.7 ± 3.5	75.7 (69.9–83.7)[a]	17	80.3 ± 2.8	79.9 (75.5–84.7)[b]	χ^2 20.089	**< 0.001**
	Male	20	77.7 ± 3.3	77.6 (71.6–83.3)[b]	20	75.6 ± 3.9	75.5 (68.8–82.8)[b]	19	81.7 ± 3.4	80.3 (76.9–89.3)a	χ^2 19.513	**< 0.001**
	Test statistic		U = 208.5			U = 268.5			U = 127.5			
	p		0.254			0.974			0.285			
ANB	**Female**	26	2.7 ± 1	2.9 (1–4)[c]	27	6.1 ± 1.6	5.8 (4.3–10.9)[b]	17	–1.8 ± 2.1	–1 (–6.6 to 0)[a]	χ^2 60.583	**< 0.001**

	Male	20	3 ± 1	3.1 (1.1–4)[c]	20	6.7 ± 1.4	6.6 (4.3–9.8)[b]	19	–2.4 ± 2.4	–1.5 (–8.8–0)[a]	χ^2 51.615	< **0.001**
	Test statistic		U = 216.5			U = 193			U = 128.5			
	p		0.333			0.097			0.3			
S–N	**Female**	26	63.8 ± 2.1	64 (59–68)	27	64.2 ± 3.1	64 (57–70)	17	64.2 ± 3.4	65 (57–70)	F = 0.127	0.881
	Male	20	66.2 ± 3.1	66 (61–74)	20	68 ± 2.9	68 (63–74)	19	66.1 ± 3.4	66 (59–72)	F = 2.308	0.109
	Test statistic		t = –2.987			t = –4.158			t = –1.644			
	p		**0.005**			**<0.001**			0.109			
S–Ar	**Female**	26	32.8 ± 2.8	33 (28–38)	27	32.5 ± 2.1	33 (28–36)	17	31.5 ± 2.2	31 (28–35)	F = 1.433	0.246
	Male	20	33.2 ± 2.4	33 (30–37)	20	36 ± 4.9	35 (28–46)	19	33.1 ± 3.5	33 (25–38)	F = 2.781	0.076
	Test statistic		t = –0.485			t = –2.916			t = –1.543			
	p		0.63			**0.008**			0.132			
N–ANS	**Female**	26	49.3 ± 2.6	49.2 (43.3–53.3)	27	48.9 ± 2.7	48.9 (43.4–54)	17	48.3 ± 2.4	49 (43.7–53.1)	F = 0.719	0.491
	Male	20	50.5 ± 3	50.7 (44.7–56)	20	52.4 ± 3.5	52.8 (46.5–58.6)	19	50.5 ± 3.9	51.5 (44.7–56.6)	F = 2.047	0.139
	Test statistic		t = –1.477			t = –3.9			t = –2.02			
	p		0.147			< **0.001**			0.052			
ANS –	**Female**	26	46.9 ± 4[b]	47.2 (39.7–	27	48.6 ± 3.8[b]	48.9 (39.3–	17	43.1 ± 3.9[a]	42.4 (36.8–	F = 10.741	< **0.00**

	e			54.5)			56.4)			50.9)		**1**
PNS	**Male**	20	47.9 ± 4^{b}	48 (41.6–58.6)	20	49.5 ± 3.6^{b}	49.4 (44.2–56.5)	19	43.1 ± 4.3^{a}	43.4 (34.2–50.2)	F = 13.728	**< 0.001**
	Test statistic		t = –0.804			t = –0.77			**t = 0.017**			
	p		0.426			0.446			0.986			

Assessment of maxillary sinus volumes (MSV)

Comparison of MSV by gender

The Comparison of right maxillary sinus volumes (RMSV), left MSV (LMSV) and average MSV (AMSV) by gender is presented in Table 3. The RMSV of all females included in the study (12333.7 mm^3) was found to be significantly lower than the RMSV volume of males (14012.7 mm^3) (p = 0.014). The LMSV of all females included in the groups (13222.8 mm^3) is significantly lower than the LMSV of males (14457.1 mm^3) (p = 0.005). There is no statistically significant difference between the RMSV and LMSV parameters for all females included in the study (p = 0.181). Similarly, there is no statistically significant difference between the RMSV and LMSV parameters for all males included in the study (p = 0.097). In addition, the AMSV parameter for females (12778.2 mm^3) was found to be significantly lower than the AMSV parameter for males (14244.1 mm^3). Regardless of gender, it was determined that the RMSV parameter (13101.6 mm^3) for all patients included in the study is significantly lower than the LMSV parameter (13782.1 mm^3) (p = 0.040).

Table 3. Comparison of RMSV, LMSV and AMSV values according to gender

	Female (n = 70)	**Male (n = 59)**	**Total (n = 129)**	**Test statistic**	**p**
RMSV mm^3	12333.7 ± 2860.2	14012.7 ± 4866.5	13101.6 ± 3980.8	U = 1545.000	**0.014**
	12510.7 (5789.9–21755.1)	14151.3 (2298.5–26824.0)	13084.2 (2298.5–26824.0)		
LMSV mm^3	13222.8 ± 8156.2	14457.1 ± 4898.3	13782.1 ± 6876.9	U = 1446.000	**0.005**
	12632.0	15205.5	13719.1		

	(1139.7–72216.6)	(3091.3–26575.8)	(1139.7–72216.6)		
Test statistic	Z = –1.337	Z = –1.661	Z = –2.055		
p	0.181	0.097	**0.04**		
AMSV mm^3	12778.2 ± 4606.9	14244.1 ± 4735.8	13448.7 ± 4705.4	U = 1526.000	**0.011**
	12827.3 (4481.6 – 40285.4)	13929.7 (2694.9 – 26699.9)	13443.6 (2694.9 – 40285.4)		

AMSV — average maxillary sinus volumes; LMSV — left maxillary sinus volumes; RMSV — maxillary sinus volumes

The MSV amounts for the groups based on gender are shown in Table 4. In Class I, there was no significant difference in RMSV (p = 0.912), LMSV (p = 0.947), and AMSV (p = 0.947) parameters between female and male individuals. Among the females in Class II, the RMSV (12940.8 mm^3, p = 0.03), LMSV (12471 mm^3, p = 0.002), and AMSV (12705.9 mm^3, p = 0.008) parameters were significantly lower than those of males (RMSV: 15695.8 mm^3, LMSV: 16483.5 mm^3, AMSV: 16089.6 mm^3). In Class III, the RMSV parameter of female students (10765.1 mm^3) was significantly lower than that of males (13812.8 mm^3) (p = 0.019). There was no significant difference in LMSV and AMSV parameters (p > 0.05).

For all females included in the study, RMSV (p = 0.014), LMSV (p = 0.005), and AMSV (p = 0.011) parameters were found to be significantly lower than those of males.

Table 4. MSV comparison results in groups by gender

			Female (N = 70)			**Male**		**Test statistic**	**p**
		n	Mean ± SD	m (min.–max)	n	Mean ± SD	m (min.–max.)		

Class I (n = 46)	RMSV	26	12728.9 ± 2830.9	13149.7 (5789.9–19095.3)	20	12519.7 ± 4269.2	12622.1 (5129.1–22127.2)	255	0.912
	LMSV	26	12858.0 ± 3553.6	13279.6 (1782.3–18273.3)	20	12694.7 ± 4501.8	12956.9 (3977.0–22354.0)	257	0.947
	AMSV	26	12793.4 ± 3008.9	13264.1 (5756.2–18640.0)	20	12607.2 ± 4279.5	13158.6 (4592.0–22240.6)	257	0.947
Class II (n = 47)	RMSV	27	12940.8 ± 2769.8	13054.5 (6665.1–21755.1)	20	15695.8 ± 4630.0	15556.6 (9023.6–26824.0)	169	**0.03**
	LMSV	27	12471.0 ± 4138.3	13100.9 (1139.7–22495.7)	20	16483.5 ± 4208.2	15553.9 (10428.6–26575.8)	129	**0.002**
	AMSV	27	12705.9 ± 3210.2	13085.8 (6257.3–22125.4)	20	16089.6 ± 4330.4	15555.2 (10292.1–26699.9)	146	**0.008**
Class III (n = 36)	RMSV	17	10765.1 ± 2607.7	9909.2 (5892.8–15869.1)	19	13812.8 ± 5364.7	13375.1 (2298.5–22512.5)	88	**0.019**
	LMSV	17	14974.8 ± 15326.2	11044.1 (3070.3–72216.6)	19	14163.7 ± 5424.8	15628.6 (3091.3–22620.8)	111	0.173
	AMSV	17	12870.0 ± 7785.7	10476.7 (4481.6–40285.4)	19	14024.6 ± 5131.3	13929.7 (2694.9–21587.9)	107	0.087

AMSV — average maxillary sinus volumes; LMSV — left maxillary sinus volumes; RMSV — right maxillary sinus volumes

Table 5. Comparison of MSV by groups

		Class I (n = 46)	**Class II (n = 47)**	**Class III (n = 36)**	**Test statistic**	**p**
Female	RMSV	12728.9 ± 2830.9	12940.8 ± 2769.8	10765.1 ± 2607.7	χ^2	0.051
		13149.7 (5789.9–19095.3)	13054.5 (6665.1–21755.1)	9909.2 (5892.8–15869.1)		

					6.954	
	LMSV	12858.0 ± 3553.6	12471.0 ± 4138.3	14974.8 ± 15326.2	χ^2	0.363
		13279.6 (1782.3–18273.3)	13100.9 (1139.7–22495.7)	11044.1 (3070.3–72216.6)	2.025	
	Test statistic	Z = –1.029	Z = –0.288	Z = –1.065		
	p	0.304	0.773	0.287		
	AMSV	12793.4 ± 3008.9	12705.9 ± 3210.2	12870.0 ± 7785.7	χ^2	0.315
		13264.1 (5756.2–18640.0)	13085.8 (6257.3–22125.4)	10476.7 (4481.6–40285.4)	2.308	
Male	RMSV	12519.7 ± 4269.2	15695.8 ± 4630.0	13812.8 ± 5364.7	χ^2	0.126
		12622.1 (5129.1–22127.2)	15556.6 (9023.6–26824.0)	13375.1 (2298.5–22512.5)	4.139	
	LMSV	12694.7 ± 4501.8	16483.5 ± 4208.2	14163.7 ± 5424.8	χ^2	0.076
		12956.9 (3977.0–22354.0)	15553.9 (10428.6–26575.8)	15628.6 (3091.3–22620.8)	5.165	
	Test statistic	Z = –0.037	Z = –1.568	Z = –1.198		
	p	0.97	0.117	0.231		
	AMSV	12607.2 ± 4279.5	16089.6 ± 4330.4	14024.6 ± 5131.3	χ^2	0.118
		13158.6 (4592.0–22240.6)	15555.2 (10292.1–26699.9)	13929.7 (2694.9–21587.9)	4.274	
Total	RMSV	12637.9 ± 3486.9	14113.1 ± 3884.1	12373.6 ± 4504.5	χ^2	0.116
		13149.7 (5129.1–22127.2)	13280.8 (6665.1–26824.0)	12152.3 (2298.5–22512.5)	4.311	
	LMSV	12787.0 ± 3947.1	14178.4 ± 4584.3	14557.7 ± 11199.2	χ^2	0.347
		13076.0 (1782.3–22354.0)	14406.3 (1139.7–26575.8)	11808.4 (3070.3–72216.6)	2.118	
	Test statistic	Z = –0.705	Z = –1.196	Z = –1.703		
	p	0.481	0.232	0.088		
	AMSV	12712.4 ± 3573.7	14145.8 ± 4053.4	13479.4 ± 6449.3	χ^2	0.354
		13264.1 (4592.0–	13908.6 (6257.3–	12583.5 (2694.9–		

		22240.6)	26699.9)	40285.4)	2.075	

AMSV — average maxillary sinus volumes; LMSV — left maxillary sinus volumes; RMSV — right maxillary sinus volumes

Comparison of MSV by groups

The results of the statistical comparisons of RMSV, LMSV, and AMSV parameters between groups by gender are presented in Table 5. And, there was no statistically significant difference in RMSV, LMSV, and AMSV parameters among the female individuals constituting Classes I, II, and III ($p > 0.05$). Similarly, among the male individuals constituting Classes I, II, and III, there was no statistically significant difference in RMSV, LMSV, and AMSV parameters ($p > 0.05$).

Correlation between MSV and cephalometric values of groups

The relationship between cephalometric parameters and MSV for Classes I, II, and III groups is shown in Table 6. In the Class I group, there is a statistically significant weak positive correlation between RMSV ($r = 0.361$; $p = 0.014$), LMSV ($r = 0.344$; $p = 0.019$), AMSV ($r = 0.359$; $p = 0.014$) parameters, and the N-ANS parameter. In the Class II group, there is a statistically significant weak positive correlation between LMSV ($r = 0.321$; $p = 0.028$), AMSV ($r = 0.304$; $p = 0.038$) parameters, and the S-N parameter. In the Class II group, there is a statistically significant weak positive correlation between RMSV ($r = 0.356$; $p = 0.014$), LMSV ($r = 0.328$; $p = 0.024$), AMSV ($r = 0.336$; $p = 0.021$) parameters, and the N-ANS parameter. In the Class II group, there is a statistically significant weak positive correlation between RMSV ($r = 0.297$; $p = 0.043$), LMSV ($r = 0.296$; $p = 0.043$), AMSV ($r = 0.314$; $p = 0.032$) parameters, and the ANS–PNS parameter. In the Class III group, there is a statistically significant weak positive correlation between RMSV and the SNB parameter ($r = 0.416$; $p = 0.012$).

There is a moderate positive correlation between RMSV ($r = 0.454$; $p = 0.005$), LMSV ($r = 0.430$; $p = 0.01$), AMSV ($r = 0.412$; $p = 0.013$) parameters, and the S–N parameter in the Class III group. In the Class III group, there is a weak positive correlation between RMSV ($r = 0.387$; $p = 0.02$) and the N–ANS parameter.

Table 6. Examination of the relationship between RMSV, LMSV and AMSV values and cephalometric parameters within each group

			SNA	**SNB**	**ANB**	**SNGo Me**	**S–N**	**S–Ar**	**N–ANS**	**ANS–PNS**
Class I	**RMSV**	r	0.057	0.125	–0.093	–0.096	0.27	0.071	0.361	0.281
		p	0.705	0.408	0.537	0.525	0.07	0.637	**0.014**	0.058
	LMSV	r	–0.008	0.004	–0.042	–0.167	0.198	0.067	0.344	0.238
		p	0.956	0.977	0.782	0.267	0.188	0.659	**0.019**	0.111
	AMSV	r	–0.008	0.03	–0.057	–0.105	0.233	0.082	0.359	0.268
		p	0.96	0.843	0.708	0.486	0.119	0.589	**0.014**	0.072
Class II	**RMSV**	r	0.096	–0.003	0.188	–0.043	0.282	0.162	0.356	0.297
		p	0.523	0.983	0.206	0.774	0.055	0.278	**0.014**	**0.043**
	LMSV	r	0.148	0.078	0.171	–0.208	0.321	0.288	0.328	0.296
		p	0.322	0.601	0.251	0.161	**0.028**	0.05	**0.024**	**0.043**
	AMSV	r	0.142	0.051	0.195	–0.124	0.304	0.208	0.336	0.314
		p	0.343	0.735	0.19	0.405	**0.038**	0.16	**0.021**	**0.032**
Class III	**RMSV**	r	0.253	0.416	–0.162	0.092	0.454	0.163	0.387	0.32
		p	0.136	**0.012**	0.344	0.592	**0.005**	0.343	**0.02**	0.057
	LMSV	r	0.058	0.228	–0.21	0.236	0.43	0.17	0.271	0.294
		p	0.741	0.188	0.226	0.173	**0.01**	0.33	0.115	0.087
	AMSV	r	0.084	0.274	–0.237	0.209	0.412	0.155	0.271	0.281
		p	0.626	0.105	0.164	0.222	**0.013**	0.367	0.111	0.097

AMSV — average maxillary sinus volumes; LMSV — left maxillary sinus volumes; RMSV — right maxillary sinus volumes

DISCUSSION

The correlation between MSV and craniofacial morphology has been a subject of considerable interest and investigation in the fields of dentistry, otolaryngology, and anthropology. In this study, we sought to elucidate the relationship between these two anatomical features through a comprehensive analysis of imaging data and craniofacial measurements. Our findings shed light on the complex interplay between maxillary sinus size and craniofacial morphology, providing valuable insights into the potential implications for clinical practice, including orthodontic treatment planning, sinus surgery, and forensic anthropology. In this discussion, we will delve into the implications of our results, address potential limitations, and suggest avenues for future research in this intriguing area of study.

Sagittal jaw relationships are one of the primary considerations in orthodontic treatment planning. However, at times, the location and size of MS can impact these plans [4]. While there are numerous studies in the literature that evaluate MSV, three-dimensional studies examining its relationship with jaw relationships are limited, and their results vary [32, 33]. There are limited studies in the literature that investigate the correlation between cephalometric radiographs, different sagittal jaw relationships, and MSV [20].

Sagittal jaw relations are among the issues that are primarily evaluated in orthodontic treatment planning, but sometimes the MS location and size can affect the plans [4, 38, 39]. There are a limited number of studies in the literature examining the correlation between cephalometric radiographs and different sagittal jaw relationships and MSV [20, 40–43]. The aim of this study is to evaluate the MSVs of individuals between the ages of 12 and 24, who have different skeletal sagittal but similar vertical jaw relationships, and the relationship between MSV and craniofacial structures with CBCT.

In our study, it was observed that there was no difference between RMSV, LMSV and AMSV of individuals in all malocclusion groups. Similarly, many studies evaluating MSV have reported that there is no difference between right and left MSV [1, 6, 32, 33, 44]. However, while the right and left MSV of individuals of the same gender are not different, the mean of left MSV in the general population was measured to be greater than the mean of right MSV. It has been stated that there may be a difference in terms of right and left MSV in individuals with nasal septum deviation [45]. A recent retrospective study examined the relationship between MSV and nasal septum deviation. In moderate and severe groups, MSV was found to be smaller on the same side compared with the opposite side of deviation. Additionally, MSV was found to be greater in male patients than in female patients, and it decreased with age [46]. In our study, the groups were not evaluated in terms of nasal septum deviation.

In many studies, it has been published that “MSV of males is larger than that of females” [1, 29, 33, 47, 48]. The results of our study, in terms of the general population, are consistent with these studies. In our study, the difference between genders in terms of MSV among malocclusion groups is observed only in the Class II group, where all RMSV, LMSV, and AMSV are larger, whereas in the Class III group, only RMSV is observed. Oktay explained that female patients with Angle Class II malocclusion have larger maxillary sinuses compared to females and males in other groups [19]. A recent study reported that the volume of the maxillary sinus was influenced solely by sagittal skeletal pattern and exhibited higher values in individuals with Class III malocclusion. Gender did not exert a significant influence on the observed variations in maxillary sinus volume [34]. In contrast, in another study, sagittal position of the upper jaw does not appear to affect maxillary sinus volume, and men tend to have larger maxillary sinus volumes than women [49].

The maximum age difference between individuals in Classes I, II, and III in our study was 12 years. There was no significant difference in mean age between the groups. It is known that MSV increases during infancy and adolescence [50]. Ikeda [51] reported that the maxillary sinus reaches adult dimensions at the ages of 12–15 and remains constant until the age of 20. Some authors suggest that MSV increases until the age of 20 and then decreases, while others report that MS growth continues until the thirties in males and until the twenties in females [6, 7]. Park et al. [3] reported that MSV reaches maximum volume at the age of 15 and subsequently changes in shape and size during adulthood, especially due to tooth loss. The present study included cases without posterior tooth loss that would affect MSV and without a wide age range. Endo et al. [20] stated that there is no difference in maxillary sinus size between males and females, while Shrestha et al. [33] reported that males have larger MSV than females in individuals aged 21–64.

In studies where MSV is measured according to sagittal skeletal jaw relationships, different results have been reported. Saccucci et al. [31] state that there is no statistically significant difference in MSV among sagittal skeletal groups. However, Shrestha et al. [33] report that the Class II group has a larger MSV compared to Class III in their study. This difference between studies has been attributed to the small sample size and ethnic and racial differences. Studies evaluating MS size in 2D, conducted on panoramic radiographs and lateral cephalometric radiographs, indicate no statistical difference among Class I, Class II, and Class III groups [19, 20]. Shrestha et al. [33]. measured the highest MSV in the Class II group in their study. In our study, no significant difference in MSV was observed according to skeletal jaw angles. The differing results of our study suggest that the groups may be related to vertical jaw size. Difference in two studies, they did not make a distinction based on vertical facial development model in groups according to sagittal jaw relationship in their studies. Additionally, the ages and races of the individuals comprising the groups was different [31, 33]. Similar sagittal skeletal malocclusion individuals may have different vertical facial developments. Vertical development of the facial skeleton is associated with many skeletal units such as nasomaxillary complex, alveolar processes, and mandible [52]. Shrestha et al. [33] indicate that the high-angle group tends to have the largest MSV among vertical skeletal groups. Okşayan et al. [32] stated that high-angle individuals showed statistically lower values in terms of maxillary sinus length and width compared to low-angle individuals, but vertical facial development had no effect on right and left MSV. Due to the difference in results among studies, in our study, Class I, II, and III groups were formed from individuals with a normal vertical (SNGoMe = 27°–38°) facial skeleton to create more homogeneous study groups. However, the presence of posterior crossbite was not evaluated when forming the groups in our study. In the presence of posterior crossbite, MSV was significantly lower compared to cases with normal posterior occlusion [53]. It is recommended to evaluate this situation in future studies.

Due to the significantly lower radiation dose compared to computed tomography (CT) scans commonly used in medical applications, CBCT scans are widely used for diagnostic imaging purposes in all fields of dentistry today [54]. Medical imaging processing technologies enable the use of three-dimensional reconstructed images of the skull generated from CBCT scans. With these technologies, measurements of the anatomical structure of the head and calculation of MSV can be performed [32, 33].

In this study, when comparing the cephalometric values of SNA, SNB, and ANB of individuals with the same malocclusion, similar results were observed in both genders. It is understood that classification is based on ANB in intergroup comparisons. Skeletal disharmony may result from abnormal jaw position or inadequate/excessive jaw growth, leading to abnormal maxillary and/or mandibular dimensions [55]. In this study, SNA and ANB angles were not significantly correlated with MSV in any group. Only in the Class III group, a moderate and positive correlation was observed between SNB angle and MSV. This result is partially inconsistent with their findings [20] study, where they stated that the anteroposterior protrusions of the maxilla and mandible in the sagittal direction had no effect on MS size. Shrestha et al. [33] mentioned a positive correlation between ANB and MSV in their studies. Asantogrol et al. [56] conducted a study to evaluate MSV in patients with different maxillary sagittal patterns using the SNA angle. The results demonstrated that there was no statistical difference between the patterns. In a similar vein, a second study found that different sagittal positions of the maxilla do not seem to influence the volume of the maxillary sinus [49]. There are a limited number of studies on this issue in the literature.

It is noted that there is a similar correlation tendency between cephalometric values in males and females with similar malocclusions [55]. However, in our study, anterior cranial base length (S-N) was statistically significantly shorter in Class I and Class II groups, and S-Ar was statistically significantly shorter only in the Class II group in females compared to males. However, no significant difference was observed in cranial base length (S-N and S-Ar) in the comparison of malocclusion classes. Varrela [57] reported that children with skeletal

Class II malocclusion had cranial bases similar to those of normal individuals. The results showed that an increase in the degree of the index increases the prevalence of bad habits and mouth breathing, meaning that these factors are associated with more severe malocclusions [58]. In their intergroup comparison, a significant difference was found for upper lip thickness between Class II and Class III, and lower lip length between Class I and Class III, and between Class II and Class III. And also, they found that significant difference for nasolabial angle was found between Class II and Class III. Similarly, they reported that a significant difference for the vertical chin parameter was found between Class I and Class III, and between Class II and Class III [59]. In studies examining the relationship between the cranial base and malocclusion, it is hypothesized that genetic factors play a more significant role in the growth of the skull base than environmental factors. Furthermore, it is postulated that the main growth centers of the skull base are caused by cranial base synchondrosis [60–62]. In the present study, a moderate positive correlation was observed between anterior skull base (SN) length and both right and left MSV in the Class III group. In the Class II group, a weak correlation was observed with only RMSV. In their study, Endo et al [20] demonstrated that individuals with large cranial bases tend to have enlarged MS. However, a good level of positive correlation was not observed in all groups in our study.

This is explained by bone apposition in the tuberosity region, thus allowing the maxilla to move forward [20, 63, 64]. However, there was generally no good correlation between ANS-PNS and MSV in all groups. Only a weak positive correlation was observed between MSV and ANS-PNS only in the Class II group. This result is inconsistent with their findings [20] study. According to our study results, although the relationship between palatal plane length and MSV is very weak, it was observed only in the Class II group. In the literature, it is noted that the height of the maxillary sinus is associated with the basal bone height in the vertical craniofacial dimension [65]. The midface height (N–ANS) can be affected by the effects of vertical facial development. Since our study groups were composed of individuals with a normal vertical facial pattern (SNGoMe), no difference was observed in N–ANS length in intergroup comparisons. Gender differences were observed only in the Class II group. When examining the relationship between MSV and N-ANS, a weak positive correlation was observed in the Class II and Class I groups and only in the RMSV of the Class III group. It has been stated in studies that alveolar bone height may be the most important factor for volumetric changes in the maxillary sinus [3]. Additionally, it has been measured that the anteroposterior (length) and craniocaudal (height) dimensions are nearly equal in MS size measurements, and they are greater than the mediolateral dimension [66].

This study was conducted on a limited number of samples. Only facial sagittal and vertical evaluations can be made on cephalometric radiographs. In future studies, transversal measurements of the face and jaws should be evaluated and their relationship with MSV should be evaluated. MS is anatomically and functionally related to the nose. In future studies, the relationship between nasal anatomy or function and MSV should be evaluated. These constitute the limitations of our study.

CONCLUSIONS

As a result of this study, gender-specific MSV was found to be effective in different sagittal skeletal malocclusions with similar vertical facial structure. The right and left MSVs were similar in both sexes. However, in the general population, the right MSV was measured to be smaller than the left MSV.

In the class II group, the MSV was measured to be larger in males than in females. In addition, anterior skull base, midface length, and palate length were found to be associated with MSV. In the class III group, there was no relationship between palate length and MSV.

Correlations between MSV and midface height were observed in all malocclusion groups, although weak and with different distributions. This relationship should be considered in the planning and execution of surgical and orthodontic treatment involving the midface. But, it is obvious that this relationship with the maxillary dimension needs to be investigated in more samples and ethnic backgrounds. Additionally, studies on maxillary stenosis and nasal septal deviation need to be investigated in this context.

Article information and declarations

Data availability statement

Data available on request due to corresponding author.

Ethics statement

The local Ethics Committee of the Dicle University Faculty of Dentistry approved the study.

Author contributions

Kamile Keskin and Atılım Kurt analyzed the data of the study and examined the data clinically. All authors evaluated this retrospective morphological study together and finalized the study.

Funding
None.

Conflict of interest: No potential conflict of interest was reported by the authors.

REFERENCES

1. Emirzeoglu M, Sahin B, Bilgic S, et al. Volumetric evaluation of the paranasal sinuses in normal subjects using computer tomography images: A stereological study. Auris Nasus Larynx. 2007;34(2):191-5. doi: 10.1016/j.anl.2006.09.003.

2. Núñez-Cook S, Vidal-Mugica F, Salinas P. Anatomy and computed tomography of the nasal cavity, nasal conchae, and paranasal sinuses of the endangered Patagonian huemul deer (Hippocamelus bisulcus). Anat Rec (Hoboken). 2024;307(1):141-154. doi: 10.1002/ar.25230.

3. Park IH, Song JS, Choi H, et al. Volumetric study in the development of paranasal sinuses by CT imaging in Asian: A Pilot study. Int J Pediatr Otorhinolaryngol. 2010;74(12):1347-50. doi: 10.1016/j.ijporl.2010.08.018.

4. Livas C, Halazonetis DJ, Booij JW, et al. Maxillary sinus floor extension and posterior tooth inclination in adolescent patients with Class II Division 1 malocclusion treated with maxillary first molar extractions. Am J Orthod Dentofacial Orthop. 2013;143(4):479-85. doi: 10.1016/j.ajodo.2012.10.024.

5. Hosemann W, Grimm A. [Surgical anatomy of the maxillary sinus]. HNO. 2020;68(8):555-565. doi: 10.1007/s00106-020-00868-3.

6. Ariji Y, Kuroki T, Moriguchi S, et al. Age changes in the volume of the human maxillary sinus: A study using computed tomography. Dentomaxillofac Radiol. 1994;23(3):163-8. doi: 10.1259/dmfr.23.3.7835518.

7. Jun BC, Song SW, Park CS, et al. The analysis of maxillary sinus aeration according to aging process; volume assessment by 3-dimensional reconstruction by high-resolutional CT scanning. Otolaryngol Head Neck Surg. 2005;132(3):429-34. doi: 10.1016/j.otohns.2004.11.012.

8. Dolan KD, Smoker WR. Paranasal sinus radiology, Part 4A: Maxillary sinuses. Head Neck Surg. 1983;5(4):345-62. doi: 10.1002/hed.2890050410.

9. Andersson JA, Cervin A, Lindberg S, et al. The paranasal sinuses as reservoirs for nitric oxide. Acta Otolaryngol. 2002;122(8):861-5.

10. Salvolini L, Bichi Secchi E, Costarelli L, et al. Clinical applications of 2D and 3D CT imaging of the airways--a review. Eur J Radiol. 2000;34(1):9-25. doi: 10.1016/s0720-048x(00)00155-8.

11. Hou Z, Qu X, Hou L, Ren F. Comparison between effects of mini-implant anchorage and face-bow anchorage in orthodontics for children. J Clin Pediatr Dent. 2024;48(1):198-203. doi: 10.22514/jocpd.2024.022.

12. Sieron HL, Sommer F, Hoffmann TK et al. Function and physiology of the maxillary sinus. HNO. 2020;68(8):566-572. doi: 10.1007/s00106-020-00869-2.

13. Soriano RM, M Das J. Anatomy, Head and Neck, Maxilla. 2023. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024

14. Pucci R, Cassoni A, Weyh A, et al. Transoral versus transfacial surgical approach to maxillary tumors: evaluation of outcomes and perspectives. Int J Oral Maxillofac Surg. 2024;53(2):101-108. doi: 10.1016/j.ijom.2023.05.006.

15. Butaric LN, McCarthy RC, Broadfield DC. A Preliminary 3D Computed Tomography Study of the Human Maxillary Sinus and Nasal Cavity. Am J Phys Anthropol. 2010;143(3):426-36. doi: 10.1002/ajpa.21331.

16. Ozcan KM, Hizli O, Ulusoy H, et al. Localization of orbit in patients with maxillary sinus hypoplasia: a radiological study. Surg Radiol Anat. 2018;40(10):1099-1104. doi: 10.1007/s00276-018-2054-9.

17. Nelke K, Morawska A, Błaszczyk B, et al. Anatomical and Surgical Implications of the Usage of Bichat Fat Pad in Oroantral Communication, Maxillary, Palatal, and Related Surgeries-Narrative Review. J Clin Med. 2023;12(15):4909. doi: 10.3390/jcm12154909.

18. Vucic S, Dhamo B, Jaddoe VWV, et al. Dental development and craniofacial morphology in school-age children. Am J Orthod Dentofacial Orthop.

2019;156(2):229-237.e4. doi: 10.1016/j.ajodo.2018.09.014.

19. Oktay H. The study of the maxillary sinus areas in different orthodontic malocclusions. Am J Orthod Dentofacial Orthop. 1992;102(2):143-5. doi: 10.1016/0889-5406(92)70026-7.

20. Endo T, Abe R, Kuroki H, et al. Cephalometric evaluation of maxillary sinus sizes in different malocclusion classes. Odontology. 2010;98(1):65-72. doi: 10.1007/s10266-009-0108-5.

21. Said OT, Rossouw PE, Fishman LS, et al. Relationship between anterior occlusion and frontal sinus size. Angle Orthod. 2017;87(5):752-758. doi: 10.2319/010617-18.1.

22. Kim S, Ward LA, Butaric LN, et al. Human maxillary sinus size, shape, and surface area: Implications for structural and functional hypotheses. Am J Biol Anthropol. 2022;179(4):640-654. doi: 10.1002/ajpa.24630.

23. Alhazmi A. Association between Maxillary Sinus Dimensions and Midface Width: 2-D and 3-D Volumetric Cone-beam Computed Tomography Cross-sectional Study. J Contemp Dent Pract. 2020;21(3):317-321.

24. Butaric LN, Maddux SD. Morphological Covariation between the Maxillary Sinus and Midfacial Skeleton among Sub-Saharan and Circumpolar Modern Humans. Am J Phys Anthropol. 2016;160(3):483-97. doi: 10.1002/ajpa.22986.

25. Buller J, Bömelburg C, Kruse T, et al. Does maxillary sinus size affect the risk for zygomatic complex fractures?. Clin Anat. 2023;36(4):564-569. doi: 10.1002/ca.23986.

26. Miranda-Viana M, Freitas DQ, Machado AH, et al. Do different sexes, skeletal and breathing patterns influence the maxillary sinuses volume? A retrospective study. Forensic Imaging. 2021;27:200479.

27. Chakravarty MM, Aleong R, Leonard G, et al. Automated analysis of craniofacial morphology using magnetic resonance images. PLoS One. 2011;6(5):e20241. doi: 10.1371/journal.pone.0020241.

28. Kilic C, Kamburoglu K, Yuksel SP, et al. An assessment of the relationship between the maxillary sinus floor and the maxillary posterior teeth root tips using dental cone-beam computerized tomography. Eur J Dent. 2010;4(4):462-7.

29. Aktuna Belgin C, Colak M, et al. Three-dimensional evaluation of maxillary sinus volume in different age and sex groups using CBCT. Eur Arch Otorhinolaryngol. 2019;276(5):1493-1499. doi: 10.1007/s00405-019-05383-y.

30. Favato MN, Vidigal BC, Cosso MG, et al. Impact of human maxillary sinus volume on grafts dimensional changes used in maxillary sinus augmentation: a multislice tomographic study. Clin Oral Implants Res. 2015;26(12):1450-5. doi: 10.1111/clr.12488.

31. Saccucci M, Cipriani F, Carderi S, et al. Gender assessment through three-dimensional analysis of maxillary sinuses by means of Cone Beam Computed Tomography. Eur Rev Med Pharmacol Sci. 2015;19(2):185-93.

32. Okşayan R, Sökücü O, Yeşildal S. Evaluation of maxillary sinus volume and dimensions in different vertical face growth patterns: a study of cone-beam computed tomography. Acta Odontol Scand. 2017;75(5):345-349. doi: 10.1080/00016357.2017.1310294.

33. Shrestha B, Shrestha R, Lin T, et al. Evaluation of maxillary sinus volume in diferent craniofacial patterns: a CBCT study. Oral Radiol. 2021;37(4):647-652. doi: 10.1007/s11282-020-00506-2.

34. Lessa AMG, Oliveira VS, Costa RBA, et al. Anatomical study of the maxillary sinus: which characteristics can influence its volume? Surg Radiol Anat. 2023;45(1):81-87. doi: 10.1007/s00276-022-03055-x.

35. Steiner CC. Cephalometrics for you and me. Am J Orthod. 1953;39:729-55.

36. McNamara JA Jr. A method of cephalometric evaluation. Am J Orthod. 1984;86(6):449-69. doi: 10.1016/s0002-9416(84)90352-x.

37. Ricketts RM. The influence of orthodontic treatment on facial growth and development. Angle Orthod. 1960;30:103-33.

38. Alberto PL. Surgical Exposure of Impacted Teeth. Oral Maxillofac Surg Clin North Am. 2020;32(4):561-570. doi: 10.1016/j.coms.2020.07.008.

39. Baidas LF, Alshihah N, Alabdulaly R, et al. Severity and Treatment Difficulty of Impacted Maxillary Canine among Orthodontic Patients in Riyadh, Saudi Arabia. Int J

Environ Res Public Health. 2022;19(17):10680. doi: 10.3390/ijerph191710680.

40. Plaza SP, Reimpell A, Silva J, et al. Relationship between skeletal Class II and Class III malocclusions with vertical skeletal pattern. Dental Press J Orthod. 2019;24(4):63-72. doi: 10.1590/2177-6709.24.4.063-072.oar.

41. Sadry S, Koca CG, Kaya I. Evaluation of the relationship between the maxillary third molars and pterygomaxillary fissure by cephalometric radiographs. Folia Morphol (Warsz). 2021;80(2):425-431. doi: 10.5603/FM.a2020.0112.

42. Huang X, Gong X, Gao X. Age-related hypertrophy of adenoid and tonsil with its relationship with craniofacial morphology. BMC Pediatr. 2023;23(1):163. doi: 10.1186/s12887-023-03979-2.

43. Pajević T, Juloski J, Glišić B. Malocclusion from the prehistoric to the medieval times in Serbian population: Dentoalveolar and skeletal relationship comparisons in samples. Homo. 2019;70(1):31-43. doi: 10.1127/homo/2019/1009.

44. Maspero C, Farronato M, Bellincioni F, et al. Three-Dimensional Evaluation of Maxillary Sinus Changes in Growing Subjects: A Retrospective Cross-Sectional Study. Materials (Basel). 2020;13(4):1007. doi: 10.3390/ma13041007.

45. Orhan I, Ormeci T, Aydin S, et al. Morphometric analysis of the maxillary sinus in patients with nasal septum deviation Eur Arch Otorhinolaryngol. 2014;271(4):727-32. doi: 10.1007/s00405-013-2617-7.

46. Razavi M, Shams N, Pirasteh SMA. Determining the effects of deviated nasal septum on maxillary sinus volume using cone-beam computed tomography. Immnunopathol Persa. 2022,9(1):e34427.

47. Kawarai Y, Fukushima K, Ogawa T, et al. Volume quantification of healthy paranasal cavity by threedimensional CT imaging. Acta Otolaryngol Suppl. 1999;540:45-9.

48. Fernandes CL. Volumetric analysis of maxillary si_nuses of Zulu and Europen crania by helical, multislice computed tomography. J Laryngol Otol. 2004;118(11):877-81. doi: 10.1258/0022215042703705.

49. Ay Ünüvar Y, Köse E. Evaluation of Maxillary Sinus Volume of Class III Individuals with Different Jaw Positions by Cone- Beam Computed Tomography. Turk J Orthod.

2023;36(3):180-185. doi: 10.4274/TurkJOrthod.2022.2022.12.

50. Iturralde-Garrote A, Sanz JL, Forner L, et al. Volumetric Changes of the Paranasal Sinuses with Age: A Systematic Review. J Clin Med. 2023;12(10):3355. doi: 10.3390/jcm12103355.

51. Ikeda A.Volumetric measurement of the maxillary sinus by coronal CT scan. Nihon Jibiinkoka Gakkai Kaiho. 1996;99(8):1136-43. doi: 10.3950/jibiinkoka.99.1136.

52. Opdebeeck H, Bell WH. Am J Orthod. 1978;73(5):499-511. doi: 10.1016/0002-9416(78)90240-3.

53. Akkurt A, Doğru M. Three dimensional evaluation of the effect of rapid maxillary expansion on maxillary sinus volume. J Stomatol Oral Maxillofac Surg. 2022;123(6):e930-e935. doi: 10.1016/j.jormas.2022.07.006.

54. Adibi S, Zhang W, Servos T, et al. Cone Beam Computed Tomography for General Dentists. J Dent Educ. 2012;11(76):1437-42.

55. Chin A, Perry S, Liao C, et al. The relationship between the cranial base and jaw base in a Chinese population. Head Face Med. 2014;10:31. doi: 10.1186/1746-160X-10-31.

56. Asantogrol F, Etoz M, Topsakal KG, et al. Evaluation of the maxillary sinus volume and dimensions in different skeletal classes using cone beam computed tomography. Ann Med Res. 2021;28(4):709-15.

57. Varrela J. Early developmental traits in Class II malocclusion. Acta Odontol Scand. 1998;56(6):375-7. doi: 10.1080/000163598428356.

58. Grippaudo C, Paolantonio EG, Antonini G, et al. Association between oral habits, mouth breathing and malocclusion. Acta Otorhinolaryngol Ital. 2016;36(5):386-394. doi: 10.14639/0392-100X-770.

59. Chaudhary A, Giri J, Gyawali R, et al. A Retrospective Study Comparing Nose, Lip, and Chin Morphology in Class I, Class II, and Class III Skeletal Relationships in Patients Visiting to the Department of Orthodontics, BPKIHS: A Cephalometric Study. Int J Dent. 2022;2022:2252746. doi: 10.1155/2022/2252746.

60. Nie X. Cranial base in craniofacial development: developmental features, influence on

facial growth, anomaly, and molecular basis. Acta Odontol Scand. 2005;63(3):127-35. doi: 10.1080/00016350510019847.

61. Dileep S, Khader MA, Ali H, et al. Cranial base parameters in adults with skeletal class I and class II skeletal pattern. J Orthod Sci. 2022;11:41. doi: 10.4103/jos.jos_8_22.

62. Ahmed AAE, Abuaffan AH. Correlation between cranial base morphology and skeletal maloclusion in a sample of Sudanese orthodontic patients. J Dent Probl Solut. 2020;7(2):90-5.

63. Chhatwani S, Rose-Zierau V, Haddad B, et al. Three-dimensional quantitative assessment of palatal bone height for insertion of orthodontic implants - a retrospective CBCT study. Head Face Med. 2019;15(1):9. doi: 10.1186/s13005-019-0193-9.

64. Savoldi F, Xu B, Tsoi JKH, et al. Anatomical and mechanical properties of swine midpalatal suture in the premaxillary, maxillary, and palatine region. Sci Rep. 2018;8(1):7073. doi: 10.1038/s41598-018-25402-y.

65. Atul Kumar H, Nayak USK, Kuttappa MN. Comparison and correlation of the maxillary sinus dimensions in various craniofacial patterns: A CBCT Study. F1000Res. 2022;11:488. doi: 10.12688/f1000research.110889.2.

66. Hettiarachchi PVKS, Gunathilake PMPC, Jayasinghe RM, et al. Linear and Volumetric Analysis of Maxillary Sinus Pneumatization in a Sri Lankan Population Using Cone Beam Computer Tomography. Biomed Res Int. 2021;2021:6659085. doi: 10.1155/2021/6659085.