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Original Article

Evaluation of Maxillary Sinus Volume of Class III Individuals with Different Jaw Positions by Cone-Beam Computed Tomography

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Main Points

- Different sagittal positions of the maxilla have no effect on maxillary sinus volume.
- Males have greater maxillary sinus volume than females.
- Cone-beam computed tomography images can be used to calculate volumes and areas of sinuses using additional software.

ABSTRACT

Objective: To compare maxillary sinus volumes and surface areas among individuals with Class III skeletal patterns, with different sagittal positions of maxilla and Class I patients with normal jaw positions using cone-beam computed tomography (CBCT).

Methods: CBCT images of 168 patients were analyzed retrospectively. The calculated surface areas and sinus volumes of 58 patients with Class I, normal mandibular and maxillary position (0<ANB<4, 84>SNA>80, 82>SNB>78) were compared with 61 patients with Class III retrognathic maxillary and normal mandibular positions (MRs) (ANB<0, SNA<80, 82>SNB>78) and 49 patients with Class III normal maxillary and prognathic mandibular positions (MP) (ANB<0, 84>SNA>80, SNB>82). Also, volume differences between genders and sides were investigated. One-way ANOVA and t-test were used to compare age, gender, skeletal patterns, and maxillary sinus measurements.

Results: CBCT images of 94 females and 74 males were examined. There was no statistically significant difference in the right and left maxillary sinus volume and surface area measurements among Class I, Class III MR, and Class III MP groups ($p>0.05$). When the maxillary sinus volume and surface area were evaluated according to gender, the right maxillary sinus surface area and volume of males were found to be statistically significantly higher than those of females ($p=0.012$ and $p=0.024$). Similarly, the left maxillary sinus surface areas and volumes of males were also found to be significantly higher than those of females ($p=0.000$ and $p=0.002$).

Conclusion: Different sagittal positions of the maxilla do not appear to affect maxillary sinus volume, and males tend to have greater maxillary sinus volume than females. CBCT images can be used to calculate intrabony air spaces.

Keywords: Cone-beam computed tomography, Class III malocclusion, maxillary sinus volume

INTRODUCTION

Maxillary sinuses are intrabony air-filled spaces located laterally to the nasal cavity and connected to them through an ostium. They extend inferiorly to the apices of the posterior teeth. They are the first paranasal sinuses to develop. However, there is no consensus on the exact timing of maxillary sinus development. According to the literature, the earliest development occurs during the third week of gestation. The maxillary sinus expands progressively with the resorption of the neighboring nasal capsule and extends into the ossifying maxilla by 20 weeks of gestation. Growth continues through early adulthood and results in an elongated oval shape

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with prominent anterior-posterior expansion.[1,2] During early embryonic growth, three mesenchymal processes contribute to the development of midface structures: the lateral nasal, medial nasal, and maxillary processes. The deep parts of the maxillary process contribute to the formation of the maxillary sinus.[3]

By the end of the 8th year, the maxillary sinus has reached nearly 50% of its final size and its growth rate slows down after the age of 12. However, it continues to grow until reaching adulthood. In adults, the maxillary sinus volume is approximately 15 mL, and its anteroposterior distance and width measure are 34 mm and 23-25 mm, respectively.[2,3]

Due to the proximity of maxillary sinuses to posterior teeth, dentists should be aware of the anatomical features and disorders of the sinonasal region.[4] Knowledge of the symptoms of maxillary sinusitis and the anatomy of the maxillary sinus helps prevent misdiagnosis and complications during surgical procedures.[4,5] Understanding the anatomy and the location of the maxillary sinus is also important for dental implant treatment with sinus lift, endodontic treatment of maxillary posterior teeth and orthodontic mini-implant treatment.[6] Morphometric analysis of the maxillary sinus is valuable for identification when the loss of other skeletons rests occurs.[5,7]

The dimensions of the maxillary sinus can be influenced with tooth loss and aging. Different sinus dimensions may be observed according to gender and malocclusions. The vertical and sagittal growth patterns of the jaws can also impact the development of the maxilla and maxillary sinuses. Some authors argue that there is a difference between maxillary sinus widths and malocclusions, while others claim that there is no difference.[8-11] Considering the complex anatomical structure of the maxillary sinus, diagnostic methods such as computed tomography (CT) and magnetic resonance imaging are considered the gold standard for examining the anatomical and pathologic features of the sinuses. However, their use is limited due to their high cost, limited availability, and the use of the high-dose radiation for CT. Cone-beam CT (CBCT) is an advanced imaging method hat offers the advantage of a lower radiation dose while enabling the examination of paranasal structures and accurate calculation of maxillary sinus volume.[12,13]

The maxillary premolars and molars are usually quite close to or in contact with the maxillary sinus wall. Therefore, the expansion of maxillary sinus after the extraction of first molar tooth, with the downward movement of the alveolar process, plays an important role in orthodontic treatment planning.[14] Due to their placement in the body of the maxilla and their direct relationship with the maxillary posterior teeth, the maxillary sinuses can easily be affected by the anatomical features and dimensional changes of the maxilla. Thus, it has been suggested that the volumetric change of the maxillary sinuses can be more accurate when considering the malocclusion classification and the position of the maxilla. In the present retrospective study, we aimed to compare maxillary sinus volumes among individuals with Class III skeletal patterns with different sagittal positions of the maxilla, and Class I patients with normally positioned jaws using CBCT. The null hypothesis was that there would be no difference in maxillary sinus volume between the Class III and Class I skeletal patterns.

METHODS

The Clinical Research Ethics Committee of Aydın Adnan Menderes University Faculty of Dentistry (approval no: ADÜDHF2021/22, date: 07.07.2021) approved this retrospective study protocol. The design of the study was retrospective, and no additional radiation was given to the patients for this research. CBCT scans were performed and examined for accurate diagnosis of dental problems. An informed consent form was signed by all patients or their parents.

The G-power 3.1.9.4 (Heinric-Heine-Universität Düsseldorf, Germany) program was utilized to calculate the sample size for this study. The study of Aktuna Belgin et al.[4], which bears similarity to our study, was used as a reference for calculating the sample size. From the study data, the effect size was determined to be 0.656. Based on this effect size value, the required sample size was calculated to be 124 participants with 62 participants in each group, considering a power analysis with a double-tailed test. For the analysis, a type I error rate of 0.05 and a study power of 0.95 were assumed.

For this research, CBCT images were analyzed from the archive of Aydın Adnan Menderes University, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology taken between 2015 and 2020. Scans that met our inclusion criteria were selected from among these datasets. Patients with maxillary sinus pathology, a history of sinus operation, previous orthodontic treatment, or orthognathic surgery were excluded from the study. Only artifact-free CBCT images showing bilateral maxillary sinuses and sinuses without mucosal thickening, hypoplasia, and individuals with complete dentate were included in the study. All CBCT images were obtained using a single 360º rotation with a ProMax 3D scanner (Planmeca, Helsinki, Finland). The imaging settings were 8 mA and 90 kV, with an exposure time of 13.5 s. The field of view options were 8×8, 16×10, and 20×10 cm. The images were examined with slice thickness of 0.2 mm.

The anteroposterior skeletal type was determined by ANB measurements, classifying individuals as Class I (0<ANB<4) and Class III (ANB<0). The mandibular and maxillary positions to the cranial base were determined using the SNB and SNA angles, respectively, with reference ranges of 84>SNA>80 and 82>SNB>78.[15-17] As a result, the subjects were divided into three groups: Class I patients with normal mandibular and maxillary positions relative to the anterior cranial base and each other, Class III patients with retrognathic maxillary and normal mandibular positions relative to the anterior cranial base, and Class III patients with normal maxillary and prognathic mandibular position relative to the anterior cranial base. The

Dolphin 3D Imaging program (V.11, Chatsworth, Calif,USA) was used to obtain lateral cephalograms from CBCT images and measure three angular parameters (SNA, SNB and ANB). All data were collected and lateral cephalometric measurements were performed by a single experienced operator (Y.A.Ü.).

A total of 168 patients aged between 18 and 50 (94 female, 74 male) with Class I and III sagittal skeletal patterns were included in this research. The volumes and surface areas of three groups were compared: 58 patients with Class I normal mandibular and maxillary position (0<ANB<4, 84>SNA>80, 82>SNB>78), patients with 61 Class III retrognathic maxillary and normal mandibular position (ANB<0, SNA<80, 82>SNB>78) and 49 patients with Class III normal maxillary and prognathic mandibular position (ANB<0, 84>SNA>80, SNB>82).

Sinus volume and area measurements were conducted using Simplant Pro software (version 13.0, Materialise, Leuven, Belgium) digital imaging program. Volume data was obtained in mm^3 and surface area data in mm^2. To calculate the volume and surface area of the maxillary sinuses from CBCT data, the air value threshold was utilized to determine the maxillary sinus contour and to reveal the volume value, and the drawing/erasure mask and segmentation wizard technique were used. Standardization was achieved by keeping the threshold values constant for all individuals. The left and right maxillary sinuses of each individual were determined by threshold and masking without loss in coronal, axial, and sagittal sections, and the volume and surface area values were recorded by three-dimensional shaping of the maxillary sinuses (Figure 1) Sinus volume and area measurements were performed by a single experienced radiologist (E.K.).

Statistical Analysis

To assess the method error of the measurements, 20% of the images were re-recorded and re-measured 1 month later. The intraclass correlation coefficient, kappa coefficient, and weighted kappa coefficient was used for observer reliability.

Descriptive statistics, including maximum, minimum, mean and standard deviation values for each group were calculated using SPSS for Windows (Statistical Package for Social Sciences, v.11.0, Chicago, Illinois, USA). Statistical significance was set at 0.05. A chi-square test was performed to control for the balanced distribution of gender among the groups. The Shapiro-Wilk test was used to determine the normal distribution of the data. Since the distribution of variables was normal, intergroup comparisons of age, skeletal patterns, and maxillary sinus measurements were performed using one-way ANOVA, and t-test was also used to examine the difference in gender.

RESULTS

The intraclass correlation coefficient results were between 0.928 and 0.941 for all variables assessed, indicating good observer reliability. The gender distribution of the groups is presented in Table 1. A chi-square test was used to ensure a balanced the distribution of sex among the groups. No differences were found between the groups because of the similar male-female composition.

A total of 168 patients, 94 females and 74 males, between the ages of 18 and 50 was included in the study. Descriptive demographic characteristics of the groups are given in Table 2. There was no statistically significant age difference between the groups, and the mean age was 33.00±11.42 for the Class I normal group, 37.77±12.10 for the Class III maxillary retrusion group, and 36.12±11.55 for the Class III mandibular protrusion group ($p>0.05$). As we used FMA, SNA, SNB, and ANB to form the groups, statistically significant differences in skeletal variables

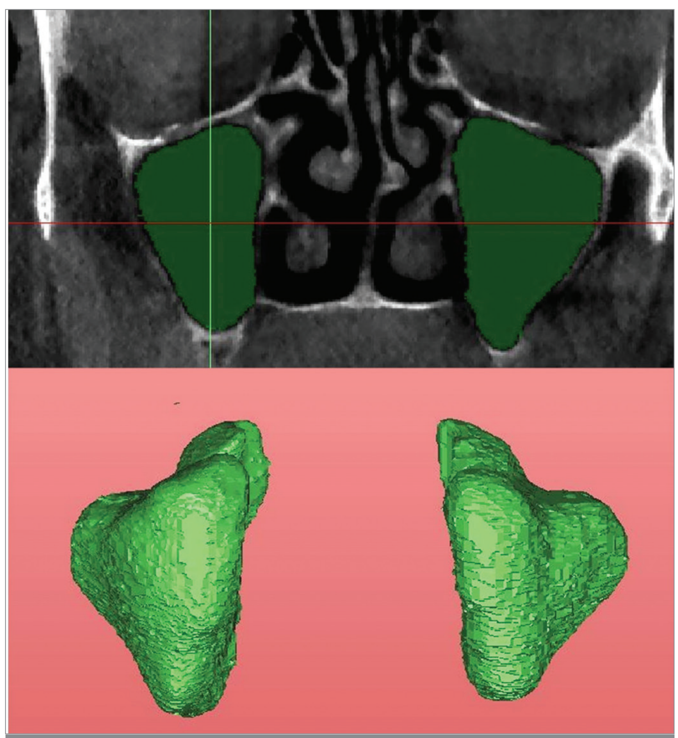

Figure 1. The three-dimensional shaping of the maxillary sinuses

Table 1. The gender distribution of the groups

	Class I normal		Class III maxillary retrusion		Class III mandibular protrusion		Total		p value
	n	%	n	%	n	%	n	%	
Female	31	32.97	34	36.17	29	30.85	94	55.95	0.837
Male	27	36.48	27	36.48	20	27.02	74	44.04	
Total	58	34.52	61	36.30	49	29.16	168	100	

Table 2. Descriptive statistics showing the means, standard deviations, minimum and maximum values of the Class I and Class III groups and results of intergroup comparisons using one-way ANOVA

	Class I normal (n=58)			Class III maxillary retrusion (n=61)			Class III mandibular protrusion (n=49)			p value
	Mean ± SD	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD	Min.	Max.	
Age (years)	33.00±11.42	18	50	37.77±12.10	18	50	36.12±11.55	18	50	0.083
SNA(°)	81.86±1.24[a]	80.00	84.00	75.07±1.16[b]	73.80	79.60	82.07±1.45[a]	80.00	84.00	0.000***
SNB(°)	79.14±1.05[a]	78.00	82.00	79.88±1.44[a]	78.50	82.00	84.88±1.36[b]	82.50	86.60	0.000***
ANB(°)	2.72±0.74[a]	1.50	3.90	-4.81±1.24[b]	-7.20	-0.40	-2.81±1.79[b]	-0.60	-6.40	0.000***
Right maxillary sinus volume (mm³)	16423.03±7260.20	3657.00	43024.00	14830.54±5184.01	3657.00	29157.00	17301.54±6685.61	4616.00	35460.00	0.121
Right maxillary sinus surface area (mm²)	4216.35±1183.32	1571.00	7849.00	3844.68±827.66	1571.00	5629.00	4256.42±1020.55	1620.00	6771.00	0.059
Left maxillary sinus volume (mm³)	15892.27±7121.62	4076.00	39281.00	14500.27±5173.68	4076.00	26077.00	17182.38±6605.78	5634.00	35329.00	0.088
Left maxillary sinus surface area (mm²)	4243.71±1516.78	1599.00	10898.00	3874.88±984.81	1599.00	6113.00	4268.09±1024.91	2110.00	6334.00	0.148

SD, Standard deviation; Min, Minimum; Max, Maximum; *p<0.05; **p<0.01; ***p<0.001; [a,b], Different lower cases in the same row represent statistically significant differences between groups

were expected between the groups.

The distributions of right and left maxillary sinus volume and surface area measurements, as well as comparisons between groups are shown in Table 2. There was no statistically significant difference between the Class I, Class III MR, and Class III MP groups (p>0.05). Therefore, the Class III subgroups were combined and compared with the Class I group. No statistically significant difference was found between the Class I and Class III groups (p>0.05, Table 3).

When evaluating the maxillary sinus volume and surface area according to gender, the right maxillary sinus volume and surface area of males were found to be statistically significantly higher than those of females (p=0.012 and p=0.024). Similarly, the left maxillary sinus volume and surface areas of males were also found to be significantly higher than those of females (p=0.000 and p=0.002) (Table 4).

DISCUSSION

The growth of maxillary sinuses decelerates after 12 years of age and persists until early adulthood.[1,18] The growth mechanism of maxillary sinuses is still not well understood. Proposed factors influencing the alteration of maxillary sinus volume include traction of facial structures, nasal airflow, muscle mass, and brain growth, which may affect cell adherence and migration.[1,19] Due to their morphology, maxillary sinuses are related to zygomatic bone, nasal floor, and maxillary dentition. The most common variations of maxillary sinuses are extensions to the zygomatic bone between the roots of posterior teeth and edentulous areas.[20,21] Therefore, maxillary sinus volume may be affected by neighboring structures. In this study, none of the patients had tooth loss, thickening of the maxillary sinus mucosa, or intraosseous pathology.

In the literature, volumetric changes of maxillary sinuses have been occasionally investigated in relation to factors such as nasal septal deviation, aging, dentition status, sinus pathology, sex, and race.[4,11,22,23] Park et al.[24] calculated the paranasal sinus volumes in an Asian population. While several studies have investigated the relationship between maxillary sinus volume and nasal septal deviation, no consensus has been reached.[1,25] Panou et al.[26] studied changes in maxillary sinus volume in Class III patients undergoing bimaxillary orthognathic surgery. Another orthodontic study involving children, examined how both maxillary sinus volumes increased with rapid maxillary expansion and facemask therapy.[13] In this study, the effect of different sagittal positions of the maxilla on maxillary sinus volume was investigated. Sipahi et al.[27] previously examined the effects of different skeletal malocclusions and nasal septal deviations on maxillary sinus volume, and found no significant difference was found between the groups. Similarly, in the present study, no significant difference in maxillary sinus volume was observed between different sagittal positions of the maxilla.

Table 3. Comparisons of the Class I and Class III groups in terms of maxillary sinus volume and surface area

	Class I (n=58)			Class III (n=110)			p value
	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD	
Right maxillary sinus volume (mm^3)	3657	43024	16423.03±7260.20	3657	35460	15931,26±5999.86	0.640
Right maxillary sinus surface area (mm^2)	1571	7849	4216.35±1183.32	1571	6771	4028.09±937.01	0.261
Left maxillary sinus volume (mm^3)	4076	39281	15892.27±7121.62	4076	35329	15695.03±5978.58	0.849
Left maxillary sinus surface area (mm^2)	1599	10898	4243.71±1516.78	1599	6334	4050.04±1017.35	0.326

SD, Standard deviation; Min, Minimum; Max, Maximum

Table 4. Maxillary sinus volume and surface area assessment according to gender

	Female			Male			p value
	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD	
Right maxillary sinus volume (mm^3)	3657	29157	14518.53±4820.26	4616	43024	18111.25±7623.16	0.012*
Right maxillary sinus surface area (mm^2)	1571	5629	3877.10±841.34	1620	7849	4367.44±1176.68	0.024*
Left maxillary sinus volume (mm^3)	4076	26077	14131.50±4444.58	5634	39281	17835.74±7748.87	0.000***
Left maxillary sinus surface area (mm^2)	1599	5707	3758.74±870.70	2110	10898	4571.85±1421.43	0.002**

SD, Standard deviation; Min, Minimum; Max, Maximum; *p<0.05; **p<0.01; ***p<0.001

Also, in the present study, the presence of nasal septal deviation and its effect on maxillary sinus volume were not investigated.

In studies examining maxillary sinus volume, males generally tend to have a greater volume than females. Right and left maxillary sinus volumes were calculated differently in some published studies. Although Demir et al.[28] reported no significant difference between the left and right maxillary sinus volume, whereas Prabhat et al.[29] found that the right maxillary sinus volume was greater than the left one. Additionally, Takahashi et al.[30] found a negative correlation between age and maxillary sinus volume. Furthermore, Jun et al.[14] reported variations in maxillary sinus growth across different age groups. In the present study, similar age groups were selected for both genders and maxillary sinus volumes were examined in patients with different maxillary development and without any tooth loss. As seen in previous studies, males had a greater sinus-volume surface area compared to females, although this difference was not statistically significant in the present study. Moreover, it was observed that the right maxillary sinus volume tended to be greater than the left maxillary sinus volume in all groups. Varying results might arise due to factors such as the selected region, sample size, and age groups in different studies.

Maxillary sinus measurements have been performed using various imaging methods, including panoramic radiographs, lateral cephalograms, CBCT, CT, and MR imaging.[31,32] Linear measurements are commonly carried out on lateral cephalograms and panoramic radiographs.[8] However, accurate measurements can be hindered due to different magnifications in each region. For volumetric measurements, three-dimensional imaging methods are more appropriate. Among these, CBCT offers many advantages over CT such as lower radiation dose, cost-effectiveness, precise measurements and improved accessibility.[33] In this study, patients were not exposed to additional radiation doses, and additional software was utilized to calculate maxillary sinus volumes.

CONCLUSION

Maxillary sinus volume can be influenced by various factors. Volumetric studies of maxillary sinuses offer a new perspective in orthodontic practice. A comprehensive analysis of maxillary sinuses can be crucial in orthognathic surgery treatment planning. Future studies can be conducted by considering the dental and skeletal characteristics of the individuals and the condition of the paranasal structures. Different sagittal positions of the maxilla and Class III skeletal patterns do not affect maxillary sinus volume. Additionally, it was observed that males have a greater maxillary sinus volume compared to females. Utilizing CBCT images with additional software can be used to calculate the volumes and areas of sinuses accurately.

Ethics

Ethics Committee Approval: The Clinical Research Ethics Committee of Aydın Adnan Menderes University Faculty of Dentistry (approval no: ADÜDHF2021/22, date: 07.07.2021) approved this retrospective study protocol.

Informed Consent: An informed consent form was signed by all patients or their parents.

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Author Contributions: Concept - Y.A.Ü., E.K.; Design - Y.A.Ü., E.K.; Supervision - E.K.; Data Collection and/or Processing - Y.A.Ü., E.K.; Analysis and/or Interpretation - Y.A.Ü., E.K.; Writing - Y.A.Ü.; Critical Review - E.K.

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