Ann Med Res 2021;28(4):709-15

Annals of Medical Research
DOI: 10.5455/annalsmedres.2020.05.529

Original Article

Evaluation of the maxillary sinus volume and dimensions in different skeletal classes using cone beam computed tomography

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Abstract

Aim: The extension of the maxillary sinus is an important issue for fixed orthodontic treatments and maxillofacial surgery. The aim of this study is to investigate the dimensions and volume of the maxillary sinus in different skeletal classes and, also the effect on the anteroposterior growth pattern of the maxilla.

Materials and Methods: The cone-beam computed tomography (CBCT) images of 48 patients were obtained from the archive of the Department of Oral and Maxillofacial Radiology. The CBCT images were taken prior to orthognathic surgery for the surgical planning of all patients. According to the sagittal skeletal position of the maxilla, the patients were divided into three groups: normal maxilla group, retrognathic maxilla group and, prognathic maxilla group. Dimensional and volumetric measurements of the maxillary sinus were performed by the same oral and maxillofacial radiologist.

Results: Although no statistical difference was observed between different skeletal groups regarding the maxillary sinus dimensions and volume, the results did show that there was an inverse and statistically significant correlation between the left maxillary sinus width and age ($p<0.05$). There was a statistically significant difference between males and females for the width, height, and depth of right maxillary sinus, the right maxillary sinus volume, the height and depth of left maxillary sinus.

Conclusion: In conclusion, for orthodontists and maxillofacial surgeons, the dimensional and volumetric measurements performed by CBCT act as a pathfinder role in the insertion of miniscrews, orthodontic tooth movement through the maxillary sinus, and the orthognathic surgeries such as Le Fort osteotomies.

Keywords: Maxillary sinus volume; maxillary sinus; orthognathic surgery; three-dimensional analysis

INTRODUCTION

The maxillary sinus (MS) is the largest of the four paranasal sinuses and, also the first sinus to occur. The paranasal sinuses develop within viscerocranium bones. Triangular pyramid-shaped MS which is seated in the body of the maxilla comprises three recesses: the alveolar recess marked inferiorly, delimited by the maxillary alveolar process; the infraorbital recess marked superiorly, bounded by the inferior orbital surface of the maxilla, and the zygomatic recess marked laterally, bordered by the zygomatic bone (1). Therefore, the development dynamics of the bones of the viscerocranium also point to the growth of sinuses since the paranasal sinuses are confined within viscerocranium bones. The size of the facial skeleton and MS volume has a remarkably close relation. As the shape and size of the MS reflect the development of bony structures, it has been suggested that the MS may be related to midfacial growth and the shape of mid-face (2-4). The MS can also affect the position of maxilla to the skull base and the anteroposterior direction of the maxillary development.

The MS begins to develop in the prenatal period and its volume is about 6-8 cm^3 at birth. The MS development in fetal life is mostly in the anterior-posterior direction (5). In the postpartum growth period, the MS growth is on the rise in the first three years and between 7-12 years of age (6). The MS reaches mature dimensions between 12-15 years (7). Lorkiewicz-Muszyńska et al. (2) reported that the volume and all diameters of the MS reached their maximum magnitude at the end of the 16th year.

Received: 26.05.2020 **Accepted:** 14.06.2020 **Available online:** 21.04.2021
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Thus far, it has been used different imaging techniques including orthopantomographs (8), lateral cephalograms (6), computed tomography (CT) images (9), magnetic resonance imaging (MRI) scans (10) and cone-beam computed tomography (CBCT) images (1,11-13) to measure the MS dimensions. The conventional radiographs enable only two-dimensional evaluation of the anatomical structures. The images might be different from the actual size of the MS and the borders of the MS cannot be defined completely due to the superimposition of the adjacent structures (6). Moreover, neither lateral cephalograms nor orthopantomograms can be used to evaluate the transverse dimension of the MS. There are a lot of advantages of CBCT imaging such as lower radiation dose, shorter acquisition time, and easier accessibility when compared to CT as well as lower costs when compared to MRI. Besides, the CBCT used commonly in dentistry instead of CT or MRI will be more useful for three-dimensional evaluation regarding the anterior or posterior movement of the maxilla in the patients requiring orthognathic surgery (1).

This study aims to investigate the dimensions and volume of the MS in different skeletal classes and, also the effect on the anteroposterior growth pattern of the maxilla. Moreover, we evaluate the relationship between the determination of age and gender and MS dimensions using CBCT.

MATERIALS and METHODS

The CBCT images of 48 patients included in the present study were obtained from the archive of the Department of Oral and Dentomaxillofacial Radiology. The selection criteria of the patients in the study were as noted below: the patients with completed maxillary growth and development (≥16 years old), no serious pathological findings in the MS, no skeletal deformities in the midfacial region and the patients with CBCT images by reason of pre-operative planning for orthognathic surgery. The exclusion criteria included the history of maxillofacial neoplasia, a history of trauma and surgery in the maxillofacial region, the patients with systemic diseases such as Paget disease, Wegener's granulomatosis, thalassemia, and fibrous dysplasia, tooth loss in the maxillary posterior region.

All CBCT images were received using the same NewTom 5G device (FP, Quantitative Radiology, Verona, Italy). The exposure parameters were 0.25 mm voxel size, 0.25 slice thickness and, 18x16 mm FOV (field of view), which allows the detail examination of the maxilla, the mandible and the paranasal sinuses for the orthognathic surgery. The digital images were reviewed using the computer software program NNT (NNT software, version 3.0; NewTom, Verona, Italy) on the monitor (E190S; Dell, Round Rock, TX, USA). Subsequently, the images were exported to SimPlant Pro Software (version 13.0: Materialise, Leuven, Belgium) as DICOM formats for measurements.

Volumetric and Dimensional Measurements

The Grey scale values corresponding to Hounsfield unit values for each patient were set to measure the MS volume. The editing masks and segmentation procedures were conducted manually and the connection of MS with surrounding anatomical structures was erased. After the thresholding process was accurately confirmed on axial, coronal and, sagittal planes, the MS volume was calculated automatically by the software (Figure 1).

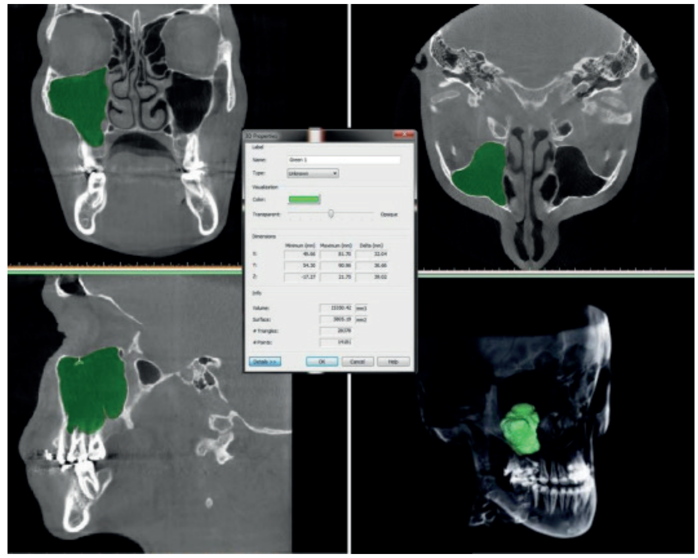

Figure 1. 3D volume reconstruction of the maxillary sinus

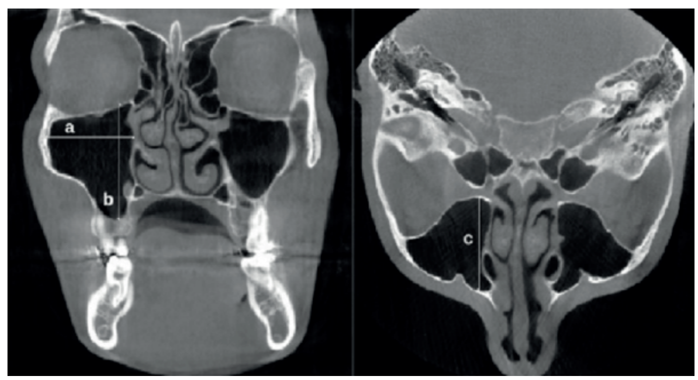

Figure 2. The coronal and axial CBCT images. Measurement of the width: the longest distance from the most medial wall of the sinus to the most lateral wall of the sinus (a) and the height: the longest distance from the lowest point of the sinus floor to the highest point of the sinus roof (b). Measurement of the length: the longest distance from the most anterior point to the most posterior point of the medial wall (c)

The dimensional measurements for both the right and left MSs were performed on axial and coronal CBCT images. The slices in which the width, height, and depth of the MS had the greatest size were detected for measurements (Figure 2). The width of the MS was defined as the longest distance perpendicular from the medial wall of the sinus to the most lateral wall of the lateral process of the MS in the coronal view. The height was defined as the longest distance from the lowest point of the sinus floor to the highest point of the sinus roof in the coronal view. The depth was defined as the longest distance from the most anterior point to the most posterior point of the medial wall in the axial view. All volumetric and dimensional measurements were performed and recorded by the same oral radiologist. The images of 10 patients selected randomly were reexamined one week later and the measurements were recorded to assess intra-observer reliability.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics v 22.0 software (IBM Corp., Armonk, NY, USA). For continuous variables, descriptive statistics were given median (minimum-maximum), and categorical variables were given descriptive statistics with frequency and related percentage values. Kruskal-Wallis test, Mann-Whitney U test, and Pearson chi-square test were used in comparisons between the groups. The correlation between continuous variables was determined with Spearman's rank correlation coefficient. Intra-class coefficient (ICC) was used for the evaluation of intra-observer compliance. The level of significance was obtained as $\alpha = 0.05$.

RESULTS

The CBCT images of 48 patients (28 females, 20 males, mean age: 20.16 years) selected in the study were examined by a specialist orthodontist. According to the sagittal skeletal position of the maxilla (Sella-nasion-A point (SNA) angle: normal value, 82 ± 2°), the patients were divided into three groups: normal maxilla group (11 females, 5 males, mean age: 20.5), retrognathic maxilla group (8 females, 8 males, mean age:19) and, prognathic maxilla group (9 females, 7 males, mean age:21) (14).

Table 1. Results of intra-observer accuracy of the maxillary sinus measurements

Measurements	ICC	p value
Right Maxillary Sinus		
Width	0.858	<0.001
Height	0.876	<0.001
Depth	0.885	<0.001
Volume	0.895	<0.001
Left Maxillary Sinus		
Width	0.876	<0.001
Height	0.865	<0.001
Depth	0892	<0.001
Volume	0.878	<0.001

ICC: Intraclass Correlation Coefficient

Table 2. Descriptive statistics of different skeletal groups

	Normal maxilla group (N= 16)	Retrognathic maxilla group (N= 16)	Prognathic maxilla group (N= 16)	p value
Sex				
Female	11 (68.70%)	8 (50%)	9 (56.30%)	0.549
Male	5 (31.30%)	8 (50%)	7 (43.70%)	
Mean age	20.50 (15-39)	19 (15-37)	21 (16-44)	0.863

N: Number of patients, p value <0.05 is considered significant

Table 3. Comparison of the maxillary sinus volume and dimensions between groups according to Kruskal-Wallis, Mann-Whitney U and Pearson chi-square tests

Measurements	G1 mean (range)	G2 mean (range)	G3 mean (range)	p value
Right Maxillary Sinus				
Width	26.66 (13.98-38.82)	26.59 (17.15-34.47)	28.10 (20.07-34.83)	0.273
Height	39.23 (19.89-46.97)	35.55 (22.27-47.33)	38.51 (31.34-44.62)	0.275
Depth	36.78 (31.81-46.49)	37.30 (25.70-42.67)	37.71 (33.85-41.59)	0.857
Volume	12.31 (4.18-21.49)	15.42 (7.79-28.51)	13.91 (11.07-17.61)	0.536
Left Maxillary Sinus				
Width	25.95 (16.26-34.47)	25.73 (15.18-31.45)	27.92 (18.30-38.80)	0.287
Height	37.17 (21.86-44.62)	35.63 (22.53-43.87)	38.72 (32.16-44.80)	0.492
Depth	36.55 (30.58-44.74)	37.25 (23.88-41.07)	37.05 (32.43-39.46)	0.844
Volume	13.76 (4.65-20.26)	14.33 (1.40-27.49)	13 (8.87-19.39)	0.684

G1: Normal maxilla group; G2: Retrognathic maxilla group; G3: Prognathic maxilla group; p value <0.05 is considered significant

Table 1 summarizes the intra-observer reliability in terms of MS measurements. Considering that the concordance between the first and second series of measurements, there was a high level of agreement for dimensions and volumes of the right and left MSs ($p<0.001$) (Table 1). The age and gender distribution of the groups were presented in Table 2. Furthermore, no statistical difference was observed between different skeletal groups regarding the MS dimensions and volume (Table 3).

Table 4 shows that there was an inverse and statistically significant correlation between the left MS width and age ($p=0.015$). According to the results of gender assessment, there was a statistically significant difference between males and females in the width, height, and depth of right MS, the right MS volume, the height and depth of left MS ($p<0.05$) (Table 5).

Table 4. The correlation of measurements with age variables

Measurements	Age variable	
	r	p value
Right Maxillary Sinus		
Width	-0.225	0.124
Height	-0.229	0.118
Depth	-0.224	0.127
Volume	-0.213	0.156
Left Maxillary Sinus		
Width	-0.348	0.015
Height	-0.190	0.197
Depth	-0.208	0.156
Volume	-0.161	0.285

r: Spearman's rank correlation coefficient; p value <0.05 is considered significant

Table 5. Comparison of the maxillary sinus volume and dimensions with sex variables

Measurements	Female (N=28) mean (range)	Male (N=20) mean (range)	p value
Right Maxillary Sinus			
Width	24.71 (17.15-38.82)	28.25 (13.98-38.82)	0.030
Height	36.22 (22.27-45.15)	38.96 (19.89-47.33)	0.047
Depth	36.49 (25.70-42.67)	38.78 (32.10-46.49)	0.005
Volume	12.08 (5.72-18.95)	16.01 (4.18-28.51)	0.004
Left Maxillary Sinus			
Width	25.53 (15.18-38.80)	27.16 (18.25-34.47)	0.272
Height	36.19 (21.86-41.73)	38.96 (22.25-44.80)	0.007
Depth	36.30 (23.88-44.74)	38.84 (32.43-42.61)	0.009
Volume	13.15 (1.40-19.39)	13.79 (6.46-27.49)	0.054

N: Number of patients, p value <0.05 is considered significant

DISCUSSION

The aim of this study was to evaluate the MS volume and dimensions for the different skeletal classes. In the present study, due to the MS is located in the body of the maxilla and it has a close contiguity with the maxillary posterior teeth, the patients were classified according to the SNA angle, which determines the position of the maxilla to the skull base. The majority of the patients in the presented study were individuals who need a fixed orthodontic treatment and orthognathic surgery. Orthognathic surgery treatment includes Le Fort osteotomies and the procedures of maxillary protraction or retraction.

The Le Fort 1 osteotomy is of the most common orthognathic surgical procedure used for the correction of the maxillary deformities. Nocini et al. (15) investigated the prevalence of complications for patients who undergone Le Fort 1 osteotomy. According to their findings, the Le Fort 1 osteotomies affect the MS health. These osteotomies may lead to the sinusitis symptoms postoperatively and the iatrogenic alterations such as the decrease in the MS volume, the disruption of the integrity of medial and lateral walls of MS (15). Therefore, the knowledge of anatomical features of the MS is very crucial. To view preoperatively MS and to measure its dimensions and volume using CBCT, prevents postsurgical complications.

The MS floor is formed by the alveolar process of the maxilla and it is a compact bone layer lined with periosteum. The sinus floor maintains contiguity with the maxillary posterior teeth throughout life (16). While the MS anatomically extends to the inter-radicular site of maxillary posterior teeth in some subjects, the MS has been completely pneumatized into the alveolar process of the missing tooth space in some subjects after tooth extraction. In orthodontic treatments, compensatory new bone apposition requires to occur, before bone resorption, in the direction of tooth movement to continue the integrity of the sinus wall. Moreover, a complication like the perforation of the sinus membrane may also occur. Therefore, the moving of the teeth through the MS during orthodontic treatments is considered to be one of the most difficult problems (17).

Oh et al. (18) stated that the tooth movement through MS can be successfully performed without any significant side effect. However, maintaining light continuous forces and moving tooth more slowly are important to provide both the bodily movement and the direct bone resorption (18). From this point of view, the examination of the relationship of the MS extension with the maxillary posterior teeth on 3D-CBCT slices enables to apply force systems accurately and to the treatment planning more carefully for providing the bodily movement with bone apposition.

The mini screws that have been using to strengthen anchorage in orthodontic tooth movement are generally placed in the maxillary posterior alveolar region between the second premolar and first molar teeth. However, the extension of the MS may accidentally lead to the MS perforation. Motoyoshi et al. (19) investigated the frequency (10%) of MS perforation after mini screw insertion to facilitate safely placement of orthodontic anchorage screws. They reported that the extension of sinus floor besides vertical inclination and length of miniscrews should be considered to avoid MS perforations.

Many previous studies have used different measurement methods for MS dimensions. Oktay (8) performed the areal measurements of the MS in different skeletal malocclusion classes (according to Angle's classification) on the panoramic radiographs. Oktay (8) showed that the female patients with Angle Class II had larger MS and no statistical difference was found between males and females. The most important limitation of this study was the study population which were between 6 and 30 years of age. However, considering that the growth/development of the MS depends on the aging process, the wide age range of the study population might affect the results.

Endo et al. (6) classified the patients between 12 and 16 years according to ANB angle, and also performed other cephalometric angular measurements together with the area and dimensions of the MS on the lateral cephalograms. They reported that there was no statistically significant difference between skeletal malocclusion classes and genders with two-way ANOVA test, in terms of the height and length of the MS, the lower and upper MS area. They found that none of the MS measurements correlated with SNA, SNB (Sella-nasion-B point) and ANB (A point-nasion-B point) angles. Based on these findings, they concluded that the anteroposterior deviation of the maxillary and mandibular alveolar bones did not affect the MS size. In the present study, authors considered that exclusion of the patients younger than 16 years old and the evaluation of the MS volume, as well as all dimensions (height, width, and length), may provide more accurate and reliable results regarding the relationship of MS size with sagittal skeletal jaw position. Nevertheless, our results were consistent with those of Endo et al. (6).

These results which did not show any significant difference between different skeletal groups and dimensions, and the volume of the MS may be due to an insufficient number of the patients included in the study. The small number of patients was one of the limitations of this study. Hence, further studies with larger sample sizes are required to confirm our findings and the role of skeletal malocclusions on MS volume/dimensions.

Erdur et al. (13) investigated whether there was any difference in the MS volume of the patients with unilateral cleft lip and palate (UCLP) using CBCT. They reported that the MS volume of the patients with UCLP was lower compared with the control group. However, no statistical difference was observed between the cleft side and non-cleft side. Since the differences in sinus volume like MS hypoplasia lead to maxillary sinusitis, measuring sinuses of the patients with CLP is remarkably useful to predict potential sinus diseases. Tikku et al. (7) (subjects with age between 12-14 years) and Ağaçayak et al. (20) (subjects older than 21 years) studied the alterations in the MS volume of mouth breathers. Both of them showed that the MS volume of mouth breathers was significantly lower than those of nasal breathers. Song et al. (9) evaluated the MS volume and dimensions in different craniofacial deformities with mid-facial hypoplasia. The MS volume, height, width and depth significantly decreased in patients with Crouzon syndrome, whereas no statistically significant difference was found in patients with midfacial hypoplasia after palatoplasty and hemifacial microsomia. But, as they stated, these results may be affected by some factors that the study group with Crouzon syndrome was composed of children aged 3.5 to 7 years and other groups were composed of adults. This was because they used preoperative CT scans of patients with Crouzon syndrome who generally had Le Fort III osteotomy, at five years of age. However, the period between 7 and 12 years is the period of secondary rapid development with an increase in MS development, the first rapid period is 0-3 years. The short height and depth of the MS detected in patients with Crouzon syndrome play a very important role as a warning concerning the increased risk of damages to the surrounding structures during maxillary surgery. The structures such as teeth, nasal airways, and the orbit may be affected by the mentioned risks (9). Furthermore, the small volume of the MS can cause to develop chronic sinusitis (21).

Karatas et al. (22) ascertained the effect of different degrees of the nasal septal deviation on the MS volume. Although there was no statistically significant difference in the mild (0-15°) and severe (>15°) groups, they reported that there was a statistically significant difference between ipsilateral and contralateral sides in the moderate group (9-15°). According to these results, when evaluating alterations in the MS volume, exclusion of the patients with nasal septal deviation leading to a decrease in sinus volume provides more accurate findings. In present study, the presence of the patients with nasal septal deviation may be considered as the limitation of this study.

Considering the results of age-related volumetric changes of the MS in the literature, Cohen et al. (23) showed that younger patients had statistically larger MS volume compared to those older than 65 years. Cohen et al. (23) and Jun et al. (24) revealed a negative correlation between the age and the MS volume. In present study, although the left MS width showed a statistically significant and inverse correlation with the aging parameter (correlation coefficient: (-0.348), p=0.015), the relationship of age with MS volume and other dimensions was not statistically significant. This result is likely to be based on a small number of patients and groups composed of younger patients.

In the current literature, many studies investigate the usage of the measurements of the MS dimensions in sex determination. Paknahad et al. (11) reported that the most conspicuous parameter was the MS height and followed by depth and width in gender assessment. Ahmed et al. (25) stated that the most conspicuous parameter was the MS width. On the contrary to these studies, Saccucci et al. (1) evaluated the three-dimensional analysis of the MS in sex determination and revealed that the MS volume showed no statistical difference between genders. According to results of present study, for right MS, there was a statistically significant difference between the gender variable and MS volume, depth, width, height.

For left MS, the MS height and depth were found statistically significant between gender groups. Consequently, the authors think that differences in ethnic groups, measurement methods, used radiographic techniques, sample size and homogeneity of age distribution may have affected the results of the studies.

Oksayan et al. (12) evaluated the effect of the MS volume and dimensions on the vertical face growth patterns, comprising three groups as high-angle, normal-angle and low-angle regarding SN-GoGn (Sella-Nasion-Gonion-Gnathion) angle. According to their results, although both right and left MS in high and normal-angle groups were smaller than those of low-angle group, there was no significant difference between vertical growth patterns and the MS volumes of right and left sides. In the right MS measurements, only the MS depth was statistically higher in the low-angle group compared to the high-angle group. The left MS depth and width in the high-angle group were statistically smaller than that in the low-angle group. In present study, the width was higher in the prognathic maxilla group compared to the normal and retrognathic maxilla group, for the left and right MS. The height was higher in the normal maxilla group for the right side, in the prognathic maxilla group for the left side. The depth was higher in the prognathic maxilla group for the right side, in the retrognathic maxilla group for the left side. However, no statistical difference was found between groups in terms of the right/left MS volume and dimensions. Consistent with results of present study, Saccucci et al. (1) stated that the MS volume did not change in different sagittal skeletal patterns and the maxilla and jaw positions were independent of MS dimensions.

CONCLUSION

In present study, it was aimed to determine the differences in the MS volume and dimensions in different skeletal groups classified according to the SNA angle. The relationship between many MS parameters and the gender variable was found statistically significant, whereas there was no statistically significant difference between different skeletal groups. In conclusion, for orthodontists and maxillofacial surgeons, the dimensional and volumetric measurements performed by CBCT act as a pathfinder role in the insertion of mini screws, orthodontic tooth movement through the MS, and the orthognathic surgeries such as Le Fort osteotomies.

Competing interests: The authors declare that they have no competing interest.

Financial Disclosure: There are no financial supports.

Ethical approval: This study was approved by the Ethics Committee Board of Erciyes University (protocol number 2019/192).

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