Oral Radiology (2019) 35:287–295
https://doi.org/10.1007/s11282-018-0360-x

ORIGINAL ARTICLE

Investigation of maxillary sinus volume relationships with nasal septal deviation, concha bullosa, and impacted or missing teeth using cone-beam computed tomography

Fahrettin Kalabalık[1] · Elif Tarım Ertaş[2]

Received: 19 December 2017 / Accepted: 23 October 2018 / Published online: 24 November 2018

Abstract

Objectives The aim of this retrospective study was to investigate the correlations of maxillary sinus volume with nasal septal deviation, concha bullosa, impacted teeth, and missing teeth in the maxillary posterior region on maxillary sinus volume using cone-beam computed tomography (CBCT) images.

Methods The study cohort comprised 252 CBCT images of 252 patients retrospectively selected from the records in our CBCT archive. All CBCT images were exported to 3D modeling software for calculation of maxillary sinus volumes. Nasal septal deviation cases were grouped as mild, moderate, and severe. Concha bullosa was classified as lamellar, bulbous, and extensive. Maxillary sinus volume differences were evaluated by comparing the bilateral sinus volumes in patients with nasal septal deviation, unilateral concha bullosa, and unilateral impacted or missing maxillary posterior teeth.

Results The findings revealed that males had a significantly higher mean sinus volume than females ($p < 0.01$) and that sinus volume tended to decrease with age ($p < 0.05$). In moderate and severe nasal septal deviation cases, the maxillary sinus volume was significantly smaller on the same side as the deviation than on the contralateral side ($p < 0.05$). There were no significant correlations between maxillary sinus volume and concha bullosa, unilateral impacted teeth, or unilateral missing teeth ($p > 0.05$).

Conclusions The present findings suggest that maxillary sinus volume is smaller on the same side as the deviation in moderate and severe septal deviation cases and that the maxillary sinus volume tends to decrease with increasing age.

Keywords CBCT · Maxillary sinus · Middle turbinate · Nasal septum

Introduction

The paranasal sinuses are air-filled cavities located within the skull bones around the nasal cavity. They consist of the maxillary, frontal, and sphenoid sinuses and the ethmoid air cells. Their development and final shape show numerous variations, and even identical twins can have different sinus configurations [1, 2].

✉ Fahrettin Kalabalık
kalabalikfahrettin@hotmail.com

[1] Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Izmir Katip Celebi University, Aydinlik Evler Mahallesi, Cemil Meric Caddesi, 6780 Sokak No: 48, 35640 Cigli, Izmir, Turkey

[2] Dentistanbul Dental Hospital, Yildiz Caddesi No: 71, Besiktas, Istanbul, Turkey

Various imaging modalities can be used to detect paranasal sinus pathologies and anatomic variations. Cone-beam computed tomography (CBCT) is a relatively new technology in the field of oral and maxillofacial radiology, but is widely accepted as one of the pioneering tools for paranasal sinus evaluation by dentists, maxillofacial radiologists, and otolaryngologists [3]. CBCT image assessment for the nasal cavity and paranasal sinuses offers several advantages over multislice computed tomography, including easier image acquisition, greater image accuracy facilitated by high-quality bony definition, multiplanar reformation, lower radiation doses, faster scan times, and less expensive machine [4].

The maxillary sinus holds a special place in the field of dentistry because of its close proximity to the teeth and associated structures. Among the paranasal sinuses, the maxillary sinus has a crucial role in the formation of facial contours. It is the largest of the four paranasal sinuses and is the first to develop [2, 5], with onset of development in the third month of intrauterine life [6]. The average volume of the maxillary sinus at birth is 6–8 cm^3. It can be detected radiographically on a standard anteroposterior view at 5 months after birth. Pneumatization of the sinus continues both laterally and inferiorly during two rapid growth periods from birth to 3 years of age and from 7 to 12 years of age [7].

The developmental pattern of the paranasal sinuses is totally unpredictable and varies greatly among individuals [8]. The maxillary sinuses can even develop in a differently from one another in the same person [5]. After the final rapid growth phase of the maxillary sinus, many chronological and pathologic events can affect its volume. The development of the maxillary sinus has a direct relationship with the alveolar bone and palate. Because of its large volume, craniofacial anatomical features can be affected if there is a considerable change in the maxillary sinus volume [9]. Moreover, maxillary sinus hypoplasia can be associated with facial asymmetry [10]. Therefore, we focused on the volumetric changes of the maxillary sinus in this study.

There have been many studies on the relationships of maxillary sinus dimensions and volume with age and sex [5, 11–22], and a few studies have investigated the relationships of maxillary sinus volume with tooth status [9, 20, 23] and adjacent anatomical variations such as nasal septal deviation (NSD) and concha bullosa (CB) [24–28]. However, no studies have assessed the relationships between impacted upper premolar–molar teeth and maxillary sinus volume.

The aim of this study was to determine the effects of NSD, CB, impacted teeth, and missing teeth in the maxillary posterior region on the volume of the maxillary sinus using CBCT images. We also evaluated the normal volume distribution of the maxillary sinuses according to age and sex.

Materials and methods

This retrospective study was approved by the local ethics committee of Izmir Katip Celebi University (approval no. 80). All patients in our CBCT archive were informed and provided written consent regarding the use of their data for scientific research. The study was conducted at the Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Izmir Katip Celebi University, Izmir, Turkey. CBCT images of 1368 patients referred to our clinic for various complaints between October 2012 and July 2015 were retrospectively analyzed. All images were obtained with a NewTom 5G CBCT machine (QR srl, Verona, Italy) using the following parameters: 110 kVp and 1–20 mA. CBCT images with large fields of view (15 × 12 cm and 18 × 16 cm) were selected, because they included the entire maxillary sinus. The voxel size was 0.2 mm, and the slice thickness was 1.0 mm.

The exclusion criteria were: (1) < 12 years of age; (2) poor image quality with severe artefacts; (3) previous maxillary sinus surgery or grafting; (4) maxillary sinus pathology such as tumor or cyst; (5) acute or chronic sinusitis; (6) sinus or nasal polyposis; and (7) craniofacial anomalies such as cleft lip and palate. Rak et al. [29] reported that abnormal sinusitis only occurred when mucous thickening of ≥ 3 mm was present. Therefore, patients with mucous thickening of ≥ 3 mm in the maxillary sinus were considered to have sinusitis and excluded from the study. Finally, a total of 252 patients with 504 healthy maxillary sinuses were included in the study.

The CBCT scans of the patients were exported in Digital Imaging and Communications in Medicine (DICOM) format and imported into Mimics 16.0 software (Materialise Dental, Leuven, Belgium). All CBCT images were processed and analyzed by a single researcher. For determination of maxillary sinus volumes, coronal images were selected. Thresholding for each patient was performed manually by the same researcher. The sinuses were cropped in the slice, where their largest size was apparent. The connections between the sinuses and the outer air were then cropped in a slice-by-slice manner. Cropping was also performed in axial and sagittal images. After all connections between the sinuses and the outer air were eliminated, three-dimensional models of the left and right sinuses were created separately, and their volumes were calculated (Fig. 1).

Nasal septal deviation was defined as any bending of the nasal septal contour observed on coronal CBCT images, in accordance with Bhandary and Kamath [30]. The angle between a linear line drawn from the maxillary spine to the crista galli and a linear line drawn from the crista galli to the most deviated part of the nasal septum was accepted as the deviation angle. The convex side of the curvature defined the direction of the deviation. The patients were divided into three groups according to the measured angle of NSD as described by Elahi et al. [31]: mild (< 9°; Group 1), moderate (9°–15°; Group 2), and severe (≥ 15°; Group 3) (Fig. 2). The control group comprised patients without NSD. In patients with NSD, the maxillary sinus volumes on the deviation side and the contralateral side were compared. Similar comparisons were made in the NSD subgroups.

CB was defined as the presence of a pneumatized middle turbinate on a coronal image. CB was classified into three different patterns as described by Bolger et al. [32]: lamellar (pneumatization localized in the vertical lamella of the concha), bullous (pneumatization localized in the bulbous segment of the concha), and extensive (extensive pneumatization of the entire middle turbinate) (Fig. 3). The control group comprised patients without CB. In patients with unilateral CB, the maxillary sinus volumes on the CB side and the contralateral side were compared. Similar comparisons were made for all subtypes among the unilateral CB cases.

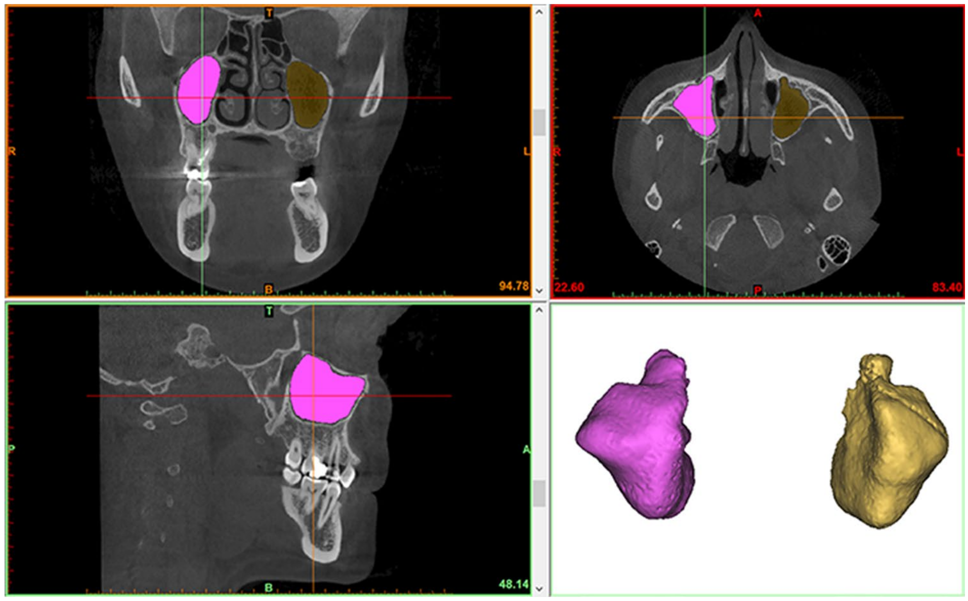

Fig. 1 Three-dimensional reconstructed images of right and left maxillary sinuses

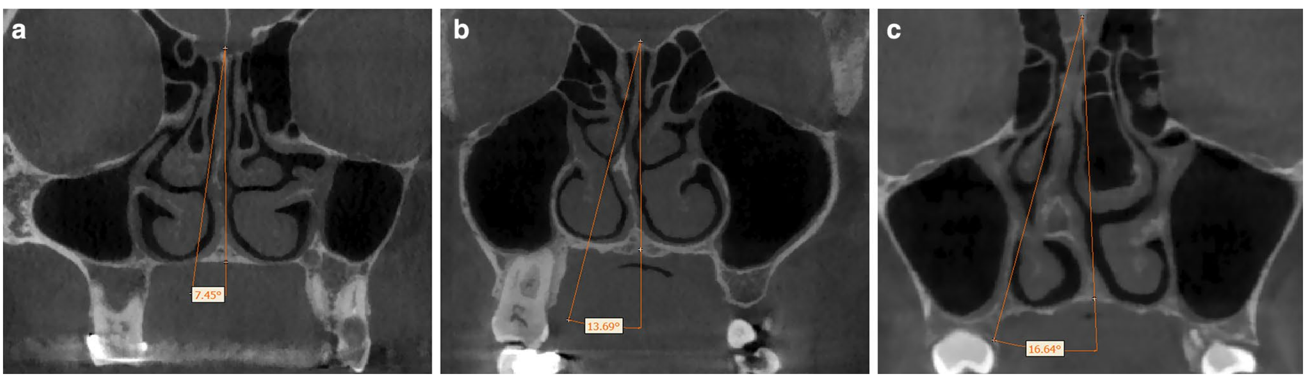

Fig. 2 Coronal CBCT images showing the definitions of nasal septal deviation based on the measured angle. **a** Mild deviation. **b** Moderate deviation. **c** Severe deviation

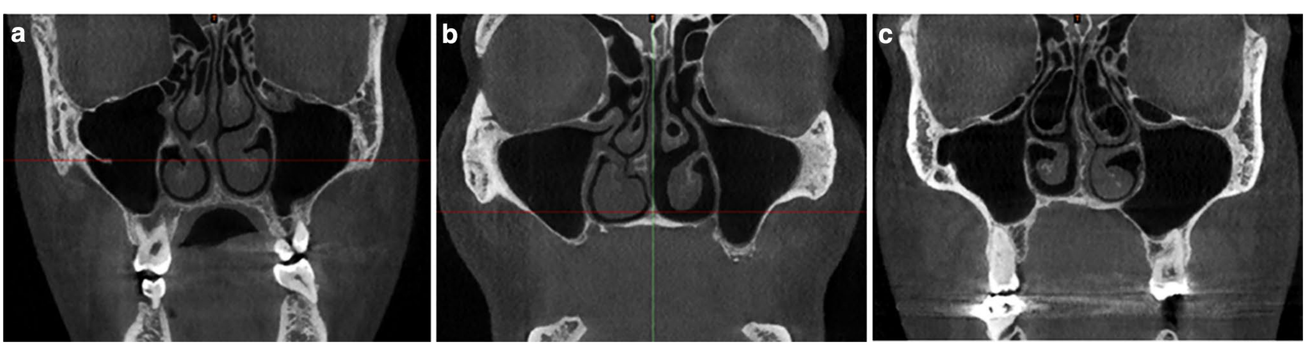

Fig. 3 Coronal CBCT images showing the definitions of concha bullosa. **a** Lamellar concha bullosa. **b** Bullous concha bullosa. **c** Extensive concha bullosa

Impacted maxillary premolars and molars were detected on axial, coronal, and sagittal images and recorded. A tooth was considered impacted if it was not exposed to the oral cavity and its root development was > 75% complete [33]. The maxillary sinus volumes on the impacted tooth side and the contralateral side were compared.

Missing maxillary premolars and molars were determined on axial, coronal, and sagittal images and recorded. Because of the high prevalence of congenitally missing maxillary third molars, the absence of these teeth was not recorded as missing teeth. The maxillary sinus volumes on the missing tooth side and the contralateral side were compared.

Statistical analysis

Statistical analysis was carried out using SPSS v.22 software (IBM, Chicago, IL, USA). Conformity of parameters to a normal distribution was assessed by the Kolmogorov–Smirnov test. A paired-sample *t* test was used to compare the mean bilateral maxillary sinus volumes. Student's *t* test was used to compare continuous variables. Correlations between parameters were evaluated by Pearson's correlation analysis. Statistical significance was determined at $p < 0.05$. For reliability testing, 63 CBCT images (25% of the images) were randomly selected for repeated measurements at 3 weeks after the first examination by the same researcher. The intraclass correlation coefficient was used to determine the reliability of the measurements.

Results

A total of 252 patients with 504 healthy maxillary sinuses were included in the study. The patients comprised 96 males and 156 females with an age range of 12–85 years (mean 31.21 ± 17.71 years). The coefficients of reliability for all measurements were > 0.98. The results of the paired-sample *t* test revealed no significant difference between the two sets of readings ($p > 0.05$). The mean right and left maxillary sinus volumes were 14.64 ± 5.19 and 14.66 ± 5.2 cm^3, respectively, with no significant difference ($p = 0.88$). The overall mean maxillary sinus volume was 14.65 ± 5.19 cm^3. The mean right, left, and total maxillary sinus volumes of male patients were significantly larger than those of female patients ($p < 0.01$) (Table 1).

A negative correlation was observed between the right, left, and total maxillary sinus volumes and age ($p < 0.05$), meaning that maxillary sinus volume tended to decrease with age (Table 2).

NSD was found in 226 (89.68%) patients. Of these, 118 (52.21%) had convexity to the right, 98 (43.36%) had convexity to the left, and 10 (4.43%) had biconvex NSD. Twenty-six (10.32%) patients had a straight nasal septum and were assigned to the control group for NSD. Patients with biconvex deviations were not included in the NSD group. The mean right and left maxillary sinus volumes in the control group were 14.51 ± 4.07 and 14.16 ± 4.41 cm^3, respectively, with no significant difference ($p = 0.32$). However, in the NSD group, the maxillary sinus volumes were significantly smaller on the same side as the deviation than on the contralateral side ($p < 0.05$) (Table 3).

The NSD angles ranged from 4.46° to 22.13°. The patients with NSD were classified as 76 mild (< 9°; Group 1), 97 moderate (9°–15°; Group 2), and 43 severe (≥ 15°; Group 3) cases. The maxillary sinus volumes were significantly smaller on the same side as the deviation than on the contralateral side in Groups 2 and 3. There was no significant difference in Group 1 (Table 4).

Table 1 Comparisons of maxillary sinus volumes between males and females

	Males ($n = 96$)	Females ($n = 156$)	p
Right MS volume (cm^3)	15.78 ± 5.23	13.93 ± 5.01	0.006**
Left MS volume (cm^3)	15.99 ± 5.38	13.84 ± 4.96	0.001**
Total MS volume (cm^3)	31.78 ± 10.32	27.78 ± 9.79	0.002**

Data are shown as mean ± SD

MS maxillary sinus

**$p < 0.01$, significant difference by Student's *t* test

Table 2 Correlations between maxillary sinus volumes and age

	Age	
	r	p
Right MS volume	−0.171	0.006*
Left MS volume	−0.124	0.049*
Total MS volume	−0.151	0.017*

Data were evaluated by Pearson's correlation analysis

r Pearson correlation coefficient, *MS* maxillary sinus

*$p < 0.05$, significant difference

Table 3 Maxillary sinus volumes according to nasal septal deviation side

	Deviation side	
	Right ($n = 118$)	Left ($n = 98$)
Right MS volume (cm^3)	13.36 ± 4.70	16.05 ± 5.49
Left MS volume (cm^3)	13.87 ± 4.75	15.52 ± 5.50
p	0.01*	0.02*

Data are shown as mean ± SD

MS maxillary sinus

*$p < 0.05$, significant difference by a paired-sample *t* test

Table 4 Maxillary sinus volumes in nasal septal deviation subgroups

Side	Group 1 ($n=76$)	Group 2 ($n=97$)	Group 3 ($n=43$)
Deviation side volume (cm^3)	14.03 ± 4.82	13.36 ± 5.12	14.66 ± 6.06
Contralateral side volume (cm^3)	14.40 ± 5.03	14.90 ± 5.27	15.34 ± 5.58
p	0.07	0.04*	0.03*

Data are shown as mean ± SD

*$p < 0.05$, significant difference by a paired-sample *t* test

Table 5 Maxillary sinus volumes in 62 patients with unilateral concha bullosa

Side	Volume (cm^3)
Concha bullosa side	14.17 ± 4.93
Contralateral side	13.73 ± 4.93
p	0.63

Data are shown as mean ± SD

$p > 0.05$, no significant difference by a paired-sample *t* test

Table 6 Maxillary sinus volumes according to unilateral concha bullosa subtypes

	Lamellar ($n=36$)	Bulbous ($n=8$)	Extensive ($n=18$)
Concha bullosa side volume (cm^3)	13.71 ± 4.73	15.55 ± 4.09	14.48 ± 4.25
Contralateral side volume (cm^3)	13.11 ± 5.18	16.13 ± 4.21	13.90 ± 4.59
p	0.06	0.42	0.39

Data are shown as mean ± SD

$p > 0.05$, no significant difference by a paired-sample *t* test

Among the 252 patients, 195 (77.4%) had at least one CB. Unilateral CB was present in 62 (24.6%) patients and bilateral CB in 133 (52.8%). Among the 62 unilateral CB cases, lamellar, bulbous, and extensive CB were found in 36, 8, and 18, respectively. The maxillary sinus volumes were compared in patients with unilateral CB. Similar comparisons were made for each subtype among the unilateral CB cases. No significant differences were found between the CB side and the contralateral side ($p > 0.05$) (Tables 5, 6).

The investigation for impacted maxillary molars and premolars revealed that 29 (11.5%) patients had unilaterally impacted teeth and 25 (9.9%) patients had bilaterally impacted teeth. The bilateral maxillary sinus volumes were compared in patients with unilateral impacted teeth. The maxillary sinus volumes were smaller on the same side as the impacted teeth than on the contralateral side, but the difference was not significant ($p > 0.05$) (Table 7).

Table 7 Maxillary sinus volumes in 29 patients with unilateral impacted teeth

Side	Volume (cm^3)
Impacted teeth side	14.44 ± 4.81
Contralateral side	14.63 ± 5.15
p	0.9

Data are shown as mean ± SD

$p > 0.05$, no significant difference by a paired-sample *t* test

Table 8 Maxillary sinus volumes in Group A and Group B

Side	Group A ($n=6$)	Group B ($n=33$)
Missing teeth side volume (cm^3)	14.08 ± 3.83	15.44 ± 5.92
Contralateral side volume (cm3)	14.21 ± 3.99	14.92 ± 5.57
p	0.85	0.13

$p > 0.05$, no significant difference by a paired-sample *t* test

The examination for missing maxillary molars and premolars (at least one molar or premolar) revealed that 39 (15.5%) patients had unilaterally missing teeth and 74 (29.4%) patients had bilaterally missing teeth. The 39 patients with unilaterally missing teeth were divided into two groups by age: group A, age ≤ 20 years; group B, age > 20 years. The bilateral maxillary sinus volumes were compared in both groups. The mean maxillary sinus volume was smaller on the same side as the missing teeth than on the contralateral side in group A, while it was larger in group B. No significant difference was observed in both groups ($p > 0.05$) (Table 8).

Discussion

In the previous studies, the volumes of paranasal sinuses were measured on cadaveric materials [34], dry skulls [35], computed tomography scans [9, 20, 24–27], magnetic resonance images [36], and CBCT images [19, 37, 38]. The techniques for volume measurement on cadaveric materials and dry skulls cannot be used in living subjects [11]. Furthermore, measurements on dry skulls may be larger than the actual sizes because of the lack of soft-tissue lining [20]. Measurement of maxillary sinus volumes using CBCT has certain advantages, such as low radiation doses compared with computed tomography and low cost compared with magnetic resonance imaging [19]. Therefore, CBCT images were used for measurement of maxillary sinus volumes in the present study.

The maxillary sinus has two rapid growth phases, one between birth and 3 years of age and another between 7 and 12 years of age. After these rapid growth phases, the maxillary sinus volume becomes approximately adult-sized between 12 and 15 years of age [7, 39]. Some authors reported that the maxillary sinus volume does not increase significantly after 12 years of age [40, 41]. Therefore, it was decided to evaluate the maxillary sinus volume in patients aged > 12 years in this study.

In the present study, a negative correlation was observed between maxillary sinus volume and age, meaning that the maxillary sinus volume tended to decrease with age. This finding was consistent with the previous reports by Cho et al. [9] and Cohen et al. [18]. In other studies, Kim et al. [14], Sahlstrand-Johnson et al. [11], and Emirzeoğlu et al. [17] found no significant correlation between maxillary sinus volume and age in patients aged > 18 years. However, these three studies all included less than 80 patients, and the lack of correlation may have been related to the low numbers of patients. Meanwhile, Karakas et al. [21] showed that the volume of paranasal sinuses increased with age in patients aged 5–55 years. However, this positive correlation can probably be explained by their inclusion of very young patients.

There have been many studies on the relationship of maxillary sinus volume with sex. Several authors reported differences in maxillary sinus volumes between males and females [5, 11–18], while other authors showed no such difference [19, 20]. We found that the mean right, left, and total maxillary sinus volumes in male patients were significantly larger than those in female patients. This difference in maxillary sinus volumes between sexes can probably be attributed to the fact that males are generally physically larger than females in most dimensions.

In the present study, there was no significant difference in mean volumes between the right and left maxillary sinuses, consistent with the previous studies [11, 20]. Because maxillary sinus volumes can vary by age and sex, as observed in our study and other studies, we compared the bilateral maxillary sinus volumes, rather than comparing different patient groups, when investigating the maxillary sinus volume changes in the presence of NSD, CB, and impacted or missing maxillary posterior teeth.

There are a few studies on the relationship of maxillary sinus volume with NSD. In our study, there was no significant difference between the right and left maxillary sinus volumes in the control group. However, in the NSD group, the maxillary sinus volumes were significantly smaller on the same side as the deviation than on the contralateral side. Orhan et al. [24] compared maxillary sinus volumes in patients with NSD and control patients. They found that maxillary sinus volumes were significantly smaller on the same side as the deviation than on the contralateral side in patients with NSD. They did not find a significant difference between the left and right maxillary volumes in the healthy control patients, as also observed in our study. Aydın et al. [42] compared the maxillary sinus volumes of 36 patients with antrochoanal polyps on the ipsilateral and contralateral sides to the deviation and found no significant difference in the mild, moderate, and severe deviation groups. Kapusuz Gencer et al. [25] reported that maxillary sinus volumes were higher on the contralateral side to severe septal deviations, while mild and moderate septal deviations had no significant effect on maxillary sinus volumes. In another study investigating the effect of septal deviations on frontal and maxillary sinus volumes, moderate septal deviation was found to significantly impact the maxillary sinus. These findings suggested that maxillary sinus volumes tended to be higher on the contralateral side to moderate septal deviations [28]. In our study, although mild septal deviations lacked any significant effect on maxillary sinus volumes, moderate and severe deviations had a significant impact on these parameters. Contrary to our study, Kucybala et al. [26] found that NSD had no impact on maxillary sinus volume, for either right or left deviations. However, they did not categorize their patients according to the angle of NSD. In our study, mild septal deviation lacked any significant effect on maxillary sinus volume, consistent with the previous studies [25, 28, 42]. Therefore, the study by Kucybala et al. [26] may have contained high numbers of patients with a small deviation angle or mild deviation.

Nasal obstruction caused by NSD can increase nasal airway resistance and cause turbulent nasal airflow, precipitating dryness and crusting of the nose, frequent nosebleeds, and recurrent sinusitis [43, 44]. The resultant impaired nasal breathing can lead to chronic mouth breathing, which in turn can result in moderate-to-severe maxillary constriction, and a vertical skeletal growth pattern characterized by long anterior lower face height, bilateral maxillary crossbite, high arched palate, low tongue posture, and insufficient lip support [45, 46]. In addition, it has been hypothesized that nasal respiration enables normal growth and development of the craniofacial structures. According to the functional matrix theory, undisturbed nasal airflow is a continuous stimulus for lowering of the palate and lateral maxillary growth, indicating a close relationship between nasal breathing and dentofacial morphology [47]. Our study showed that mild and moderate septal deviations caused insufficient growth of the maxillary sinus on the same side as the deviation. The insufficient growth probably arose from inadequate ventilation of the maxillary sinus on the deviation side. Based on these findings, we suggest that nasal respiration should be controlled in dental patients, especially adolescent patients. If any impaired nasal breathing is present, the patients should be referred to an otorhinolaryngologist. Thus, treatment of conditions that can lead to impaired nasal breathing, such as NSD, may result in avoidance of craniofacial disorders. Furthermore, based on its greater image accuracy, the authors recommend that dentists should use CBCT as a reliable tool for NSD evaluation, and further suggest that when NSD is diagnosed on CBCT examination, patients should be referred to an otorhinolaryngologist for further evaluation.

CB is defined as pneumatization of the middle turbinate and is one of the most common anatomic variations of the osteomeatal complex region [48]. We hypothesized that pneumatization of the middle turbinate may affect maxillary sinus growth and volume, because the turbinates are the first structures to develop in the lateral nasal wall. However, we did not find a relationship between unilateral CB and maxillary sinus volume. We also found no relationship between each subtype of unilateral CB and maxillary sinus volume. Demir et al. [27] also demonstrated no significant association between CB and maxillary sinus volumes. Kucybala et al. [26] compared the maxillary sinus volumes in a patient group with bilateral CB and another patient group without CB or with unilateral CB. They reported that CB did not affect the left and right maxillary sinus volumes in unilateral CB cases, similar to our study and Demir et al. [27]. However, they found larger right and left maxillary sinus volumes in bilateral CB cases compared with unilateral CB cases or patients without CB. In their study, the patients did not have a homogeneous age (range 18–97 years) or sex distribution. Maxillary sinus volume can vary according to age and sex, as seen in our study and many other studies [5, 9, 11–17]. The nonhomogeneous patient distribution may have affected the outcome of their comparisons performed in independent groups. We consider that a new study taking age and sex distributions into consideration may provide more reliable results when assessing the effect of bilateral CB on maxillary sinus volume.

Impacted teeth cause many complications [49]. To the best of our knowledge, no previous studies have investigated the relationship between impacted maxillary premolars or molars and maxillary sinus volume. In the present study, bilateral maxillary sinus volumes were compared in patients with unilateral impacted teeth. Although no significant difference was detected between the two sides, maxillary sinus volumes were smaller on the same side as the impacted teeth than on the contralateral side. Based on this result, we believe that impacted teeth may have a negative effect on maxillary sinus volume.

Many authors have reported that maxillary sinus pneumatization occurs after posterior maxillary tooth extraction [50, 51]. Nevertheless, there are only a few studies on the relationship of maxillary sinus volume with missing maxillary molars or premolars. Cho et al. [9] suggested that periodontitis and premolar or molar loss did not affect maxillary sinus volume. Ariji et al. [20] reported that the mean maxillary sinus volume of dentate patients was significantly greater than that of edentulous patients. However, when they took the age distribution into consideration, there was no significant difference in volume between dentate and edentulous patients. Takahashi et al. [23] reported a trend toward a reduction in maxillary sinus volume with molar loss, based on research using elderly Japanese cadavers. Velasco-Torres et al. [52] observed that total maxillary sinus volume was significantly smaller in total and partially edentulous patients than in dentate patients. These studies compared maxillary sinus volumes in a pool of patients rather than in the same patients. This can lead to reduced accuracy, because maxillary sinus volume varies with age and sex. Therefore, we compared bilateral maxillary sinus volumes in patients with unilaterally missing maxillary premolars or molars to avoid the effects of age and sex on sinus volume. While the mean maxillary sinus volume was smaller on the same side as the missing teeth than on the contralateral side in patients aged ≤ 20 years, it was larger in patients aged > 20 years. However, no significant difference was observed in both groups. According to our findings, missing maxillary premolars or molars may negatively affect sinus volume and its development in patients aged ≤ 20 years, but may have a positive effect on sinus volume in patients aged > 20 years because of sinus pneumatization.

A limitation of this study is that the numbers of patients with unilaterally impacted or missing maxillary premolars and molars were relatively small. We believe that further studies with larger sample sizes are required to clarify the association between impacted or missing maxillary posterior teeth and maxillary sinus volume in the general population.

In conclusion, the present study revealed a significant reduction in maxillary sinus volume on the deviation side for moderate and severe NSD. Because of insufficient growth of the maxilla and maxillary sinus, this reduction may result in dental malocclusion and maxillary asymmetry. Our findings suggest that CB has no association with maxillary sinus volume. Impacted or missing maxillary premolars and molars may be related to maxillary sinus volume. Further research should focus on maxillary sinus volume in patients with impacted or missing maxillary premolars and molars.

Acknowledgements This study was supported by Izmir Katip Celebi University Scientific Research and Project Coordinatorship, Turkey (Project No: 2015-TDR-SABE-0013). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Compliance with ethical standards

Conflict of interest Fahrettin Kalabalık and Elif Tarım Ertaş declare that they have no conflict of interest.

Human rights statement All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions.

Informed consent Informed consent was obtained from all patients for being included in the study.

Animal rights statement This article does not contain any studies with animal subjects performed by any of the authors.

References

1. Harris AM, Wood RE, Nortje CJ, Thomas CJ. The frontal sinus: forensic fingerprint? A pilot study. J Forensic Odontostomatol. 1987;5:9–15.
2. Ruprecht A, Lam EWN. Paranasal sinus diseases. In: White SC, Pharoah MJ, editors. Oral radiology: principles and interpretation. 7th ed. St. Louis: Mosby Elsevier; 2014. p. 472–91.
3. Orhan K, Aksoy S, Oz U. CBCT imaging of paranasal sinuses and variations. In: Gendeh BS, editor. Paranasal sinuses. 1st ed. London: InTech; 2017. p. 57–77.
4. Kamburoğlu K, Schulze D, Murat S, Melo SLS, Li Z, Bornstein MM, et al. CBCT imaging of sinonasal disease. In: Scarfe WC, editor. Maxillofacial cone beam computed tomography. Louisville: Springer; 2018. p. 1155–205.
5. Jun BC, Song SW, Park CS, Lee DH, Cho KJ, Cho JH. 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;132:429–34.
6. Scuderi AJ, Harnsberger HR, Boyer RS. Pneumatization of the paranasal sinuses: normal features of importance to the accurate interpretation of CT scans and MR images. AJR Am J Roentgenol. 1993;160:1101–4.
7. Graney DO, Rice DH. Anatomy. In: Cummings CW, Harker LA, Krause CJ, Schuller DE, editors. Otolaryngology: head and neck surgery. 2nd ed. St. Louis: Mosby Elsevier; 1993. p. 901–6.
8. Clemente MP. Surgical anatomy of the paranasal sinus. In: Levine HL, Clemente MP, editors. Sinus surgery: endoscopic and microscopic approaches. New York: Thieme; 2005. p. 1–56.
9. Cho SH, Kim TH, Kim KR, Lee JM, Lee DK, Kim JH, et al. Factors for maxillary sinus volume and craniofacial anatomical features in adults with chronic rhinosinusitis. Arch Otolaryngol Head Neck Surg. 2010;136:610–5.
10. Brito TP, Pinheiro LAM, Silva VG, Zappelini CEM, Maunsel RCK, Gusmão RJ. Maxillary sinus asymmetry in children: report of two cases and literature review. J Rhinol Otol. 2013;1:63–7.
11. Sahlstrand-Johnson P, Jannert M, Strombeck A, Abul-Kasim K. Computed tomography measurements of different dimensions of maxillary and frontal sinuses. BMC Med Imaging. 2011;11:8.
12. Teke HY, Duran S, Canturk N, Canturk G. Determination of gender by measuring the size of the maxillary sinuses in computerized tomography scans. Surg Radiol Anat. 2007;29:9–13.
13. Gosau M, Rink D, Driemel O, Draenert FG. Maxillary sinus anatomy: a cadaveric study with clinical implications. Anat Rec (Hoboken). 2009;292:352–4.
14. Kim J, Song SW, Cho JH, Chang KH, Jun BC. Comparative study of the pneumatization of the mastoid air cells and paranasal sinuses using three-dimensional reconstruction of computed tomography scans. Surg Radiol Anat. 2010;32:593–9.
15. Ekizoglu O, Inci E, Hocaoglu E, Sayin I, Kayhan FT, Can IO. The use of maxillary sinus dimensions in gender determination: a thin-slice multidetector computed tomography assisted morphometric study. J Craniofac Surg. 2014;25:957–60.
16. Fernandes CL. Volumetric analysis of maxillary sinuses of Zulu and European crania by helical, multislice computed tomography. J Laryngol Otol. 2004;118:877–81.
17. Emirzeoglu M, Sahin B, Bilgic S, Celebi M, Uzun A. Volumetric evaluation of the paranasal sinuses in normal subjects using computer tomography images: a stereological study. Auris Nasus Larynx. 2007;34:191–5.
18. Cohen O, Warman M, Fried M, Shoffel-Havakuk H, Adi M, Halperin D, et al. Volumetric analysis of the maxillary, sphenoid and frontal sinuses: a comparative computerized tomography based study. Auris Nasus Larynx. 2018;45:96–102.
19. Saccucci M, Cipriani F, Carderi S, Di Carlo G, D'Attilio M, Rodolfino D, et al. Gender assessment through three-dimensional analysis of maxillary sinuses by means of cone beam computed tomography. Eur Rev Med Pharmacol Sci. 2015;19:185–93.
20. Ariji Y, Kuroki T, Moriguchi S, Ariji E, Kanda S. Age changes in the volume of the human maxillary sinus: a study using computed tomography. Dentomaxillofac Radiol. 1994;23:163–8.
21. Karakas S, Kavakli A. Morphometric examination of the paranasal sinuses and mastoid air cells using computed tomography. Ann Saudi Med. 2005;25:41–5.
22. Masri AA, Yusof A, Hassan R. A three dimensional computed tomography (3D-CT): a study of maxillary sinus in Malays. CJBAS. 2013;1:125–34.
23. Takahashi Y, Watanabe T, Iimura A, Takahashi O. A study of the maxillary sinus volume in elderly persons using Japanese cadavers. Okajimas Folia Anat Jpn. 2016;93:21–7.
24. Orhan I, Ormeci T, Aydin S, Altin G, Urger E, Soylu E, et al. Morphometric analysis of the maxillary sinus in patients with nasal septum deviation. Eur Arch Otorhinolaryngol. 2014;271:727–32.
25. Kapusuz Gencer Z, Ozkiris M, Okur A, Karacavus S, Saydam L. The effect of nasal septal deviation on maxillary sinus volumes and development of maxillary sinusitis. Eur Arch Otorhinolaryngol. 2013;270:3069–73.
26. Kucybala I, Janik KA, Ciuk S, Storman D, Urbanik A. Nasal septal deviation and concha bullosa—do they have an impact on maxillary sinus volumes and prevalence of maxillary sinusitis? Pol J Radiol. 2017;82:126–33.
27. Demir UL, Akca ME, Ozpar R, Albayrak C, Hakyemez B. Anatomical correlation between existence of concha bullosa and maxillary sinus volume. Surg Radiol Anat. 2015;37:1093–8.
28. Karatas D, Koc A, Yuksel F, Dogan M, Bayram A, Cihan MC. The effect of nasal septal deviation on frontal and maxillary sinus volumes and development of sinusitis. J Craniofac Surg. 2015;26:1508–12.
29. Rak KM, Newell JD 2nd, Yakes WF, Damiano MA, Luethke JM. Paranasal sinuses on MR images of the brain: significance of mucosal thickening. AJR Am J Roentgenol. 1991;156:381–4.
30. Bhandary SK, Kamath PS. Study of relationship of concha bullosa to nasal septal deviation and sinusitis. Indian J Otolaryngol Head Neck Surg. 2009;61:227–9.
31. Elahi MM, Frenkiel S, Fageeh N. Paraseptal structural changes and chronic sinus disease in relation to the deviated septum. J Otolaryngol. 1997;26:236–40.
32. Bolger WE, Butzin CA, Parsons DS. Paranasal sinus bony anatomic variations and mucosal abnormalities: CT analysis for endoscopic sinus surgery. Laryngoscope. 1991;101:56–64.
33. Evans R. Incidence of lower second permanent molar impaction. Br J Orthod. 1988;15:199–203.

34. Uchida Y, Goto M, Katsuki T, Akiyoshi T. A cadaveric study of maxillary sinus size as an aid in bone grafting of the maxillary sinus floor. J Oral Maxillofac Surg. 1998;56:1158–63.
35. Anagnostopoulou S, Venieratos D, Spyropoulos N. Classification of human maxillar sinuses according to their geometric features. Anat Anz. 1991;173:121–30.
36. Barghouth G, Prior JO, Lepori D, Duvoisin B, Schnyder P, Gudinchet F. Paranasal sinuses in children: size evaluation of maxillary, sphenoid, and frontal sinuses by magnetic resonance imaging and proposal of volume index percentile curves. Eur Radiol. 2002;12:1451–8.
37. Panou E, Motro M, Ates M, Acar A, Erverdi N. Dimensional changes of maxillary sinuses and pharyngeal airway in Class III patients undergoing bimaxillary orthognathic surgery. Angle Orthod. 2013;83:824–31.
38. Lopes de Rezende Barbosa G, Pimenta LA, Pretti H, Golden BA, Roberts J, Drake AF. Difference in maxillary sinus volumes of patients with cleft lip and palate. Int J Pediatr Otorhinolaryngol. 2014;78:2234–6.
39. Ikeda A, Ikeda M, Komatsuzaki A. A CT study of the course of growth of the maxillary sinus: normal subjects and subjects with chronic sinusitis. ORL J Otorhinolaryngol Relat Spec. 1998;60:147–52.
40. Bhushan B, Rychlik K, Schroeder JW Jr. Development of the maxillary sinus in infants and children. Int J Pediatr Otorhinolaryngol. 2016;91:146–51.
41. Weiglein A, Anderhuber W, Wolf G. Radiologic anatomy of the paranasal sinuses in the child. Surg Radiol Anat. 1992;14:335–9.
42. Aydin S, Taskin U, Orhan I, Altas B, Oktay MF, Toksoz M, et al. The analysis of the maxillary sinus volumes and the nasal septal deviation in patients with antrochoanal polyps. Eur Arch Otorhinolaryngol. 2015;272:3347–52.
43. Sooknundun M, Kacker SK, Bhatia R, Deka RC. Nasal septal deviation: effective intervention and long term follow-up. Int J Pediatr Otorhinolaryngol. 1986;12:65–72.
44. Vig KW. Nasal obstruction and facial growth: the strength of evidence for clinical assumptions. Am J Orthod Dentofac Orthop. 1998;113:603–11.
45. Laptook T. Conductive hearing loss and rapid maxillary expansion. Report of a case. Am J Orthod. 1981;80:325–31.
46. Baccetti T, Franchi L, Cameron CG, McNamara JA Jr. Treatment timing for rapid maxillary expansion. Angle Orthod. 2001;71:343–50.
47. Moss-Salentijn L. Melvin L. Moss and the functional matrix. J Dent Res. 1997;76:1814–7.
48. Peric A, Sotirovic J, Baletic N, Kozomara R, Bijelic D, Rasic D. Concha bullosa and the nasal middle meatus obstructive syndrome. Vojnosanit Pregl. 2008;65:255–8 **(in Serbian)**.
49. Frank CA. Treatment options for impacted teeth. J Am Dent Assoc. 2000;131:623–32.
50. Raja SV. Management of the posterior maxilla with sinus lift: review of techniques. J Oral Maxillofac Surg. 2009;67:1730–4.
51. Sharan A, Madjar D. Maxillary sinus pneumatization following extractions: a radiographic study. Int J Oral Maxillofac Implants. 2008;23:48–56.
52. Velasco-Torres M, Padial-Molina M, Avila-Ortiz G, Garcia-Delgado R, O'Valle F, Catena A, et al. Maxillary sinus dimensions decrease as age and tooth loss increase. Implant Dent. 2017;26:288–95.