A Retrospective Evaluation of Factors Influencing the Volume of Healthy Maxillary Sinuses Based on CBCT Imaging

The aim of this study was to evaluate the factors influencing the volume of healthy maxillary sinuses by means of cone beam computed tomography (CBCT). The sinus volumes in bilateral CBCT images of healthy maxillary sinuses of patients aged 18 years or older were evaluated using dedicated 3D volumetric software. Differences in volume based on gender, age, sinus side, and dental status were analyzed statistically. The study included 174 healthy maxillary sinuses in 87 patients (60 women and 27 men) aged between 18 to 82 years with a mean age of 29.5 years. There were 73 dentate sinuses and 101 partially dentate or edentulous sinuses. Males had significantly larger maxillary sinus volumes compared to females. Subjects below the median age of 24.3 years had a significantly larger sinus volume than older subjects. There was no difference in sinus volume between left and right sides. When partially dentate and edentulous cases were pooled together and compared to dentate cases, there was no difference in sinus volume. Gender and age influence healthy maxillary sinus volume, while sinus side and dental status do not. Neither tooth loss nor increasing age could be correlated with ongoing pneumatization of the maxillary sinus in the present population. Thus, the reported increase of the maxillary sinus volume over life and following extraction of posterior teeth in the upper jaw might be considered a misconception. To prove this hypothesis, prospective studies comparing sinus volumes using standardized time intervals before and after tooth extraction in the posterior maxilla are needed.


Cone beam computed tomography (CBCT) has been recommended as the diagnostic method of choice to evaluate alveolar bone in the posterior maxilla and assess health or pathology of the maxillary sinus prior to dental implant placement.1–4 Three-dimensional (3D) imaging can improve sinus floor elevation (SFE) procedure planning by detecting potential intra- or postoperative problems. CBCT holds advantages over traditional CT by offering reduced radiation, financial costs, and acquisition time without compromising image quality of maxillofacial structures.1

In dental medicine, the pneumatization of the maxillary sinus following tooth extraction has been described as a physiologic process that results in increased sinus volume and reduced alveolar bone height, thus complicating dental implant insertion.5,6 Currently, the causes of sinus pneumatization have not been clarified. While it has been noted that males tend to have larger sinus volumes than females,7 a lack of sexual dimorphism has also been reported.8 Secondly, despite the long-standing contention that tooth loss would result in maxillary sinus pneumatization6,10 and that tooth loss should correlate with advancing age, studies have found that age either has no effect6 or that its increase correlates with a decrease

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in sinus volume. None of the mentioned studies have used CBCT imaging and commercially available software for 3D volumetric measurements. Recently, a CBCT study reported no difference in sinus dimensions between dentate and edentulous posterior maxillae using a customized software.

Therefore, this study aimed to assess potential influencing factors on the volume of the maxillary sinus, including gender, age, sinus side, and dental status. The authors hypothesized that: (1) males had larger sinus volumes than females; (2) there was an increase in sinus volume with age; (3) there was no effect of sinus side on sinus volume; and (4) there was an increase of sinus volume in partially dentate and edentulous cases following tooth loss.

Materials and Methods

Patient Population

This retrospective study searched all CBCT images (ProMax 3D Mid, Planmeca Oy) of patients referred to the Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, The University of Hong Kong from January 2016 to March 2017. The imaging data sets were screened, applying the following inclusion criterion: patients ≥ 18 years of age with both healthy maxillary sinuses entirely visible on the CBCT scan. The detailed exclusion criteria followed those from a previous study. In addition, the CBCT images were excluded if there was pathologic change in one or both maxillary sinuses, such as thickening of the Schneiderian membrane > 4 mm, semispheric thickening of the membrane, complete opacification of the sinus, mixed flat and semispherical thickenings, or other changes (eg, bone destruction, cyst, aspergilloma, foreign body, suspected neoplasia).

The collected demographic data of the patients included gender, age at the time of imaging, and status of the dentition. The study followed the guidelines of the Declaration of Helsinki. The study protocol was approved by the local institutional review board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (approval number UW 16-495).

Radiographic Image Analysis

CBCT images were evaluated on a Philips 223V LED monitor with a resolution of 1,920 × 1,080 pixels. Data were reconstructed with 0.5-mm-thick slices and either a 0.2- or 0.4-mm voxel size. Image analysis was performed using a dedicated software (Romexis version 4.4.0.R, Planmeca). The volumes of the healthy maxillary sinuses were calculated. First, the center of the sinus was located manually using a multi-planar-reconstruction view (Fig 1a). Then, the sinus was selected with the “measure rectangle” or “measure ellipse” tool (Fig 1b). A voxel was chosen within the air cavity, and the “region growing” tool was used to include all contiguous voxels that fell within a predefined voxel value. The default threshold was a simulated Hounsfield unit (HU) of 300. All voxels with values below this threshold were included in the volume calculation. This threshold was adjusted for each sinus on an individual basis to include the largest number of voxels within the air cavity of the maxillary sinus and to exclude as much of the voxels within the air cavities of surrounding structures, including the nasal cavity (Fig 1c). The sinus volume was rendered in 3D (Fig 1d) and calculated and recorded in cm³.

One research assistant (J.H.) performed all radiographic analyses. All measurements were performed twice with a minimum time gap of 1 month between the two assessments to test for intra-observer repeatability. An oral and maxillofacial radiologist (R.T.) performed measurements once for 50 randomly selected cases (selection completed using a number-randomizing website) to test for inter-observer reproducibility. For further data analysis, the first readings of the first observer (J.H.) were utilized.

The status of the dentition in the posterior maxilla (from first premolar to third molar) in regards to the maxillary sinus under investigation was classified as (1) dentate, (2) partially dentate (defined as loss of ≥ 1 tooth), or (3) edentulous.

Statistical Analyses

All data were first analyzed using descriptive statistics. Each sinus side was considered independent since patients may exhibit asymmetrical maxillary sinus volumes. Splitting the patients according to median age
yielded two age groups for statistical analysis (≤ 24.3 years old; > 24.3 years old). The effects of the independent variables (gender, age, sinus side, and dental status) were evaluated with parametric tests (two-sample t test and two-way analysis of variance [ANOVA]). Post hoc pairwise comparisons for significant two-way ANOVA were evaluated with Bonferroni correction. Intra- and inter-rater agreements were assessed using interclass correlation (ICC) coefficient. \( P \leq .05 \) was considered statistically significant for all tests. Statistical procedures were carried out in SPSS (version 24.0, IBM).

**Results**

**Population and Imaging Details**

A total of 537 CBCT scans were screened initially. The six included fields of view were 10 × 6 cm, 8 × 8 cm, 10 × 10 cm, 20 × 6 cm, 20 × 10 cm, and 20 × 17 cm. After the screening process, 383 CBCT scans were excluded because they did not visualize bilateral maxillary sinuses completely. An additional 67 CBCT scans were excluded because they did not include sinuses that were both considered healthy. Thus, the final study sample consisted of 87 CBCT scans, all exhibiting both healthy maxillary sinuses (a total of 174 healthy maxillary sinuses).

There were 27 males and 60 females (representing 31% and 69% of the cases, respectively) aged between 18 to 82 years with mean and median ages of 29.6 and 24.3 years, respectively (Table 1). Dividing the subjects according to median age was chosen because most subjects were within the age range of 20 to 29 years (56 of 87 subjects [64%]). Partially dentate and edentulous cases were grouped together due to the low number of edentulous cases (8 of 174 sinuses [4.6%]), and there were 73 dentate sinuses and 101 partially dentate and edentulous sinuses (42% and 58% of the cases, respectively) (Table 1). The threshold range for the volumetric analysis was determined to be between 215 to 694 HU, and the resulting average sinus volume was 17.2 cm³ with a median of 16.7 cm³ (Table 1).

**Influence of Factors on Maxillary Sinus Volumes**

Males had larger maxillary sinus volumes than females \( (P < .001) \), and subjects under the median age of 24.3 years also had larger sinus volumes than those above the median age \( (P = .014) \) (Tables 1 and 2).

There was no difference in volume between the left and right sinuses \( (P = .470; \) Tables 1 and 2). When partially dentate and edentulous cases were pooled together and compared to dentate cases, dental status showed no differences in sinus volume \( (P = .537; \) Tables 1 and 2; Fig 2). There was
no significant interaction between gender, age, and dental status with maxillary sinus volume (all $P > .05$; Table 3).

**Intra-Observer Repeatability and Inter-Observer Reproducibility**

Intra-observer reliability exhibited almost perfect agreement with an ICC coefficient value of 0.985 ($P < .001$) for the volume of the maxillary sinuses. Inter-observer reproducibility (with the research assistant’s first set of readings) also exhibited almost perfect agreement, with an ICC coefficient value of 0.996 ($P < .001$) for the volume of the maxillary sinuses. Additionally, the inter-observer reproducibility with the research assistant’s second set of readings resulted in the same ICC coefficient value of 0.996 ($P < .001$).

**Discussion**

To the best of the authors’ knowledge, this is the first study using CBCT imaging and a semi-automated software for 3D volumetric analyses of the maxillary sinus as opposed to the traditional methods of linear measurements and respective formulas to calculate volume. Results of this study suggest that gender and age were related to maxillary sinus volume, while sinus side and dental status (tooth loss) were not. The phenomenon of pneumatization following tooth loss was not confirmed in partially dentate and edentulous subjects. On the contrary, there was a decrease in maxillary sinus volume for older subjects, irrespective of the dental status.
Influence of Gender on Maxillary Sinus Volumes

In this study, it was shown that gender influenced the sinuses, as males presented larger sinus volumes than females. This is consistent with studies involving the use of multiple imaging modalities, including CT, magnetic resonance imaging, and lateral cephalograms. However, studies using CBCT imaging have found no effect regarding sexual dimorphism. Urooge and Patil evaluated the influence of gender in 50 males and 50 females using CBCT and were unable to identify differences regarding sinus length, height, area, perimeter, and volume. However, the patient pool was of a smaller age range (20 to 50 years), and the authors used a rather imprecise formula for volume calculation. One potential source of discrepancy of the findings from the present study could be attributed to differences in the average age of patients. It has been reported that sinus development reaches completion during the third decade of life for males and during the second decade for females. Meanwhile, Saccucci et al investigated patients with an average age of 24.3 ± 6.5 years, and the authors may have analyzed a greater proportion of volumetric measurements of male sinuses, which have not yet reached maximum expansion. In contrast, the mean age of patients included in the present study was slightly higher (29.6 years).

Influence of Age on Maxillary Sinus Volumes

Several studies assessing the relationship of age and sinus volume have been completed by means of CT imaging with mixed results. Ariji et al reported that sinus volume decreases after 20 years of age, and that sinus volume declined after the third decade for males and the second decade for females. These findings were similar to the present study, which observed a decrease in volume in subjects above the median age of 24.3 years. Conflictingly, three studies have reported a lack of effect of age on sinus volume; two of them used volume-calculation methods that may have been imprecise, and one calculated the sinus volumes using plaster impressions of cadavers. This contrasted the CT studies mentioned, which agreed with the present results and used more-precise surface rendering techniques or computer software to calculate sinus volumes. Additionally, the age ranges of the subjects included in the three studies that

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Comparisons of Gender and Dentition with Age Group on Maxillary Sinus Volume, Irrespective of Sinus Side</th>
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<tbody>
<tr>
<td>Gender, age group</td>
<td>Sample size</td>
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<tr>
<td></td>
<td>(% of sample)</td>
</tr>
<tr>
<td>Male, 18–24.3</td>
<td>24 (13.8%)</td>
</tr>
<tr>
<td>Male, 24.4–82</td>
<td>30 (17.2%)</td>
</tr>
<tr>
<td>Female, 18–24.3</td>
<td>64 (36.8%)</td>
</tr>
<tr>
<td>Female, 24.4–82</td>
<td>56 (32.2%)</td>
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<tr>
<td>Gender, dental status</td>
<td>Sample size</td>
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<tr>
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<td>(% of sample)</td>
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<tr>
<td>Male, dentate</td>
<td>17 (9.8%)</td>
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<tr>
<td>Male, partially dentate and edentulous</td>
<td>37 (21.3%)</td>
</tr>
<tr>
<td>Female, dentate</td>
<td>56 (32.2%)</td>
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<tr>
<td>Female, partially dentate and edentulous</td>
<td>64 (36.8%)</td>
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<td>Dental status, age group</td>
<td>Sample size</td>
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<td></td>
<td>(% of sample)</td>
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<tr>
<td>Dentate, 18–24.3</td>
<td>40 (23.0%)</td>
</tr>
<tr>
<td>Dentate, 24.4–82</td>
<td>33 (19.0%)</td>
</tr>
<tr>
<td>Partially dentate and edentulous, 18–24.3</td>
<td>47 (27.6%)</td>
</tr>
<tr>
<td>Partially dentate and edentulous, 24.4–82</td>
<td>54 (30.5%)</td>
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showed age had no effect on sinuses; were much older than the ones for both the CT studies and the present study. Taken together, the imprecise volumetric calculations and skewed age distributions may explain the discrepancies in the literature regarding the effect of age.

However, the findings of the present study have to be interpreted with some caution as approximately 70% (60 out of 87) of the subjects were female and 75% (65 out of 87) were below the age of 30. Thus, future prospective studies should recruit a more even distribution of patients with respect to gender and age to clarify any discrepancies found in related literature.

Relationship of Dental Status on Maxillary Sinus Volumes

When partially dentate and edentulous cases were pooled and compared to dentate cases in the present study, there was a lack of effect of dental status on sinus pneumatization. Pneumatization has been defined in studies as the extension of the basal antrum of the maxillary sinus towards the alveolar ridge, or an increased depth of the sinus floor. These definitions are potentially imprecise, as Ariji and coworkers completed a CT study that showed that increases in sinus height accompanied decreases in the transverse and anteroposterior dimensions with advancing age. The same study also reported that there was no effect following tooth loss on sinus pneumatization. A recent retrospective case-control study using CBCT images reported similar findings, corroborating the present results that being edentulous exhibits no association with ongoing sinus pneumatization.

While the current study observed no pneumatization trend, one limitation was the limited number of edentulous cases included. Thus, future investigations using equal and larger samples of fully edentulous cases compared to fully dentate cases would be helpful to clarify the effect of tooth loss on sinus pneumatization. Furthermore, a prospective study design using standardized time intervals before and after tooth extraction in the posterior maxilla would be needed to validate this finding.

Intra-Observer Repeatability and Inter-Observer Reproducibility

The near-perfect intra- and inter-rater agreements have demonstrated a reliable repeatability and reproducibility of volumetrically measuring the maxillary sinus using the software described. Therefore, the software can be recommended for future research involving 3D measurements, as the high reproducibility of the results demonstrates the ease of software use between different observers.

Conclusions

Understanding the factors influencing the maxillary sinus volume is beneficial for the planning and outcome of SFE procedures through a transcrestal or lateral window technique. Based on the findings of the present radiographic study of a Hong Kong population, the following conclusions can be drawn:

- Males presented larger maxillary sinus volumes than females.
- Subjects below the median age of 24.3 years in this study presented larger maxillary sinus volumes than those above the median age.
- There was no difference in maxillary sinus volumes based on sinus side.
- When partially dentate and edentulous sinuses were pooled, there was no difference in maxillary sinus volumes. Nevertheless, with regard to the limited number of edentulous cases included and the lack of standardized time intervals before and after tooth extraction in the posterior maxilla, these findings need to be validated in future prospective studies.
- Summarizing the present findings, the factors of gender and age seem to influence healthy maxillary sinus volume, while sinus side and dental status do not. Furthermore, the semi-automated software used in the present study resulted in 3D measurements of high reproducibility, demonstrating the ease of software use for different observers.
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References


