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Is the pneumatisation of the maxillary sinus following tooth loss a reality? A retrospective analysis using cone beam computed tomography and a customised software program

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Abstract

Objectives To compare the dimensions of maxillary sinuses in dentate and edentulous patients using cone beam computed tomography (CBCT) scans and a customised software program.

Materials and methods This study comprised CBCTs of 50 dentate and 50 edentulous posterior maxillae. The observers drew two planar curves in all included sinuses in the frontal, sagittal and axial planes of the respective CBCT scans. The volume (mm^3), surface (mm^2) and maximum diameter (mm) of the sinuses were calculated using a custom-made software program. The variables analysed were the influence of the state of dentition on sinus dimensions (primary outcome) and the influence of age, gender and side on sinus dimensions; the time needed for analysis; and the intra- and inter-observer agreement (secondary outcomes).

Results There was no difference in sinus dimensions between dentate and edentulous posterior maxillae. Males had significantly ($p < 0.05$) greater volume, surface and diameter than females. Strong intra- and inter-observer agreement (Pearson correlation) was found for the calculated sinus dimensions. The time needed per analysis was less than 4 min for both observers.

Conclusions Being edentulous did not have an impact on the sinus dimensions, suggesting that there is no ongoing pneumatisation in the sinus after tooth loss. Males had larger sinuses than females in a population older than 30 years.

Clinical relevance Following tooth loss in the posterior maxilla, vertical bone height is primarily lost due to resorption of the alveolar crest, and not due to pneumatisation of the maxillary sinus. The customised software program was found to be user-friendly and efficient.

Keywords Maxillary sinus · Maxillary sinus volume · Dentate posterior maxilla · Edentulous posterior maxilla · Cone beam computed tomography · Pneumatisation

Introduction

The maxillary sinus has multiple functions, which include serving as a resonance body for the voice, contributing to

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the olfactory processes and adapting the temperature and humidity of inspired air before it passes into the bronchi and lungs. The maxillary sinus is already present at birth [1], but until eruption of the permanent teeth, its size remains negligible [2]. Its size increases through pneumatisation, with final dimensions being reached around the age of 18 [3–7].

It has been reported that another type of pneumatisation takes place after tooth extraction in the posterior maxilla, supported by remodelling on the floor of the maxillary sinus [8, 9]. As a consequence, the maxillary sinus may exhibit only a paper-thin cortical bone wall basally and on its lateral sides after tooth loss, especially in elderly people [2, 9, 10]. For patients with edentulous posterior maxillae, anatomical conditions for a planned implant therapy can be challenging. Sinus floor elevation (SFE) procedures may be needed prior to or at the same time as dental implant placement [5]. Cone

beam computed tomography (CBCT) is considered an ideal imaging technique for preoperative analysis of the maxillary sinus in combination with diagnosis and treatment planning [11–14].

The aim of this study was to evaluate pneumatisation of the maxillary sinus following tooth loss. This analysis compared the volume, surface and maximum diameter of the sinuses of patients with a dentate or edentulous posterior maxilla, using CBCT and a customised software program. Secondary objectives included analysis of the influence of gender, age and sinus side on the dimensions of the maxillary sinus; the intra-observer and inter-observer variability in measurement of dimensions; and the time needed to conduct these analyses.

Material and methods

Study design and patient selection

This retrospective case-control study is based on CBCT images from patients examined in the Section of Dental Radiology and Stomatology, Department of Oral Surgery and Stomatology, University of Bern. Out of this CBCT pool, a total of 100 cases were consecutively selected during the period from October 13, 2011, to May 2, 2016. The cases were grouped into 50 dentate posterior maxillae (all teeth present in the maxilla or all teeth present posterior to the maxillary canine) and 50 edentulous posterior maxillae (all teeth missing posterior to the maxillary canine or a completely edentulous maxilla). The inclusion criteria consisted of (1) patients older than 30 years with fully developed maxillary sinuses, (2) at least one maxillary sinus completely visible in the field of view (FOV), (3) maxillary sinus and alveolar crest free of any pathology, (4) no implant or graft in the posterior maxilla, (5) maxillary sinus without signs of previous sinus surgeries, (6) a maximum of 4 mm localised or generalised mucosal thickening of the Schneiderian membrane and (7) maxillary sinuses free of artefacts (acquisition or patient related) (Fig. 1). If both sinuses were visible on the CBCT scan, the maxillary sinus to be analysed in the present study was randomly chosen by the flip of a coin.

The study protocol was approved by the local ethics committee of the state of Bern, Switzerland (approval number 384/14). The study was performed in accordance with the Declaration of Helsinki (2013 update, www.wma.net).

Radiographic imaging (CBCT) and analysis

CBCT scans were obtained using a 3D Accuitomo 170 unit (Morita Corp., Kyoto, Japan), recorded at 80 kV and 5.0 mA using variable FOVs (in cm) with the following corresponding
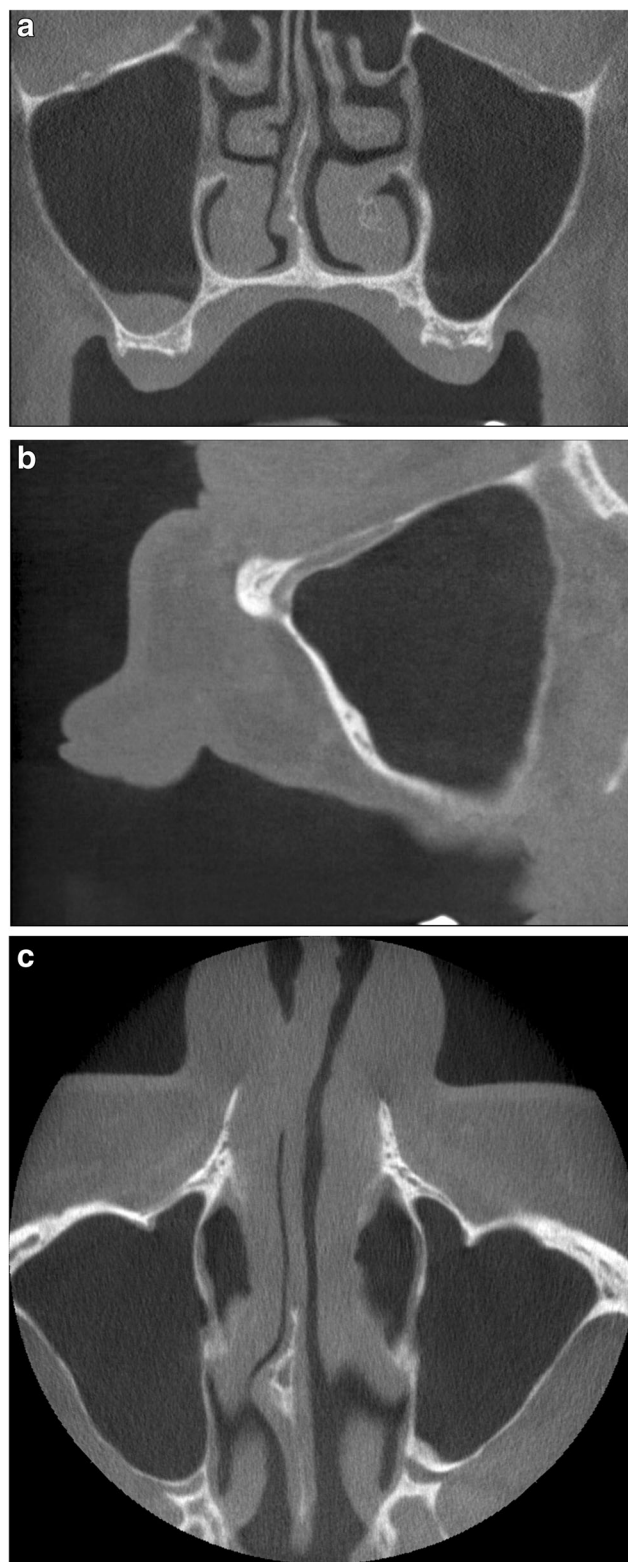

Fig. 1 CBCT images (FOV, 8 × 5 cm) of coronal (**a**), sagittal (**b**), and axial (**c**) planes of a fully visible maxillary sinus (on the left) included in this study. The right maxillary sinus did not fulfil the inclusion criteria due to > 4 mm thickening of the Schneiderian membrane

voxel sizes (in mm): 6 × 6 cm (0.125 mm), 8 × 5 cm (0.160 mm), 8 × 8 cm (0.160 mm), 10 × 5 cm (0.250 mm), 10 × 10 cm (0.250 mm), 14 × 5 cm (0.250 mm), 14 × 10 cm (0.250 mm) and 17 × 12 cm (0.250 mm). The exposure time was 17.5 s for a 360° exposition. The data were reconstructed with slices at an interval of 0.5 mm.

For the assessment of the maxillary sinus dimensions (volume/surface/maximum diameter), a customised software program was developed in collaboration with Swissmeda AG (Zürich, Switzerland) using reconstructed CBCT data sets in a DICOM format [15]. For all analyses, the software program was installed on a Dell Precision T3500 workstation (Dell, Round Rock, Texas, USA) with a 19-in. EIZO FlexScan monitor (resolution of 1280 × 1024 pixels; EIZO Nanao AG, Wädenswil, Switzerland). First, a planar curve delineating the outlines of the maxillary sinus was drawn manually for all cases. For each plane, two or a maximum of three curves were drawn (Fig. 2a–f). Based on this information about a set
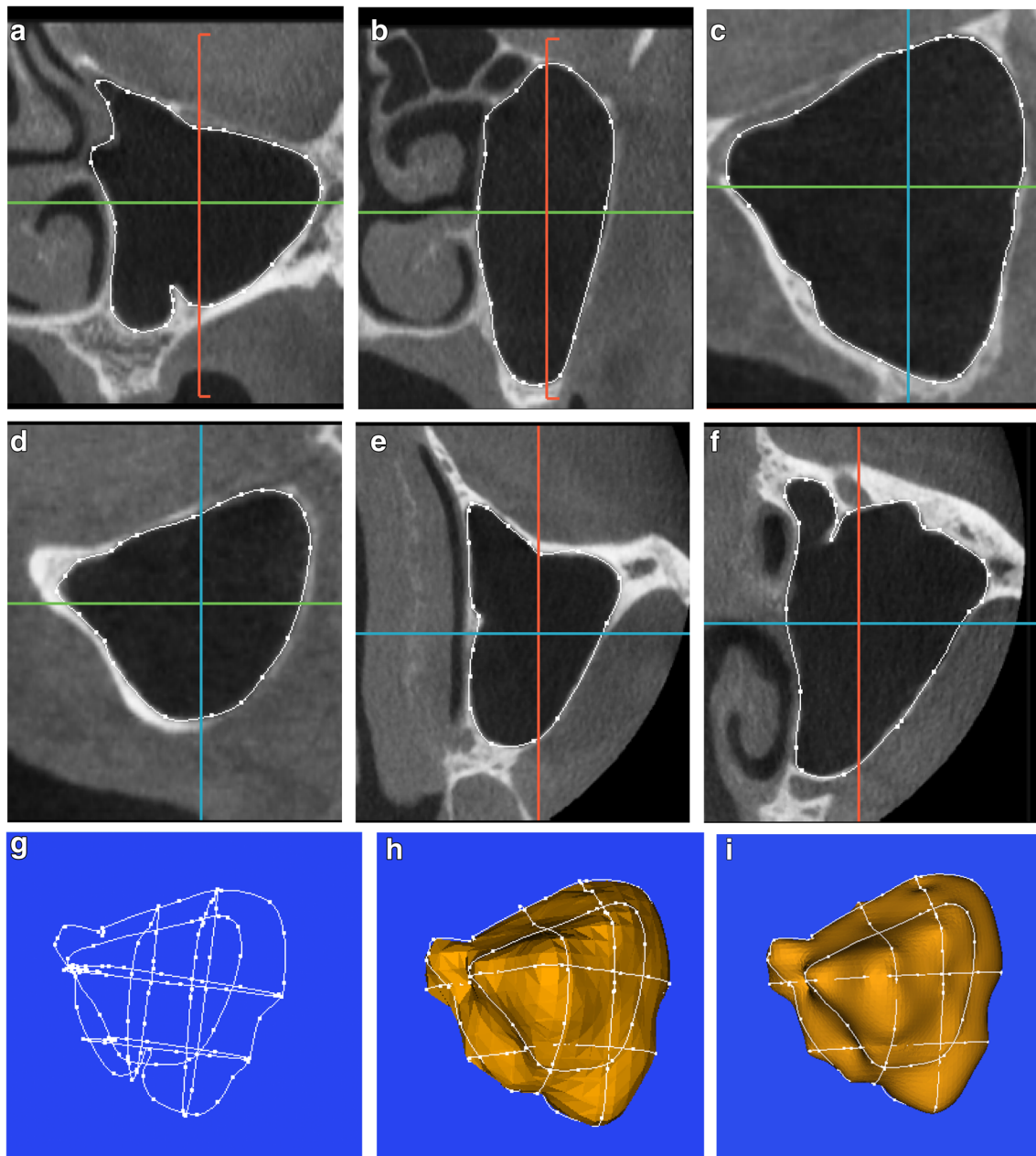

Fig. 2 A customised software program (Swissmeda AG, Zürich, Switzerland) was used to calculate the volume, surface and maximum diameter of the maxillary sinuses included. Two planar curves delineating the maxillary sinus were drawn manually in the coronal (a, b), sagittal (c, d) and axial (e, f) planes and combined for further computing (g). Three-dimensional reconstruction of the volume, surface and maximum diameter of the maxillary sinus is shown for the preview (h) and the final result (i)

of closed curves, each lying in a supporting plane, the software program estimated initial surface vectors, and the curves were adjusted at interceptions (Fig. 2g). A radial basis function with compact support was used to define an implicit form of the volume as a zero set of the radial basis function. The zero set was polygonalised by marching tetrahedrons in the bounding box of the curves. The accuracy of the volume was determined by the grid size of the marching tetrahedrons, the support grid of the radial basis functions and the sampling density of the curves [15]. For the sinus dimensions, the program produced a volume (in mm^3), a surface (in mm^2) and a maximum diameter (in mm). The software performed two outputs for each sinus. First, an initial calculation of the dimensions was generated (preview result; Fig. 2h). This was followed by a second, more time-consuming refined analysis (final result; Fig. 2i).

One calibrated and experienced observer (M.S.) performed all dimensional measurements twice to assess for repeatability (intra-observer reliability) of the values. Between the first and the second measurements, there was a time interval of at least 1 month. To test for inter-observer reliability (reproducibility), a second examiner (M.B.) independently assessed the dimensions of 20 randomly selected CBCT scans.

Statistical analysis

First, the data was analysed descriptively. For all dimensional outcomes (sinus volume, sinus surface and sinus maximum diameter), the mean, standard deviation, maximum, minimum and median were calculated. For the median, 95% confidence intervals based on the Mann-Whitney-Wilcoxon tests were determined. Linear models were used to quantify the effect of "dentate versus edentulous", "gender", "age" and "side" on the outcomes "volume", "surface" and "maximum diameter" for both software outputs (preview and final). Aberrations were calculated as relative differences of both outputs and presented as a ratio. For analysis of age as an influencing factor, the data was divided into two groups (< 62 and ≥ 62 years; median split).

For both observers, the time needed (minutes and seconds) to produce the software outputs (preview and final) for the dimensions was given as mean, standard deviation, maximum, minimum and median values. Time aberrations of both outputs were calculated as relative differences and presented as a ratio. For the median, confidence intervals (95%) based on the Mann-Whitney-Wilcoxon test were calculated.

Intra- and inter-observer agreement for volume, surface, maximum diameter of the maxillary sinuses analysed and time needed for the analysis was analysed using Pearson correlations [16].

All results were calculated with R, 3.3.3 (R Foundation for Statistical Computing, Vienna, Austria). For all tests, a p value of < 0.05 was chosen as the level of significance.

Results

Population under investigation

Of the 100 patients included, 66 were women and 34 were men (female-to-male ratio of 2:1). The mean age was 60.89 years (range 32 to 91 years; Table 1). Both maxillary sinuses were completely visible in 22 CBCT scans and only one sinus in 78. Of a total of 100 sinuses, 59 were from the right side and 41 from the left. Of the 59 right sinuses, 29 exhibited a dentate and 30 an edentulous posterior maxilla. Of the 41 left sinuses, 21 exhibited a dentate and 20 an edentulous posterior maxilla. The most frequent indication for CBCT imaging in the 100 included patients was treatment planning prior to implant placement (47%; $n = 47$).

Volumes, surfaces and maximum diameters of maxillary sinuses

The preview and final results of all patients showed mean maxillary sinus volumes of 16,260.90 and 16,511.19 mm^3, respectively. The mean surface was 3697.14 mm^2 (preview) and 3777.74 mm^2 (final), and the mean maximum diameters were 40.20 mm (preview) and 40.50 mm (final). The relative aberration between preview and final outputs was 1% for the mean surface and diameter and 2% for the mean volume (Table 2).

For the primary outcome variable, there was no association between the state of dentition (dentate/edentulous) and the volume ($p = 0.0630$), the surface ($p = 0.1278$) or the maximum diameter ($p = 0.0841$) of the maxillary sinuses analysed (Table 3). For secondary outcomes, there was no association between the dimensions of the maxillary sinuses and age or side (right/left sinus). Gender showed a significant association for sinus dimensions. Being male resulted in a significantly larger volume ($p = 0.0160$), surface ($p = 0.0083$) and diameter ($p = 0.0016$; Table 3).

Intra- and inter-observer reliability (reproducibility)

For observer I (M.S.), the Pearson correlations exhibited a strong intra-observer correlation between the first and the second sessions in terms of volume, surface and maximum diameter of the sinus analysed (Table 4). The 20 randomly selected cases analysed by observer II (M.B.) showed a strong inter-observer correlation for the dimensional values.

The time needed for the dimensional analyses was less than 4 min for all cases for both observers. Generally, observer I obtained software outputs (preview and final) faster than

Table 1 Demographic characteristics of the included patients (*n* = 100)

	Overall	Patients with dentate maxilla	Patients with edentulous maxilla*
Patients (*n*)	100	50	50
Age (years)			
Mean	60.89	53.88	67.90
Median	62.00	57.00	67.50
Maximum	91.00	81.00	91.00
Minimum	32.00	32.00	40.00
Patients in age group, *n* (%)			
< 62 years	48 (48)	36 (72)	12 (24)
≥ 62 years	52 (52)	14 (28)	38 (76)
Gender, *n* (%)			
Female	66 (66)	33 (66)	33 (66)
Male	34 (34)	17 (34)	17 (34)
Maxillary sinus, *n* (%)			
Right sinus	59 (59)	29 (58)	30 (60)
Left sinus	41 (41)	21 (42)	20 (40)

*All teeth missing posterior to the maxillary canine or fully edentulous

observer II. The mean time for obtaining previews was 122.40 s (observer I) versus 155.10 s (observer II), and the mean time for the final outputs was 177 s (observer I) versus 192 s (observer II) (Table 5). The inter-observer correlation for the time needed to obtain the preview software output showed a moderate (0.36) correlation, and that for the final software output showed a weak correlation (0.15).

Discussion

There was no significant association between the state of the dentition (dentate versus edentulous) and the volume, the surface or the maximum diameter of the included maxillary sinuses. Furthermore, secondary outcomes analysed showed no association between the dimensional measurements of the sinuses and the age or the sinus side (right/left). Gender was significantly associated with volume, surface and maximum diameter of the maxillary sinuses, with men exhibiting larger values than females. The intra- and inter-observer reliability (reproducibility) for the dimensional measurements was strong. The time needed for volume, surface and diameter analysis using the customised software program was less than 4 min for every case evaluated by both trained observers.

Until eruption of the permanent teeth, the size of the maxillary sinus remains negligible [2]. Later, the maxillary sinus expands actively, reaching its definitive shape after completion of the second dentition at the age of 13, with the end of growth of the midface and eruption of the maxillary teeth.

Around the age of 18, the maxillary sinus reaches its final size [3–7, 17].

In addition to this growth-driven pneumatisation, sinus expansion is also observed after tooth extraction in the posterior maxilla of adults due to remodelling and resorption processes on the floor of the sinus [9, 10]. It has been suggested that the presence of osteoclasts in the endosteal cells of the Schneiderian membrane allows an expansion of the sinus into the alveolar process of the maxilla following tooth loss, which may be promoted due to a lack of resistance in this region [5, 9]. Another factor contributing to this process may be reduced occlusal loading following tooth extraction in the posterior maxilla, and the resulting bone remodelling and resorption processes leading to atrophy of the alveolar process [18]. Wehrbein and Diedrich [19] suggested furthermore that pneumatisation processes are influenced by genetic factors and disposition, growth patterns and an open ostium. Some authors have stated further that a slight increase in intra-antral pressure can cause enlargement in the volume of the maxillary sinus after growth has ceased [9, 19].

The present study showed that the volume, surface and maximum diameter of the maxillary sinus are greater in males than in females. Age, side and being edentulous did not have an impact on the sinus dimensions in the present study, suggesting that there is no ongoing pneumatisation process in the sinus after tooth loss. These findings are corroborated by Uchida and co-workers [7], who analysed the volume and dimensions of 59 maxillary sinuses in 32 human cadavers by producing casts with dental impression material. As in the present study, they found no significant differences in the

Table 2 Preview and final sinus volume, sinus surface and maximum sinus diameter of all patients included (50 dentate and 50 edentulous patients)

	Preview	Final	Relative aberration*
Total patients, n	100	100	
Sinus volume (mm^3)			
Mean (maximum, minimum, SD)	16,260.90 (30,520.00, 4822.50, 5096.58)	16,511.19 (30,985.50, 4910.00, 5172.29)	0.02 (0.02, 0.02, 0.01)
Median (95% CI)	15,816.50 (15,033.00–17,058.25)	16,117.50 (15,260.00–17,329.75)	0.02
Sinus surface (mm^2)			
Mean (maximum, minimum, SD)	3697.14 (5621.50, 1668.50, 781.42)	3777.74 (5717.00, 1706.50, 801.72)	0.01 (0.02, 0.02, 0.03)
Median (95% CI)	3653.75 (3524.00–3854.50)	3732.00 (3604.75–3941.25)	0.02
Sinus diameter (mm)			
Mean (maximum, minimum, SD)	40.20 (53.50, 27.50, 4.31)	40.50 (53.50, 27.50, 4.37)	0.01 (0.00, 0.00, 0.01)
Median (95% CI)	40.00 (39.25–41.00)	40.50 (39.50–41.25)	0.01
Dentate patients, n	50	50	
Sinus volume (mm^3)			
Mean (maximum, minimum, SD)	17,116.87 (27,954.50, 4822.50, 4921.11)	17,377.94 (28,334.00, 4910.00, 4992.54)	0.02 (0.01, 0.02, 0.01)
Median (95% CI)	17,141.50 (15,788.50–18,486.00)	17,395.00 (16,025.25–18,754.75)	0.02
Sinus surface (mm^2)			
Mean (maximum, minimum, SD)	3798.30 (5164.00, 1668.50, 753.90)	3880.74 (5245.50, 1706.50, 775.67)	0.02 (0.02, 0.02, 0.03)
Median (95% CI)	3850.50 (3616.00–4030.00)	3940.75 (3688.25–4119.75)	0.02
Sinus diameter (mm)			
Mean (maximum, minimum, SD)	40.87 (49.50, 27.50, 4.38)	41.17 (50.50, 27.50, 4.45)	0.01 (0.02, 0.00, 0.02)
Median (95% CI)	40.75 (40.00–42.25)	41.25 (40.25–42.50)	0.01
Edentulous patients, n	50	50	
Sinus volume (mm^3)			
Mean (maximum, minimum, SD)	15,404.92 (30,520.00, 6082.50, 5173.75)	15,644.45 (30,985.50, 6208.50, 5252.86)	0.02 (0.02, 0.02, 0.02)
Median (95% CI)	14,453.25 (13,498.75–16,447.50)	14,657.50 (13,711.75–16,714.25)	0.01
Sinus surface (mm^2)			
Mean (maximum, minimum, SD)	3595.98 (5621.50, 2141.50, 802.78)	3674.75 (5717.00, 2184.50, 821.77)	0.02 (0.02, 0.02, 0.02)
Median (95% CI)	3549.25 (3302.50–3784.75)	3610.50 (3371.00–3870.00)	0.02
Sinus diameter (mm)			
Mean (maximum, minimum, SD)	39.52 (53.50, 32.50, 4.18)	39.83 (53.50, 32.50, 4.22)	0.01 (0.00, 0.00, 0.01)
Median (95% CI)	39.25 (38.00–40.50)	39.25 (38.50–40.75)	0.00

The values were calculated according to the mean of the first and second readings of observer I (M.S.)

*Aberrations were calculated as relative differences of preview and final values. They were presented as a ratio, where positive values indicate an increase towards the final output

volumes of maxillary sinuses with regard to side (right/left) or age, but in contrast to the present study, there was no difference in sinus volumes between genders. Ariji and co-workers [20] analysed sinus dimensions with traditional CT scans, including 194 maxillary sinuses of 115 patients ranging in age from 4 to 94. Ninety-seven patients were older than 20 years and subdivided into a dentate (133 sinuses) and an edentulous (61 sinuses) group. Similar to the present analysis, the authors found no significant difference in the mean volume between right and left sinuses. Nevertheless, they observed an increase in the maxillary sinus volume until the age of 20 years and a decrease afterwards. As in the present study, there was no significant difference in the mean volume for dentate and edentulous patients aged 50–79 years. And in contrast to the present study, no difference between genders was found in the dimensions of the sinus [20].

Limitations of the present study were the lack of a sample size calculation and that the two groups assessed (dentate and edentulous maxillae) were not matched in terms of age. Due to its retrospective nature, the limiting factor for inclusion of cases was the availability of CBCTs exhibiting an entire maxillary sinus in edentulous patients. Thus, the inclusion of 50 edentulous and 50 dentate cases was based on the assumption that if there would be no difference between the 50 cases in each group for the primary outcome, an eventual statistically significant difference of a larger sample might be of very limited clinical relevance. Furthermore, previous studies

Table 3 Factors associated with the sinus volume (in mm^3), the surface (in mm^2) and the maximum diameter (in mm) in the final software output

Measurement	Variable	*p* value
Volume (mm^3)	Dentate vs edentulous	0.0630
	Gender (female vs male)	*0.0160*
	Age (years)	0.4153
	Age groups (< 62 vs ≥ 62 years)	0.6997
	Side (right vs left)	0.1706
Surface (mm^2)	Dentate vs edentulous	0.1278
	Gender (female vs male)	*0.0083*
	Age (years)	0.4119
	Age groups (< 62 vs ≥ 62 years)	0.8219
	Side (right vs left)	0.2090
Diameter (mm)	Dentate vs edentulous	0.0841
	Gender (female vs male)	*0.0016*
	Age (years)	0.4550
	Age groups (< 62 vs ≥ 62 years)	0.7734
	Side (right vs left)	0.2231

All values were calculated using the means of the first and second readings of observer I (M.S.). Italics indicate statistical significance

either had more [20] or less [7, 19] maxillary sinuses included for volume analysis. The difference of the two groups concerning the age was because patients without teeth were generally distinctly older than patients with all teeth present in the posterior maxilla.

To quantify the progressive pneumatisation process in maxillary sinuses after tooth extraction, Wehrbein and Diedrich [19] examined 32 panoramic radiographs of adults before and during/after orthodontic space closure treatment by superimposing them. In contrast to the present study, the authors found progressive pneumatisation in the maxillary sinus, especially in the molar region. Nevertheless, these results have to be interpreted with caution, as panoramic radiographs have limited diagnostic capability and poor reliability for detecting anatomic structures in maxillary sinuses [19, 21–23].

The resorption process after tooth extraction in the upper posterior region can be so pronounced that the alveolar ridge disappears nearly completely. Then, only a paper-thin cortical basal and lateral bone wall remains on the sinus [2, 9, 10]. Implant therapy will be more challenging in such atrophic cases, as SFE procedures may be needed for dental implant placement [10, 24]. When SFE procedures are needed and in all complex implant cases, a preoperative CBCT is advantageous. It delivers detailed radiographic visualisation and determination of ridge dimensions, allows examination of the maxillary sinus and related anatomical structures and pathologies and has been recommended in recent guidelines [14, 25, 26]. Furthermore, maxillary sinus diagnostics using CBCT imaging have also been suggested for the analysis of oro-antral communications to localise dislocated foreign bodies and teeth in the maxillary sinus and before apical surgery [19, 27–30].

Recent studies have also measured volumes in CBCTs using different software calculations, for example volume changes before and after grafting procedures like SFE, volume of extraction sockets or volume of intra-osseous pathologies like cysts [15, 31–33]. In the study by Suter and co-workers [15], the methodology used to assess dimensions of nasopalatine duct cysts was similar to that of the present study [15]. To the best of our knowledge, there are not many options yet to work with a semi-automated software program generating three-dimensional volume calculations based on CBCT images, without relying on a subtraction technique or on stacking multi-segmented 2D slices. For this study, the semi-automated software program used by Suter and co-workers [15] was further refined to make it suitable for sinus volume calculations and to

Table 4 Intra-observer (first versus second analyses of observer I) and inter-observer (mean first/second readings of observer I versus observer II) agreement for sinus volume, surface and maximum diameter for all patients and for dentate/edentulous patients

	All patients (*n* = 100); preview, final	Dentate patients (*n* = 50); preview, final	Edentulous patients (*n* = 50); preview, final
Sinus volume			
Intra-observer	0.9954, 0.9950	0.9947, 0.9940	0.9958, 0.9957
Inter-observer	0.9947, 0.9945	0.9982, 0.9982	0.9916, 0.9920
Sinus surface			
Intra-observer	0.9851, 0.9581	0.9826, 0.9503	0.9868, 0.9639
Inter-observer	0.9838, 0.9653	0.9911, 0.9651	0.9817, 0.9809
Sinus diameter			
Intra-observer	0.9677, 0.9650	0.9750, 0.9753	0.9593, 0.9526
Inter-observer	0.9697, 0.9698	0.9891, 0.9852	0.9315, 0.9521

Table 5 Time needed (in s) by observer I (mean between first and second sessions) and observer II to generate preview and final dimensional output data

	Preview (s)	Final (s)	Aberration
Observer I			
Time			
Mean	122.40	155.10	0.29
Maximum	180.00	240.00	1.00
Minimum	60.00	120.00	0.00
SD	21.18	25.25	
Median	120.00	150.00	
95% CI	120.00–120.00	150.00–165.00	
Observer II			
Time			
Mean	177.00	192.00	0.10
Maximum	240.00	240.00	0.50
Minimum	120.00	120.00	0.00
SD	30.63	31.39	
Median	180.00	180.00	
95% CI	150.00–180.00	150.00–210.00	
Interrater correlation between observers I and II	0.36	0.15	

Aberrations were calculated as relative differences of preview and final values. They were presented as a ratio, where positive values indicate an increase towards the final output. Correlation: $r \leq 0.1$ (no correlation), $0.1 < r \leq 0.3$ (weakly positive), $0.3 < r \leq 0.8$ (moderately positive) and $0.8 < r \leq 1$ (strongly positive)

generate accurate and not too time-consuming outputs. This is of importance as computer-aided diagnostic software options will only be integrated in daily clinical practice if they are easy to use and do not result in a loss of time.

Therefore, the time needed for the dimensional analyses until result output was also measured in this study. Observer I was faster than observer II, with a moderate inter-observer correlation for the preview and a weak inter-observer correlation for the final output. The first observer was an experienced clinician trained specifically in the use of this software program. The second observer was an experienced clinician too, but not particularly trained in the use of this specific software. While observer I measured the 100 cases twice, observer II only measured 20 randomly selected sinuses once. The intra-observer reliability (repeatability) for the volume, surface and maximum diameter software outputs (preview and final) exhibited strong values (0.99, 0.99), which were similar to the inter-observer reproducibility (0.99, 0.99). This proves the reliability of repeated measurements using this customised software program but also demonstrates that the software is associated with a learning curve and users may become faster in performing the measurements over time. Nevertheless, the time needed for the dimensional analyses based on CBCT scans was less than 4 min for all cases

included by both observers, which seems to be a reasonable time for daily use in clinical practice as well. Interestingly, the time needed to perform a specific procedure is one of the major thresholds for implementation in daily practice.

Conclusions

On the basis of the data analysed in the present study, the following can be concluded:

- The state of dentition (dentate versus edentulous) in the posterior maxilla did not influence the volume, surface or diameter of the maxillary sinus in an analysis based on CBCT scans.
- Patient age had no significant influence on the sinus dimensions in a pool of patients older than 30 years.
- Being male had a significant influence on the sinus volume, surface and diameter.
- The time needed to analyse the volume, surface and diameter of sinuses based on CBCT scans and with the help of a customised software program was less than 4 min for all cases included by two trained observers, and there was a strong intra- and interrater correlation for these measurements.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was reviewed and approved by the local ethics committee of the State of Bern, Switzerland (approval number 384/14). All procedures in this retrospective study were conducted in accordance with the Declaration of Helsinki (1964) and its later amendments.

Informed consent For this type of study (retrospective study), formal consent is not required.

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