Comparison of Digital and Manual Determination of Maxillary Sinus Volume: A CBCT Study

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Abstract

To compare digital and manual mathematical methods in determining the volume of the maxillary sinus when utilizing CBCT scans, as well as to determine any differences in maxillary sinus volume regarding gender, patient's edentulous status and age.

A retrospective CBCT study of 247 patients was conducted (336 maxillary sinuses) to measure the maxillary sinus volume (MSV) and the supero-inferior and bucco-palatal dimensions of 639 residual ridges and the inferior cortical thickness of the maxillary sinus, at the Imam Abdulrahman bin Faisal University Dental Hospital, Dammam, Saudi Arabia. The MSV was done digitally by using OsiriX MD imaging software version (10.0), and mathematically by means of the pyramid equation: (Superoinferior x Anteroposterior x Mediolateral /3). Comparative and descriptive statistical analyses were performed using SPSS statistics version 22. The association between exposure and outcome was assessed using the student's t-test. Examiners' reliability and reproducibility were assessed by Cronbach's alpha, Intraclass correlation and Cohen's kappa tests. P-value of <0.05 was considered to be statistically significant.

There was a significant difference in the MSV between sinuses measured digitally (OsiriX MD software) and mathematically (13.87 cm3 and 9.51 cm3 respectively). Most sub-sinus residual ridge sites (79.6%) had a height of ≥5 mm.

Digital measurements of sinus volume are significantly more reliable than mathematical measurements. There were no significant differences in MSV regarding gender, patient's edentulous status and age.

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Introduction

The maxillary sinuses are the largest and the first paranasal sinuses to develop. They are pyramidal-shaped structures that have multiple functions including the warming of inhaled air and lightening the weight of the cranium.[1,2] However, assessing sinus anatomy and width is essential before planning complex surgical procedures in the posterior maxilla. Paranasal sinuses undergo the physiological process of pneumatization, whereby changes in sinus volume and topography become evident.

Comprehending sinus pneumatization will avoid serious complications that may occur during dental implant procedures, such as oro-antral communication and Schneiderian membrane perforation.[3] In the posterior maxilla, alveolar bone resorption after tooth loss can lead to a significant decrease in total bone height. This bone resorption has been found to be greatest during the first 6-24 months following tooth extraction.[4] This may limit the placing of dental implants and necessitate further surgical procedures including complex maxillary sinus augmentation (also known as sinus floor elevation).[5]

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Maxillary sinus augmentation is one of the most commonly used methods in managing the atrophic posterior maxilla prior to dental implant placement.[6] The procedure includes elevating the pneumatized membrane of the maxillary sinus allowing for space creation just superior to the sub-sinus residual ridge.[6] Furthermore, the procedure creates a suitable vertical dimension of the alveolar bone for successful osseointegration of a standard length implant.[7,8] There are two main techniques utilized in maxillary sinus augmentation. Firstly, the lateral window approach as described by Boyne and James in 1980.[9] Secondly, the osteotome-mediated sinus floor elevation procedure, as initially described by Tatum in 1986[10] and eventually modified by Summers in 1994, which includes the additional use of a set of specific osteotomes.[11] Determination of the technique of sinus augmentation is dependent on multiple factors; a major factor being the height of the sub-sinus residual ridge. Therefore, the pre-surgical radiographic interpretation of the residual ridge height aids in determining which sinus augmentation technique should be utilized.[12] If the residual ridge height is less than 5 mm, it is recommended to perform the lateral window technique. However, if the residual ridge level is 5 mm or above in height; then the osteotome-mediated crestal approach is considered to be the treatment of choice.[13-17]

In the last decade, CBCT has been recommended as an excellent tool for visualizing the dentomaxillary structures. Utilizing CBCT as a reliable diagnostic tool is thus advantageous for better treatment planning and visualization of the maxillary sinus and alveolar ridge.[18] Along with the benefits of providing clear radiographs, CBCT emits much less radiation than conventional CT scans.[19,20] Several studies have evaluated residual ridge and maxillary sinus volume (MSV) using mathematical (manual) methods, and other studies have utilized digital software, including the Simplant, SYNGO, and SMOP systems.[21-23] Studies in the medical field have shown reliability of OsiriX MD software in measuring 3D objects and length.[24] A few studies have utilized OsiriX MD software for MSV measurements in maxillofacial research.[23,25]

The aim of this study was therefore to compare digital (OsiriX MD software system) and mathematical methods in the assessment of the MSV and the linear dimensions thereof when utilizing CBCT scans, as well as to determine any differences in MSV regarding gender, patient's edentulous status and age.

Materials and methods

A retrospective Cross-sectional CBCT analysis study was conducted at the Imam Abdulrahman bin Faisal University Dental Hospital that included patients presenting at the dental hospital, and who had undergone Cone Beam Computed Tomography imaging between October 2015 and October 2019.

The study was approved and registered with the research unit ethical committee of IAU College of Dentistry. All patients gave their informed consent at the time of registration, regarding the possible use of their unidentified clinical or radiographical information for research purposes.

Data collection: One thousand nine hundred and thirty (1930) maxillary sinuses were screened from 965 patients' CBCT images taken during the time period from October 2015 to October 2019. However, only 336 maxillary sinuses and 639 residual ridges of missing maxillary posterior teeth from 247 patients met the study inclusion criteria.

All CBCT images were obtained utilizing the Cone Beam Computed Tomography machine (Carestream CS 9300, Carestream Health Inc., Kodak, Rochester, NY, USA) at the Imam Abdulrahman bin Faisal University Dental Hospital. The CBCT radiographic parameters were set at 70 kVp, 10 mA and 14.3 second scan time according to the manufacturer's recommended settings. The voxel size was 300 x 300 µm isotropic. Large Field of View (16.5 cm diameter by 13 cm length) scan imaging was only included that covered all the paranasal sinuses and nasal cavity. Demographic data were obtained from the logbook of CBCT request files. Inclusion criteria were patients aged above 25 years, images viewed of one or more missing posterior maxillary teeth, images with clear anatomical landmarks of the maxillary sinuses and absence of any sinus pathoses or sinus obliteration.

Exclusion criteria included inadequately defined images, blurry (motion) artifacts, fully dentate patients, loss of osteomeatal unit's patency, complete septation of the sinus, history of previous sinus surgeries, presence of sinus pathology, and a mucosal lining thickness of >3 mm.

Diagnostic material: Two investigators performed all measurements on images under the supervision of an oral and maxillofacial radiologist to ensure the validity of measurement methods. The process was repeated after three weeks for further assurance of validity. Ten CBCT scans were examined each day, this was to avoid visual fatigue and to ensure the examiner's ability to analyze radiographs reliably. The MSV measurement was done digitally by using OsiriX MD imaging software version (10.0) (Bernex, Switzerland), and mathematically by means of the pyramid equation: (Superoinferior x Anteroposterior x Mediolateral /3).

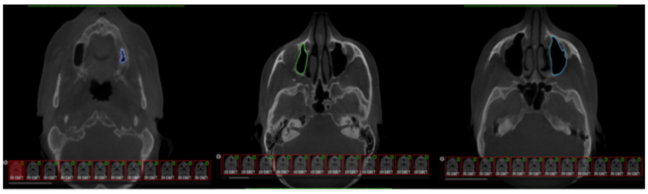

Figure 1. An axial section of three different samples. Sinus borders were traced on every fifth slice by the investigator, starting from the most inferior until the most superior border. The generation of automatic tracing by using software for untraced slices was then performed and followed-up by investigator revision. One scroll between slices accounted for 0.3mm thickness. Ultimately, a 3D (three dimensional) object representing the maxillary sinus was generated.

The MSV was measured on the axial section by tracing the sinus borders on each slice (Figure 1). Ultimately, the software generates a 3D object representing the maxillary sinus by combining all the slices, whereby it automatically measures the volume (Figure 2). The linear dimensions of the sinus were measured on the sagittal and coronal cross-sections by measuring the widest dimension superoinferiorly, mediolaterally and anteroposteriorly of the maxillary sinus (Figure 3). Cross-section measurements of the residual ridge height and width were performed in the edentulous area where there were missing posterior maxillary teeth. The length of the residual ridge was measured from the outer border of the sinus floor to the residual ridge crest. The width of the residual ridge was measured midway of the length from the most buccal point to the most lingual point of the residual ridge. In addition, the inferior border cortical thickness of the maxillary sinus was also measured in relation to residual ridge sites where there was at least one missing maxillary posterior tooth (Figure 4).

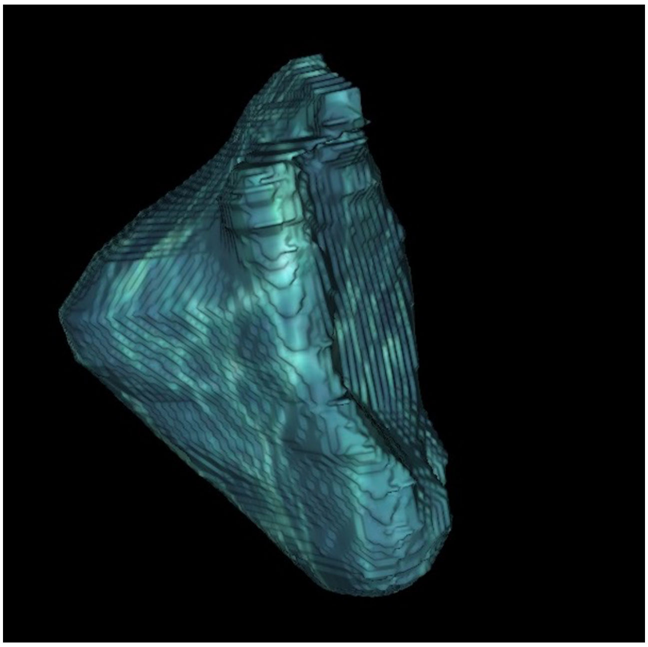

Figure 2. Software generated 3D representation of the maxillary sinus after combining all slices.

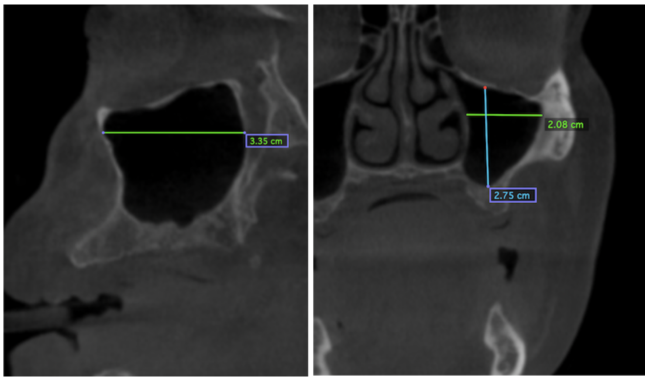

Figure 3. On the sagittal section, the anteroposterior linear dimension was measured in its widest dimension from the most posterior to the most anterior. On the coronal section, the mediolateral and superoinferior linear dimensions were measured from the most medial to the most lateral and from the most superior to the most inferior.

Viewing conditions: The analyses of images were viewed on a 23.8"W/60cm monitor (Acer, VG240Y bmiix, SNID: 93914286342, China) with a 1920x1080 resolution. The monitor was calibrated using a TG18 quality control model from the American Association of Medical Physicists (AAMP). The monitor was placed in a dim lighted room that had no windows or ambient light exposure. The room's light luminance was kept below 50 Lux (unit of illumination) and was verified and measured by a photometer (Extech Instruments. Model LT300, Boston, Massachusetts, USA) to ensure an optimal dim condition. OsiriX MD imaging software version (10.0) (Bernex, Switzerland) was used to measure and calculate the maxillary sinus volumes, linear dimensions, residual ridge height and width after exporting data from a CBCT machine.

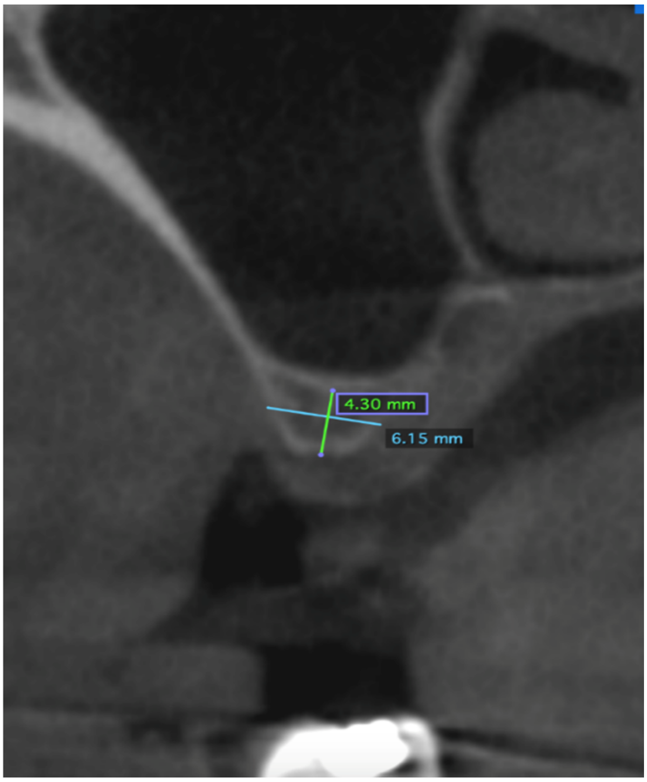

Figure 4. Cross section of edentulous area where residual ridge height, width, and inferior border cortical thickness of the maxillary sinus were measured.

Comparative and descriptive statistical analyses were performed using IBM SPSS statistics (IBM Corp, Armonk, USA) version 22 including the mean and standard deviation. The association between exposure and outcome was done using the student's t-test. A *P*-value of <0.05 was considered statistically significant. To determine examiner reliability and reproducibility, Cronbach's alpha, Intraclass correlation and Cohen's kappa tests were used. A sample of 36 cases of CBCT image evaluations, which was assessed by 3 investigators (one radiologist and two general dentists, who were trained for the images reading), was randomly selected for measurement of error.

Results

The reliability coefficient Cronbach's alpha revealed 0.998 high reliability of the observers with regards to original measurements. Inter-examiner consistency was found to be 0.995 (intra-class correlation). For measurement of inter-examiner validity and reproducibility, the difference of measured observations between the examiners was found to be ≥5%, Cohen's Kappa coefficient (k=0.664, p=0.002) showed significant inter-examiner validity and minimal error between the examiners.

Out of a total of 247 CBCT images, 140 (56.6%) were of female patients and 107 (43.4%) were of male patients. The mean age of the participants was 43.4 years (±SD=12.3), ranging from 25-73 years, which included 112 (42.3%) in the age bracket 25-39 years, 114 (46.2%) in the age bracket 20-60 years and 21 (8.5%) were aged >60 years. Of the 247 CBCT images, 166 (49.4%) involved the right sinuses and 170 (51.6%) involved the left sinuses. The majority of the participants were partially edentulous i.e. 231 (93.5%) and 16 (6.5%) were completely edentulous.

Utilizing the OsiriX MD software, the mean of the digitally measured three-dimensional sinus volume of the maxillary sinus was 13.87 cm^3 for the total sample. However, there was no significant difference in mean of the digitally measured three-dimensional sinus volume between males and females (13.79 cm^3 vs. 13.93 cm^3, respectively; *P*=0.78)

Age groups were divided into three; 25-39, 40-60 and >60 years. The mean MSV of each sinus was 14.15 cm^3, 13.34 cm^3 and 15.25 cm^3 respectively, which was found to be statistically non-significant (*p*=0.07). Moreover, there was no statistically significant difference in mean MSV between partially edentulous (13.95 cm^3) and completely edentulous patients (13.03 cm^3) (*P*=0.31). (Table 1).

The mean sinus volume using the geometric pyramid volume equation was 9.51 cm^3. There was a statistically significant difference in volume measurements between sinuses measured digitally using OsiriX MD and sinuses measured mathematically by the geometric pyramid volume equation (*P*< 0.001) (Figure 5).

		N	Digital 3D volume mean (cm^3) [SD]	*P*-value
Sinuses		336	13.87 [4.84]	-
Gender	Male	143	13.79 [5.03]	0.78*
	Female	193	13.93 [4.70]	
Age groups	25-39	138	14.15 [4.83]	0.07**
	40-60	164	13.34 [4.72]	
	>60	34	15.25 [5.20]	
Edentulous status	Partially edentulous	306	13.95 [4.87]	0.31*
	Completely edentulous	30	13.03 [4.42]	

Table 1. The mean of digitally measured three-dimensional maxillary sinus volume for different variables.

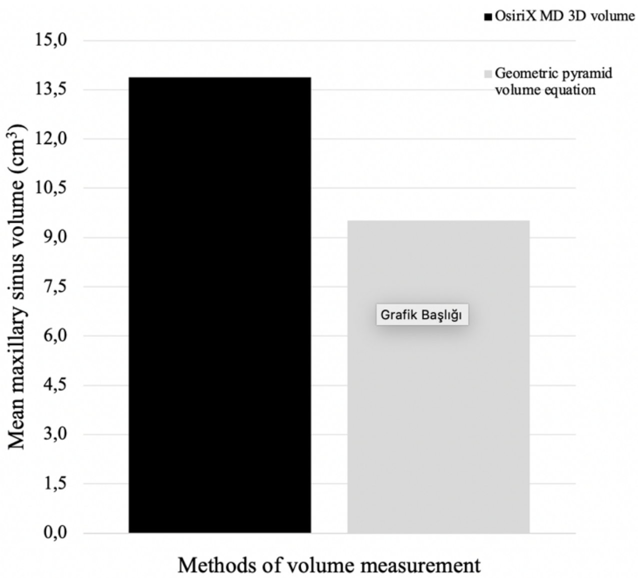

Figure 5. Comparison of the mean difference of digitally measured 3D volume by OsiriX MD software to mathematically measured pyramid volume by geometric equation.

*Significance test (T test)
P-value <0.05 is considered statistically significant

Of all included missing maxillary posterior teeth, the most frequently missing were right and left maxillary first molars (32.6%), and the least frequently missing were right and left maxillary first premolars (18.9%).

The last section of analysis included sub-sinus residual ridge measurements. The residual ridge dimensions were buccopalatally, superioinferiorly, along with the cortical plate thickness of the inferior border of the maxillary sinus in sites where there were missing posterior teeth. Regarding residual ridge atrophy, the right (7.33 mm) and left (7.07 mm) maxillary second molar areas presented with the most vertical residual ridge atrophy. Furthermore, the right (6.90 mm) and left (7.14 mm) maxillary first premolar areas presented with the most horizontal residual ridge atrophy. The mean inferior sinus border cortical thickness was 0.73 mm for all included sub-sinus residual ridge sites (Table 2).

Missing tooth	**2**			**3**			**4**			**5**		
N	74			102			61			89		
Residual ridge dimension (mm)	SI	BP	IBCT	SI	BP	IBCT	SI	BP	IBCT	SI	BP	IBCT
Mean [SD]	7.33 [3.83]	9.26 [3.12]	0.71 [0.25]	8.33 [4.51]	8.53 [3.05]	0.71 [0.24]	14.08 5.03]	6.90 [1.74]	0.78 [0.24]	11.64 [5.16]	7.37 [2.36]	0.71 [0.24]
Missing tooth	**12**			**13**			**14**			**15**		
N	60			78			106			69		
Residual ridge dimension (mm)	SI	BP	IBCT	SI	BP	IBCT	SI	BP	IBCT	SI	BP	IBCT
Mean [SD]	15.05 [5.48]	7.14 [2.14]	0.85 [0.38]	11.49 [5.21]	7.87 [2.28]	0.72 [0.26]	7.66 [3.83]	9.10 [2.58]	0.73 [0.26]	7.07 [3.62]	10.07 [2.94]	0.69 [0.22]

Table 2. Missing maxillary posterior teeth and sub-sinus residual ridge dimension (mm).
SI: Superoinferior sub-sinus residual ridge dimension.
BP: Buccopalatal sub-sinus residual ridge dimension.
IBCT: Inferior border cortical thickness of maxillary sinus.

Missing tooth	**2**		**3**		**4**		**5**	
Superoinferior sub-sinus residual ridge dimension (mm)	>5mm	≤5mm	>5mm	≤5mm	>5mm	≤5mm	>5mm	≤5mm
N (%)	76 (70.3)	26 (29.7)	52 (70.3)	22 (29.7)	77 (86.5)	12 (13.5)	57 (95)	3 (5)
Missing tooth	**12**		**13**		**14**		**15**	
Superoinferior sub-sinus residual ridge dimension (mm)	>5mm	≤5mm	>5mm	≤5mm	>5mm	≤5mm	>5mm	≤5mm
N (%)	57 (96.6)	2 (3.4)	67 (85.9)	11 (14.1)	76 (73.1)	28 (26.9)	47 (68.1)	22 (31.9)

Table 3. Prevalence of (>5 or ≤5mm) superoinferior sub-sinus residual ridge dimension in sites of missing maxillary posterior teeth.

A residual ridge height of >5 mm was found mostly in the right and left maxillary first premolar areas (95% and 96.5% respectively). Additionally, the missing maxillary second molar area had the greatest percentage of ≤5 mm residual ridge height with a mean height of 7.07 mm on the left side and 7.33 mm on the right side. The majority of sub-sinus residual ridge sites (80.3%) were found to have a height of ≥5 mm. (Table 3).

Discussion

The availability of CBCT machines in dental offices has led to a revolution in clinical practice and dental research. Moreover, the utilization of CBCT-digital software has created a valuable opportunity for researchers and clinicians to measure different anatomical structures in the human body with a high level of accuracy. In the present study, the OsiriX MD system was used to measure the maxillary sinus volume and residual ridge dimensions after extracting data from patient's CBCT images. The present study has however showed that gender, age, and edentulous status, have no impact on MSV. Moreover, software calculation of the MSV is found to be more accurate than mathematical calculations thereof. Regarding the residual ridge, the most resorbed site was found to be located in the left maxillary second molar area, presenting with a mean height of 7.07 mm. There is lack of agreement regarding the effects of age and gender on the paranasal sinuses.[26] Nonetheless, there are several studies that shed light on the effect of patient's dependent variables on MSV by means of CBCT images.[22, 26-29] However, to the best of the authors' knowledge, there are no studies which have calculated the MSV using the OsiriX MD digital system in a comparative technique of measurement.

Influence of gender on maxillary sinus volume

The results of the present study demonstrated no differences in MSV between males and females. This is consistent with the findings of other studies.[27-29] Urooge and Patil [28] evaluated 50 males and 50 females (20-50 years old) using CBCT imaging, and demonstrated no statistical differences between males and females regarding the MSV (P>0.05).[28] Another study included 200 patients; 86 males and 114 females. Patients were categorized into five groups according to age (18–24, 25–34, 35–44, 45–54, and ≥55 years) and by gender. The authors compared the MSV of males and females in each group. Only females in the 18–24 years age group demonstrated significantly larger sinus volumes as compared to males (P<0.05). However, there was no significant difference in MSV between genders in the other age groups.[29] Saccucci et al.[27] analyzed 52 patients (26 males and 26 females) with a mean age of 24.3 ± 6.5 years. They also found no statistical difference in MSV between genders (P=0.1).[27]

On the other hand, Cohen et al. calculated the volume of maxillary, sphenoid, and frontal sinuses of 201 patients whose age was ≥25 years, and concluded that all sinuses were significantly larger in men (P<0.001).[26] In contrast to the current study, they did not indicate the edentulous status of the included patients. In addition, another study analyzed 128 maxillary sinuses from 64 patients with a mean age of 46.2 years. The study concluded that males had a significantly higher mean MSV (19.0 cm^3) as compared to females (15.5 cm^3) (P=0.007).[22] The findings of the latter two studies are thus not in accord with the present study. A recent study from Malaysia among Chinese and Malays about the diameter of the maxillary sinus indicated bilateral asymmetry, where the right side revealed greater diameter than the left side in both gender and ethnicity.[30]

Influence of age on maxillary sinus volume

There is no consensus regarding the age of patients when the MS reaches its maximum size; 18 and 20 years of age has been reported in some studies.[1,31] In addition, Jun et al. reported that MS pneumatization increases rapidly until the third decade of age in males and the second decade in females, followed by a decrease in pneumatization with increasing age.[29]

However, several studies have investigated the effect of age on MSV, depicting significant variations in the age of patients.[22,26, 32-35] Luz et al.[22] assessed 128 maxillary sinuses of patients with a mean age of 46.2 years, that also included patients younger than 25 years of age. The study found no significant association between age and MSV (P=0.20).[22] Another study included 60 adults whose age was in the range of 18-65 years. Patients were equally categorized into three age groups (18-32, 33-49, and 50-65 years). They found no significant difference in MSV among the three age groups (P=0.299).[33] Another study included 133 patients (84 females, 49 males) between the age of 8 and 51 years, and they concluded that age was not significantly associated with MSV (P>0.05).[34] Those finding are in accord with the current study.

In contrast, two other studies have demonstrated contradicting results to our findings. Cohen et al.[26] calculated the volume of maxillary, sphenoid and frontal sinuses of 201 patients whose age was ≥25 years. They compared the MSV in patients between ≥65 and <65 years old, and found that young patient groups showed significantly larger maxillary sinus volumes (P<0.001).[26] This disagreement with the findings of the present study can be attributed to the inclusion criteria of patients, as they did not indicate whether the included patients were dentate or partially edentulous. Another study calculated the MSV of 174 sinuses, and they also found that subjects under the median age of 24.3 years had larger maxillary sinus volumes (P=0.014).[35] However, they included patients whose age was <25 years old in their sample. That may explain the difference in the results with the present study.

Influence of edentulous status on maxillary sinus volume

A study conducted by Velasco et al.[18], that included 196 partially edentulous and 92 completely edentulous patients, showed no significant difference in MSV between the two groups (P=0.50).[18] Another study has also found no significant association between MSV and dentition state in the posterior maxilla (P=0.52).[22] However, unlike the current study, they included sinuses that showed pathology and obliteration. The findings of the studies[18,22] are consistent with the present study results.

Digital Software versus mathematical maxillary sinus volume calculation.

Hamdy and Abdel-Wahed [36] in 2014 analyzed and calculated the MSV of 30 maxillary sinuses. They compared the MSV obtained by geometric equation to those derived from Simplant software. They concluded that there was a high correlation between the MSVs attained by the two methods, this being contradictory to the findings of the present study. Although the geometric equation which was used is identical to the one used in the present study, the utilized digital software was different.[36] Unlike the present study, they determined the MSV by measuring linear dimensions on multiple sites. For width and height (anteroposterior and mediolateral dimensions); measurements were performed along the nasal floor and root of the zygoma. Moreover, the length (superoinferior dimension) was measured by means of four lines bisecting the interdental areas between the maxillary posterior teeth. After that, the same dimensions were calculated with Simplant software. The discrepancy in results could be attributed to the usage of different software and technique application. Various digital software is available that can be utilized for the objective measurement of CBCT images. Moreover, determining which approach and the most accurate software to use for volume and length measurements, still remains to be clarified. Future studies are needed to compare digital software's so as to determine which is the most accurate, and then to compare it with manual (mathematical) methods. This can allow for a distinct reliable tool that can be employed in clinical dental practice. For example; to assess the exact amount of bone graft required for sinus lift surgery.

Residual ridge height

A study conducted by Monje et al.[37] reported that the most adequate residual ridge height was found at maxillary second molar sites (6.17 ± 2.48 mm). They also found sites with the most atrophic residual ridge height to be in the first premolar areas, measuring 4.46 ± 2.33 mm.[38] This however is in disagreement with the present study. Another study found that the residual ridge height at first molar sites (129 sites) was the lowest, measuring 4.6 ± 2.4 mm.[39] This is half the mean of residual ridge height at first molar sites described in the present study. The reasons and causes for the prevalence of the most resorbed tooth sites should be investigated. In our study, nearly 20% of missing maxillary posterior teeth sites had <5 mm residual ridge height, thus requiring definitive further complex surgical procedures in cases of (standard 10 mm length) implant placement. Two plausible scenarios could be the reason for this finding. Firstly, it is possible that surgical trauma during tooth extraction may have been the reason for bone loss.[39] Secondly, some patients, due to socioeconomic status or time limitation, may have not been able to replace their lost teeth which would eventually have caused significant alveolar ridge resorption.[40,41]

Conclusions

A limitation of this study is its cross-sectional design. Also, the time of tooth extraction data could not be obtained, otherwise, the time factor and MSV after tooth extraction could have been assessed.

There were no significant differences in the maxillary sinus volume regarding gender, patient's age and edentulous status. The digital measurement of MSV was found to be more reliable and convenient than geometric measurements. The most resorbed area was the left maxillary second molar site with a mean height of 7.07 mm.

Future studies should include the time of tooth extraction on a longitudinal basis, to study the rate of ridge resorption and maxillary sinus pneumatization. Furthermore, multicenter studies incorporating larger sample sizes should be performed to ensure more generalized volumetric values of MSV.

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Declaration of Interest

The authors report no conflict of interest.

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