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Volumetric analysis of mucous retention cysts in the maxillary sinus: A retrospective study using cone-beam computed tomography

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ABSTRACT

Purpose: The aim of this study was to evaluate the volumetric characteristics of mucous retention cysts (MRCs) in the maxillary sinus and to analyze potential associations of MRCs with dentoalveolar pathologies.

Materials and Methods: Cone-beam computed tomography (CBCT) scans exhibiting bilateral maxillary sinuses that were acquired from January 2016 to February 2019 were initially screened. A total of 227 scans (454 sinuses) that fulfilled the inclusion criteria were included. The presence, location, and volumetric characteristics of the diagnosed MRCs were evaluated on CBCT images using the 3D-Slicer software platform. The presence of MRCs was correlated with potential influencing factors including age, sex, and dentoalveolar pathology. For MRCs located on the sinus floor, factors with a potential impact on the volume, surface, and diameter were analyzed.

Results: An MRC was present in 130 (28.6%) of the 454 sinuses. Most MRCs were located on the sinus walls and floor. The mean MRC volume, surface, and diameter were 551.21 ± 1368.04 mm^3, 228.09 ± 437.56 mm^2, and 9.63 ± 5.40 mm, respectively. Significantly more sinuses with associated endodontically treated teeth/periapical lesions were diagnosed with an MRC located on the sinus floor. For MRCs located on the sinus floor, endodontic status exhibited a significant association with increased volume, surface, and diameter.

Conclusion: Periapical lesions might be a contributing factor associated with the presence and volume of MRCs located on the sinus floor. The 3D-Slicer software platform was found to be a useful tool for clinicians to analyze the size of MRCs before surgical interventions such as sinus floor elevation procedures. ***(Imaging Sci Dent 2021; 51: 117-27)***

KEY WORDS: Maxillary Sinus; Sinus Floor Augmentation; Cyst; Cone-Beam Computed Tomography

Introduction

Radiographic assessment of the maxillary sinus prior to surgical interventions in the sinus region, such as apical surgery of the upper posterior teeth, maxillary sinus floor elevation (SFE), and orthodontic treatment procedures, has been suggested in several clinical practice guidelines.[1-3] Compared with 2-dimensional radiographic techniques used in dental medicine (such as panoramic radiography), cone-beam computed tomography (CBCT) has better diagnostic value in assessing the condition of the maxillary sinus, as it enables the evaluation of anatomical variations and pathological findings in the maxillary sinus by viewing different cross-sectional planes with high spatial resolution.[4,5] Addi-

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tionally, CBCT data can be transferred into image processing software programs to build 3-dimensional (3D) models for volumetric analysis. Volumetric analysis of sinus pathology can be used to visualize the entirety of the pathological findings and to assess its morphological and volumetric characteristics. This information can substantially contribute to treatment planning of surgical procedures involving the maxillary sinus.

Mucous retention cysts (MRCs, also known as maxillary sinus pseudocysts or antral pseudocysts) have been described as among the most common pathological findings of the maxillary sinus, and usually present as a dome-shaped radiopaque soft-tissue mass attached to the bony walls of the sinus.[6-8] The presence of an MRC can complicate the above-mentioned surgical procedures, especially SFE through the lateral window and transcrestal osteotome approaches.[9,10] MRCs have been speculated to occur due to blockage of the ducts of the small mucous glands in the maxillary sinus mucosa. However, whether the blockage is caused by an inflammatory or noninflammatory response remains unclear.[11] Although previous studies have assessed the association between the presence of MRCs and dentoalveolar pathologies, their results are conflicting and far from conclusive.[12-15] Some studies concluded that dentoalveolar pathologies were not correlated with MRCs,[12,13] but others reported a positive correlation.[14,15] Most of those studies investigated correlations between dentoalveolar pathologies and MRCs in all locations of the maxillary sinus, whereas cysts located on the sinus floor may be more directly affected by dentoalveolar pathologies due to the close proximity of both entities. Moreover, it has been speculated that the size of MRCs varies according to their location in the maxillary sinus.[16] However, no data are available in the literature on the use of an image processing software program to analyze the true volumetric characteristics of MRCs in different locations of the maxillary sinus, or on potential influencing factors (such as dentoalveolar pathologies and demographic characteristics) that may be associated with the dimensions of MRCs. This information could be beneficial for evaluating the condition of the maxillary sinus, planning sinus-related surgical procedures, and monitoring treatment outcomes in dental medicine. Therefore, the aims of the present study were 1) to evaluate the reliability of an open-source semi-automatic image processing software platform (3D-Slicer) for the assessment of the volumetric characteristics of MRCs, and 2) to assess whether there is an association between factors including sex, age, and pathology of teeth in the posterior maxilla with the presence and dimensions of MRCs in different locations of the maxillary sinus.

Materials and Methods

Study population

In this retrospective study, all CBCT scans with a medium to large field of view (FOV) that depicted bilateral maxillary sinuses performed from January 2016 to February 2019 were initially eligible. The scans were taken with a ProMax 3D Mid (Planmeca, Helsinki, Finland) in patients referred to the Diagnostic Imaging Clinic, Faculty of Dentistry of the University of Hong Kong at the Prince Philip Dental Hospital. CBCT scans were excluded if any of the following exclusion criteria was present: 1) patients < 18 years old; 2) bilateral maxillary sinuses not entirely visible on the CBCT scan; 3) patients with a history of surgery or trauma in the region of the maxillary sinuses, or a history of implant treatment in the posterior maxilla; 4) artifacts (acquisition- or patient-related) presenting in the maxillary sinus region; or 5) pathology from anterior teeth (canine-to-canine) impinging into the maxillary sinuses.

The study was conducted in full accordance with the 2013 Declaration of Helsinki (www.wma.net). The study protocol was submitted to and approved by the local institutional review board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (approval number: UW 19-148).

CBCT image analysis of MRCs

The CBCT images were evaluated on a Philips 223 V LED monitor with a resolution of 1920 × 1080 pixels (Philips, Amsterdam, Netherlands). Data were reconstructed with slices of 0.5-mm thickness and a 0.4-mm voxel size. All images were first evaluated for the presence, number, and location of MRCs, status of the dentition in the posterior maxilla, and their respective endodontic and periodontal statuses using the proprietary software (ROMEXIS ver. 4.4.0.R, Planmeca, Helsinki, Finland) of the CBCT device.

Bilateral maxillary sinuses were separately evaluated in the CBCT scans. Cystic lesions presenting as spherical, ovoid, or dome-shaped structures with a smooth and uniform outline in continuity with the walls of the sinus were identified as MRCs.[11] First, the presence (radiologically absent/present) and number of MRCs in each sinus were recorded. The location of the MRC was assessed as: 1) on the sinus floor (i.e., the inferior wall of the maxillary sinus); 2) on the sinus walls (i.e., the medial, lateral, and posterior walls of the maxillary sinus); or 3) on the sinus roof (i.e., the superior wall of the maxillary sinus).

For further analysis of the potential associations between MRCs located on the sinus floor and various influencing

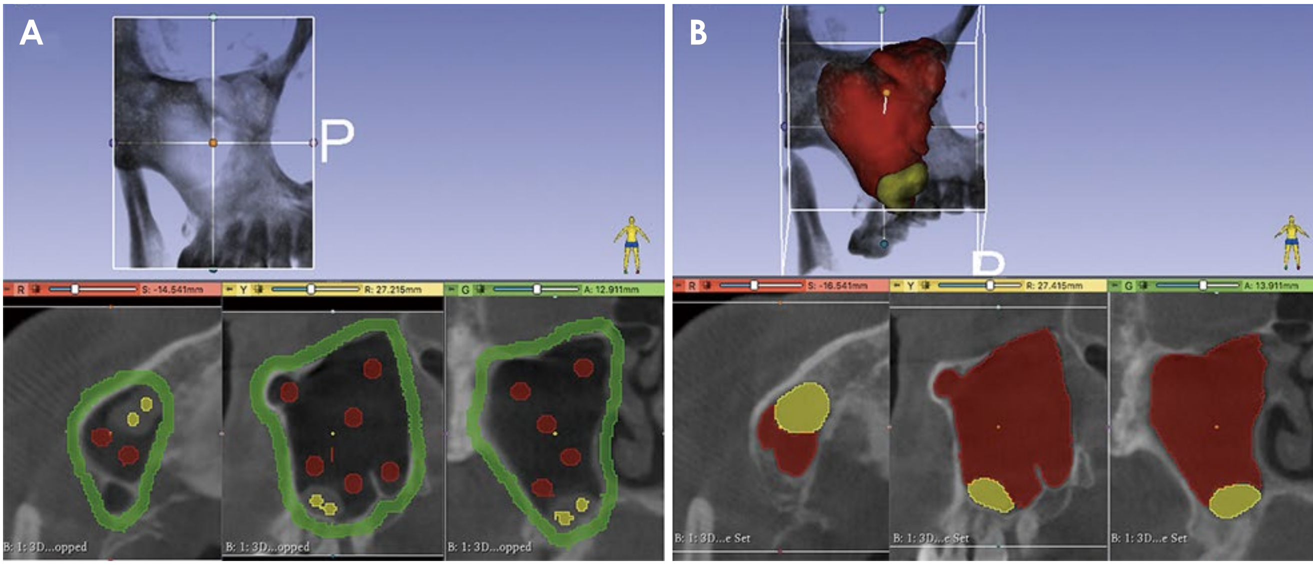

Fig. 1. Illustrative example of the segmentation process for volumetric analysis in a right maxillary sinus with 1 mucous retention cyst (MRC). First, seeds are inserted manually in the MRC (yellow dots), and the remaining pneumatized cavity (red dots) of the maxillary sinus. The boundary of the sinus on sagittal, coronal, and axial slices is then drawn (green line; A). Automatic segmentation of the MRC (yellow area) and remaining pneumatized cavity of the sinus (red area; B).

factors, MRCs were additionally classified as: 1) located on the sinus floor; or 2) not located on the sinus floor.

CBCT image analysis of the status of the dentition

For all CBCT scans included in the present study, the status of the maxillary posterior dentition (distal to the maxillary canines, with inclusion of the third molars) in association with the respective sinus was classified as:[17] 1) dentate (i.e., presence of all teeth from the third molar to the first premolar on the unilateral posterior maxilla); 2) partially edentulous (i.e., absence of at least 1 tooth from the third molar to the first premolar on the unilateral posterior maxilla); or 3) completely edentulous (i.e., absence all teeth from the third molar to the first premolar on the unilateral posterior maxilla).

If teeth were present in the posterior maxilla, they were assessed for the presence of potential endodontic or periodontal pathology. The endodontic status of the teeth in the respective posterior maxilla was classified as follows, assigning the largest code value whenever applicable:[17] 1) no endodontically treated tooth and no visible periapical lesion; 2) endodontically treated tooth/teeth without a visible periapical lesion; or 3) presence of visible periapical lesion(s).

Similarly, teeth with periodontal pathology were classified as follows, assigning the largest code value whenever applicable:[17] 1) no periodontal bone loss; 2) horizontal and/or vertical periodontal bone loss deeper than the midlevel of the respective root without furcation involvement; or 3) periodontal bone loss with furcation involvement.

Volumetric analysis of MRCs

For CBCT scans containing MRCs, CBCT images were exported as Digital Imaging and Communications in Medicine (DICOM) files and imported into 3D Slicer 4.10, an open-source medical image processing software platform (www.slicer.org).[18] The software platform was installed on a Dell OptiPlex 9010 Desktop (Dell, Round Rock, TX, USA) with an 18.5-inch Dell LCD monitor (resolution of 1366 × 768 pixels; Dell, Round Rock, TX, USA). For the assessment of the volumetric characteristics of the detected MRCs, segmentation and measurements of the MRCs were performed using a region-growing algorithm as follows: 1) manually defining the region of the maxillary sinus and cropping the volume of the selected region; 2) manually marking seeds on the MRC (s) and the remaining pneumatized cavity of the maxillary sinus on the selected sagittal, coronal, and axial slices, respectively (Fig. 1); 3) manually drawing the boundary of the sinus on 1 selected sagittal, coronal, and axial slice; 4) automatic segmentation of MRCs and the remaining pneumatized cavity of the sinus using a region-growing algorithm through the Grow From Seeds tool in the Segment Editor module of 3D-Slicer (Fig. 1); 5) exporting the segments to models and obtaining automatic measure-

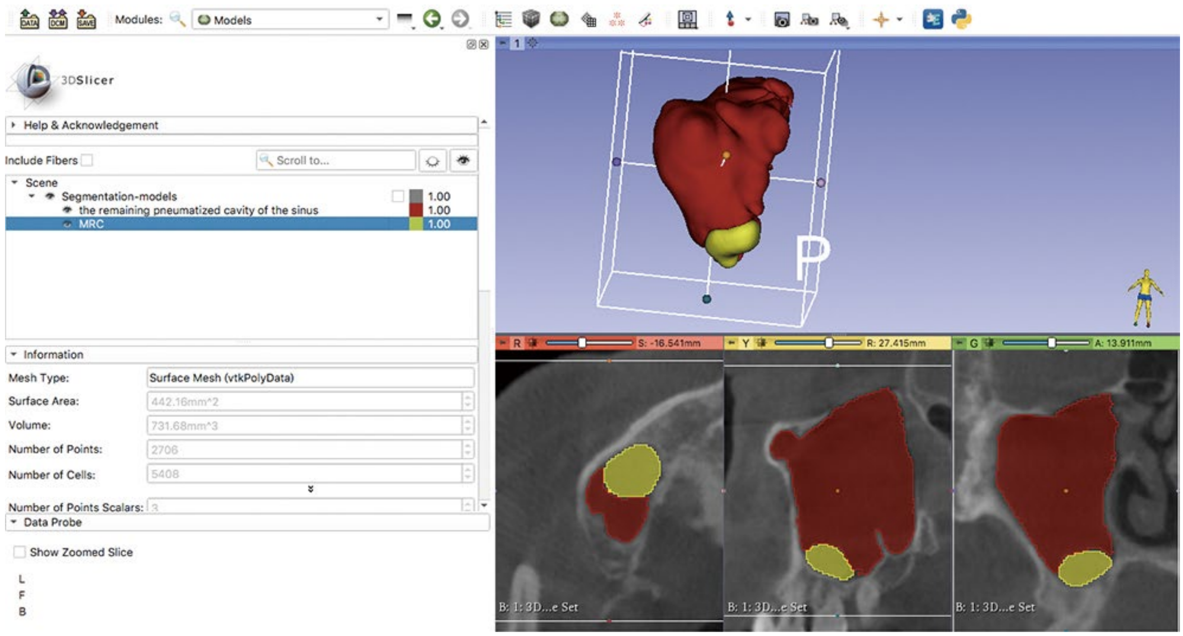

Fig. 2. Automatic measurement of the volume (mm^3) and surface (mm^2) of a mucous retention cyst using the 3D Slicer 4.10 software, demonstrating a volume of 731.66 mm^3 and a surface of 442.16 mm^2 for this case.

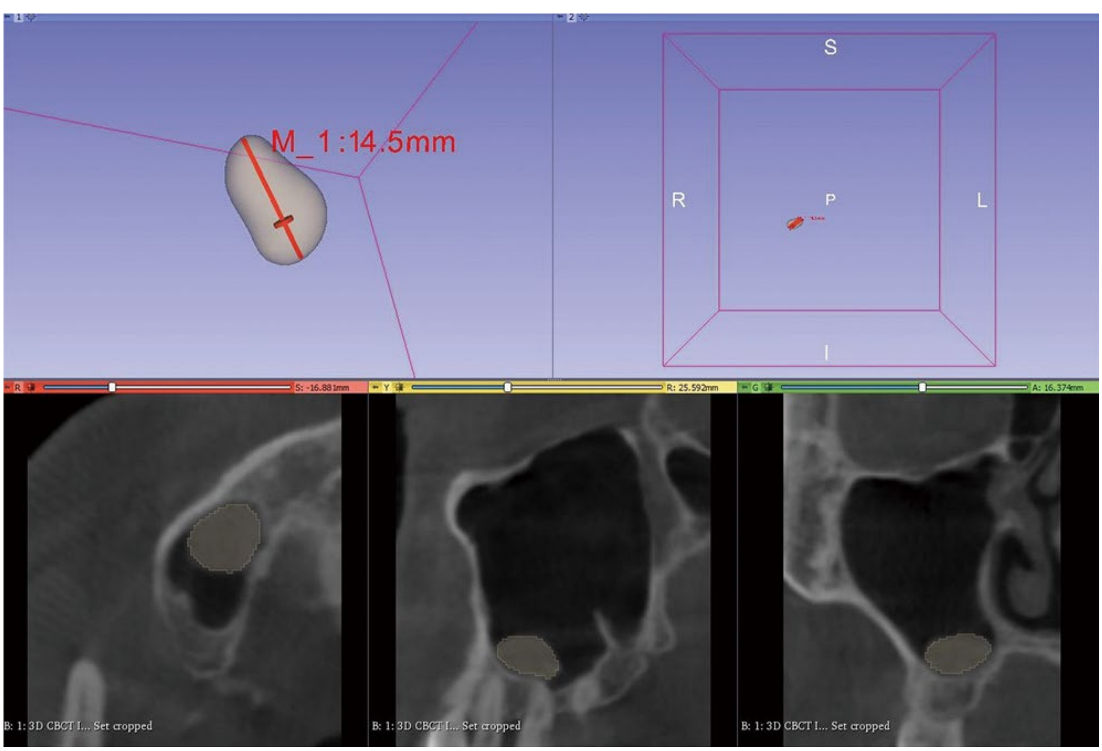

Fig. 3. Manual measurement of the maximum diameter (mm) of a mucous retention cyst on a semi-transparent 3-dimensional image demonstrates a diameter of 14.5 mm for this case.

ments of the volume (in mm^3) and surface (in mm^2) of each MRC model (Fig. 2); 6) determining the long axis of the MRC model in a volume-rendered window of the software platform, and obtaining a manual measurement of the long axis (in mm), corresponding to the maximum diameter of the MRCs (Fig. 3).

The observations of the categorical variables (the presence, number, and location of MRCs; status of the dentition in the posterior maxilla; endodontic and periodontal health) were performed by 2 examiners to test for inter-observer reproducibility. The measurements of continuous variables (the volume, surface, and maximum diameter of MRCs) were performed by 1 examiner only. Furthermore, 1 examiner performed all of the above observations and measurements twice with a time interval of at least 1 month between each observation/measurement to test for intra-observer repeatability. For categorical variables, inconsistent findings among the 3 observations were resolved by discussion to reach a final diagnosis that was used for further data analysis. The mean of the 2 measurements of continuous variables was calculated and used for the subsequent statistical analyses.

Statistical analysis

All data were first analyzed descriptively. For all continuous variables (MRC volume, surface, and maximum diameter), the mean, standard deviation, maximum, minimum, and median values were calculated. For intra-observer repeatability and inter-observer reproducibility, intra-class correlation coefficients and Cohen kappa values were calculated.[19] Correlations between any 2 of the 3 continuous variables (MRC volume, surface, and maximum diameter) were calculated using Pearson correlation coefficients. The impact of potential influencing factors on MRC presence was evaluated on the patient level (age and sex) and the sinus level (status of the dentition, endodontic and periodontal statuses) with either the chi-square test or the Mann-Whitney *U* test.

The effects of potential influencing factors in relation to the volume, surface and maximum diameter of MRCs located on the sinus floor were evaluated with the Mann-Whitney *U* test (sex), Kruskal-Wallis 1-way analysis of variance (ANOVA) (status of the dentition, endodontic and periodontal statuses), or Pearson correlation coefficients (age). Differences in the volume, surface and maximum diameter of MRCs in different locations were evaluated with Kruskal-Wallis 1-way ANOVA. When a sinus had more than 1 MRC in the same location of the maxillary sinus, only the largest MRC present was chosen for the above volumetric analyses.

The significance level chosen for all of the statistical tests mentioned above was set at 0.05. All analyses were performed using SPSS (version 25.0; IBM Corp., Armonk, NY, USA).

Results

A total of 297 CBCT scans with a medium to large FOV were screened initially, from which 70 scans were excluded based on the exclusion criteria listed above. The main reason for excluding CBCT scans was a history of surgery or trauma in the region of the maxillary sinuses, or a history of implant treatment in the posterior maxilla (64.3%, 45 of 70). This was followed by the bilateral maxillary sinuses not being entirely visible on the CBCT scan (12.9%, 9 of 70). Eventually, a total of 227 scans (454 sinuses) were included for further analysis in the present study. The included CBCT scans were from 141 female and 86 male patients with a mean age of 31.4 years (range, 18-84 years; Table 1). The FOV of the included scans was 20×17 cm for 188 patients, 20×10 cm for 36 patients, and 10×10 cm for 3 patients. The voxel size was 400 μm for the scans performed with a FOV of 20×17 cm or 20×10 cm, or 200 μm for those with a FOV of 10×10 cm. A majority of the sinuses assessed exhibited complete dentition (291 of 454, 64.1%) with no endodontically treated tooth or periapical lesion (357 of 439, 81.3%), and no visible periodontal bone loss (358 of 439, 81.5%; Table 1).

Intra- and inter-observer agreement

Intra-observer reliability was high for the observations (MRC presence, number, and location, and dental status) and measurements (MRC volume, surface, and maximum diameter; Table 2). The inter-observer reproducibility exhibited excellent agreement for the status of dentition; substantial agreement for MRC presence, number, and location, and endodontic status; and moderate agreement for periodontal status (Table 2).

Characteristics of MRCs

Table 3 presents a descriptive analysis of the presence and dimensions of MRCs in different locations of the maxillary sinus. Strong correlations were found between the measurements of volume, surface, and diameter (volume and surface, $r=0.93$; volume and diameter, $r=0.78$; surface and diameter, $r=0.86$).

Potential factors influencing the characteristics of MRCs

The analysis of the 454 sinuses from 227 CBCT images exhibited that for all MRCs combined, the potential influencing factors evaluated did not have a significant impact on the presence of MRCs (Table 1). However, significantly more

Table 1. Demographic and analytical data regarding the presence of mucous retention cysts (MRCs) diagnosed in different locations of the maxillary sinus, and their association with potential risk factors including sex, age (patient-level), status of the dentition, and endodontic and periodontal statuses (sinus-level)

	Total	MRCs in the maxillary sinus (all locations)			MRCs on the sinus floor		
	n (100%)	Present n (%)	Absent n (%)	*P* value	Present n (%)	Absent n (%)	*P* value
Patient level (n = 227)							
Sex Male	86	41 (47.7%)	45 (52.3%)	$P = 0.504$	23 (26.7%)	63 (73.3%)	$P = 0.697$
Female	141	60 (42.6%)	81 (57.4%)		34 (24.1%)	107 (75.9%)	
Age (mean ± SD)	31.4 ± 14.0	30.4 ± 12.8	32.2 ± 15.0	$P = 0.451^{\dagger}$	32.1 ± 14.2	31.1 ± 14.0	$P = 0.657^{\dagger}$
Sinus level							
Status of the dentition in the posterior maxilla							
Dentate	291	84 (28.9%)	207 (71.1%)	$P = 0.404$	45 (15.5%)	246 (84.5%)	$P = 0.454$
Partially edentulous	148	44 (29.7%)	104 (70.3%)		27 (18.2%)	121 (81.8%)	
Completely edentulous	15	2 (13.3%)	13 (86.7%)		1 (6.7%)	14 (93.3%)	
Total	454	130 (28.6%)	324 (71.4%)		73 (16.1%)	381 (83.9%)	
Endodontic status (first premolar to third molar)							
No endodontically treated tooth or periapical lesion	357	98 (27.5%)	259 (72.5%)	$P = 0.184$	50 (14.0%) (1)	307 (86.0%)	$P < 0.05$, $(1) < (2) = (3)^{\ddagger}$
Endodontically treated teeth without periapical lesion	31	13 (41.9%)	18 (58.1%)		9 (29.0%) (2)	22 (71.0%)	
Presence of periapical lesion(s)	51	17 (33.3%)	34 (66.7%)		13 (25.5%) (3)	38 (74.5%)	
Total	439	128 (29.2%)	311 (70.8%)		72 (16.4%)	367 (83.6%)	
Periodontal status (first premolar to third molar)							
No periodontal bone loss	358	108 (30.2%)	250 (69.8%)	$P = 0.616$	57 (15.9%)	301 (84.1%)	$P = 0.706$
Periodontal bone loss without furcation involvement	60	15 (25.0%)	45 (75.0%)		12 (20.0%)	48 (80.0%)	
Periodontal bone loss with furcation involvement	21	5 (23.8%)	16 (76.2%)		3 (14.3%)	18 (85.7%)	
Total	439	128 (29.2%)	311 (70.8%)		72 (16.4%)	367 (83.6%)	

The chi-square test was performed unless otherwise mentioned, †: Mann-Whitney *U* test, ‡: pairwise comparisons with Bonferroni adjustment. SD: standard deviation sinuses associated with endodontically treated teeth and/or periapical lesions were diagnosed with an MRC located on the sinus floor (Table 1). An analysis of potential factors influencing the volume, surface, and maximum diameter of MRCs was specifically done for MRCs located on the sinus floor. Age, sex, status of the dentition in the posterior teeth, and periodontal status exhibited no associations (P values ranging from 0.177 to 0.902). In contrast, endodontic status exhibited a significant correlation with the volume (P = 0.004), surface (P = 0.002), and diameter (P = 0.002, Table 4) of the MRCs. Sinuses associated with periapical lesions had a significantly larger MRC volume, surface, and diameter (Table 4).

Table 2. Analysis of intra- and inter-observer agreement

Observed parameters		Intra-observer	Inter-observer
MRC	Presence	0.87	0.79
	Number	0.83	0.80
	Location	0.82	0.76
	Volume	0.98*	/
	Surface	0.98*	/
	Maximum diameter	0.97*	/
Status of the dentition in the posterior maxilla		0.97	0.91
Endodontic status		0.89	0.63
Periodontal status		0.90	0.54

The Cohen kappa value was calculated unless otherwise mentioned. *: intra-class correlation coefficients. Agreement was rated as low (<0.41), moderate (0.41-0.60), substantial (0.61-0.80), or excellent (>0.80). MRC: mucous retention cyst

The analysis of the 169 MRCs observed in 130 of the 454 sinuses demonstrated that MRC dimensions had significant differences according to location (floor, walls, or roof of the maxillary sinus). The MRCs located on the sinus floor exhibited a significantly larger volume, surface, and diameter than those located on the sinus walls or roof (Table 5).

Discussion

The present study investigated the frequency, location, and volumetric characteristics of MRCs in 454 maxillary sinuses from 227 CBCT images. In addition, this study evaluated whether age, sex, or status and health of the dentition in the posterior maxilla influenced the presence of MRCs in different locations. Furthermore, the present study

Table 3. Descriptive analysis of the presence and dimensions of mucous retention cysts (MRCs) in different locations of the maxillary sinus

	MRCs in the sinus (all locations)	MRCs on the sinus floor	MRCs on the sinus walls	MRCs on the sinus roof
Sinus level				
Present	130 (28.6%)	73 (16.1%)	59 (13.0%)	14 (3.1%)
Absent	324 (71.4%)	381 (83.9%)	395 (87.0%)	440 (96.9%)
Total	454 (100%)	454 (100%)	454 (100%)	454 (100%)
MRC level	n = 169 (100%)	n = 76 (45.0%)	n = 77 (45.5%)	n = 16 (9.5%)
Volume (mm^3)				
Mean ± SD	551.21 ± 1368.04	1,010.09 ± 1,941.32	165.10 ± 169.54	229.67 ± 171.97
Median (95% CI)	166.68 (141.34-202.28)	340.73 (219.64-524.78)	116.91 (84.76-141.34)	197.45 (120.67-306.05)
Maximum	12,141.74	12,141.74	996.49	742.88
Minimum	17.38	26.64	17.38	39.89
Surface (mm^2)				
Mean ± SD	228.09 ± 437.56	454.25 ± 599.55	132.66 ± 107.25	183.40 ± 116.31
Median (95% CI)	134.69 (121.80-160.63)	264.99 (173.74-313.91)	102.30 (84.46-125.37)	159.26 (108.67-225.87)
Maximum	2,979.90	2,979.90	513.82	473.59
Minimum	20.78	26.94	20.78	49.66
Maximum diameter (mm)				
Mean ± SD	9.63 ± 5.40	12.00 ± 6.61	7.61 ± 3.15	8.04 ± 2.50
Median (95% CI)	7.83 (7.33-8.55)	10.38 (8.43-11.60)	6.71 (6.06-7.48)	8.08 (6.76-9.25)
Maximum	31.45	31.45	18.21	12.70
Minimum	3.44	3.76	3.82	3.44

CI: confidence interval, SD: standard deviation

Table 4. Analysis of the association between the endodontic status and the volumetric characteristics of mucous retention cysts (MRCs) located on the sinus floor

	Medians (95% CI)	Kruskal-Wallis 1-way ANOVA test		
		H	Mean rank	*P* value
Volume (mm^3)				
No endodontically treated tooth or periapical lesion	287.40 (183.79-524.78)	11.21	35.62 (1)	$P<0.05$
Endodontically treated teeth without periapical lesion	75.21 (52.49-423.37)		20.78 (2)	(2) < (3)†
Presence of periapical lesion(s)	1,415.32 (268.69-3,410.23)		50.77 (3)	
Surface (mm^2)				
No endodontically treated tooth or periapical lesion	247.36 (149.91-313.27)	12.77	35.50 (1)	$P<0.05$
Endodontically treated teeth without periapical lesion	78.18 (44.71-285.98)		19.89 (2)	(1) = (2) < (3)†
Presence of periapical lesion(s)	961.20 (215.74-1,661.82)		51.85 (3)	
Maximum diameter (mm)				
No endodontically treated tooth or periapical lesion	9.31 (7.52-11.60)	12.54	35.35 (1)	$P<0.05$
Endodontically treated teeth without periapical lesion	7.17 (5.09-11.07)		20.50 (2)	(1) = (2) < (3)†
Presence of periapical lesion(s)	19.10 (11.07-23.80)		52.00 (3)	

†: pairwise comparisons with the Dunn-Bonferroni *post hoc* test, H: test statistic for the Kruskal-Wallis test. ANOVA: analysis of variance

Table 5. Analysis of the dimensions of mucous retention cysts (MRCs) diagnosed in different locations of the maxillary sinus

	Median (95% CI)	Kruskal-Wallis 1-way ANOVA test		
		H	Mean rank	*P* value
Volume (mm^3)				
Floor	340.73 (198.96-539.34)	30.63	106.89 (1)	$P<0.05$
Walls	116.91 (87.16-140.54)		63.11 (2)	(1) > (2) = (3)*
Roof	197.45 (126.74-306.05)		86.38 (3)	
Surface (mm^2)				
Floor	264.99 (159.53-314.56)	28.46	106.00 (1)	$P<0.05$
Walls	102.30 (85.88-125.37)		63.82 (2)	(1) > (2) = (3)*
Roof	159.26 (107.49-225.98)		87.19 (3)	
Maximum diameter (mm)				
Floor	10.38 (8.03-11.77)	24.99	105.38 (1)	$P<0.05$
Walls	6.71 (6.06-7.38)		66.01 (2)	(1) > (2) = (3)*
Roof	8.08 (6.61-9.25)		79.59 (3)	

*: pairwise comparisons with the Dunn-Bonferroni *post hoc* test, H: test statistic for the Kruskal-Wallis test. ANOVA: analysis of variance

specifically assessed the impact of potential influencing factors on the volume, surface, and diameter of MRCs located on the sinus floor and analyzed the difference of MRC dimensions in different locations of the maxillary sinus. The frequency of MRCs was 28.6% (130 of 454), which is well above the range reported by previous studies using panoramic radiographs (3.2%-14.0%),[20-22] but within the range reported by investigations using CT/CBCT (3.6%-35.6%).[12,13,23,24] The variability in the reported frequency of MRCs may result from differences among the investigated populations, the type of imaging technique (panoramic radiographs versus CBCT), and the partial or entire visualization of the observed maxillary sinuses.[17]

Active debate continues regarding whether the occurrence of MRCs may be associated with dentoalveolar pathologies. Some studies have stated that pathologies of teeth in the posterior maxilla were not associated with the presence of MRCs in the maxillary sinus,[12,13,17,21] while other studies reported a positive correlation.[14,15,25] Curi et al.[15] reported that the presence of periapical or endoperiodontal lesions increased the possibility of having MRCs in the maxillary sinus by 4.1 and 23.8 times, respectively. Souza-Nunes et al.[14] stated that periapical and endodontic pathology in the maxillary posterior teeth was significantly associated with the presence of MRCs located on the sinus floor. The discrepancies in the results of previous studies may be due to differences in the study design in terms of the location of MRCs. Studies evaluating the association between dentoalveolar pathologies and the presence of MRCs for all locations of the maxillary sinus were less likely to find a significant association[12,17,21] than those assessing MRCs located on the sinus floor.[14,25] In the present study, potential influencing factors, including dentoalveolar pathologies, were correlated with the presence of MRCs in all locations and more specifically with the presence of MRCs located on the sinus floor. An association was found between endodontic status and the presence of MRCs located on the sinus floor. Sinuses associated with endodontically treated teeth and/or periapical lesions had a significantly higher chance of having MRCs in that location. These findings support the hypothesis that dentoalveolar pathologies could specifically have an impact on MRCs located on the sinus floor due to the close proximity of both entities. Furthermore, the findings in the literature are inconsistent regarding possible associations between sex/age and the presence of MRCs.[13,21,22,26] In the present study, no significant association of sex and age with MRC presence was found.

Few studies have provided data on MRC dimensions in terms of the diameter measured on cross-sectional images.[13,17] However, a linear 1-dimensional measurement may not offer an accurate and objective assessment of the true characteristics of an MRC. Volumetric analysis by automated image segmentation and measurement has been recommended as a useful tool to characterize the size of lesions more accurately.[27] The increasing interest in 3D models has enhanced the need for a better understanding of the true volumetric characteristics of all kinds of lesions, as well as potential factors influencing their dimensions.[28] The free and publicly available 3D-Slicer software platform enables semi-automated image segmentation and measurement using a region-growing algorithm, which has been validated as more accurate and stable than the manual slice-by-slice delineation approach.[29,30] Therefore, the use of the 3D-Slicer software platform with a region-growing approach is highly recommended to analyze the size of lesions for both clinical and research purposes.[29,30] The present study evaluated the reliability of the 3D-Slicer software platform using a region-growing algorithm to assess the volumetric characteristics of MRCs in different locations of the maxillary sinus, as well as their dimensions in relation to potential influencing factors including sex, age, and dentoalveolar pathologies. The present analysis demonstrated that MRCs located on the sinus floor had a significantly larger volume, surface, and diameter than those located on the walls or roof. These findings strengthen the hypothesis that the size of MRCs varies according to their location in the maxillary sinus.[16] Additionally, the present study found that patients with periapical lesions in the maxillary posterior teeth exhibited MRCs with a larger volume, surface, and diameter. Based on these results, it might be speculated that periapical lesions are likely to cause an increased accumulation of exudate in an MRC. This may eventually lead to growth of the MRC, specifically for lesions located on the maxillary sinus floor. Therefore, clinicians should examine the endodontic status of the maxillary posterior teeth in close relation to MRCs on the sinus floor, and ideally treat any endodontic pathology that is present before surgical interventions in the posterior maxilla such as SFE.

SFE procedures, including lateral window and transcrestal osteotome approaches, are predictable and effective surgical techniques for dental implant placement in patients with limited vertical bone height in the posterior maxilla.[31] The presence of MRCs located on the floor and lateral wall of the maxillary sinus can complicate SFE procedures.[9] It has been suggested that MRCs located on the sinus floor or lateral wall should be removed before or simultaneously with SFE procedures.[9,32] On one hand, removal of an MRC prior to a planned SFE results in an additional surgical intervention and prolonged treatment period, which may discourage patients from opting for such a therapeutic approach.[33] On the other hand, surgical removal of a MRC from the sinus simultaneously with SFE carries a significant risk of perforation of the sinus membrane, which might cause postoperative infection and acute sinusitis.[9] Instead of removing the MRC, elevating the sinus floor and the MRC together has been proposed as a modified surgical approach for SFE in the presence of a MRC located on the sinus floor.[34] Nevertheless, it has been demonstrated that 29.4% of the diagnosed MRCs exhibited an increase in size after an observation period of at least 3 years when left untreated.[35] Therefore, there remains a risk of obstruction of the primary maxillary ostium resulting from the still-present MRC above the newly elevated sinus floor, which then may cause sinusitis.[33] Volumetric analysis by building CBCT-generated 3D models enables accurate localization and volumetric measurement of MRCs in the maxillary sinus. This information may be useful for the surgeon to determine the appropriate surgical approach for SFE, or to monitor dimensional changes if the lesions is observed over time instead of being removed.

To the best of our knowledge, this is the first study to use a semi-automatic image processing software platform to assess volumetric characteristics of MRCs in relation to potential influencing factors including sex, age, and dento-alveolar pathologies. Nevertheless, the findings should be interpreted with some caution due to some relevant limitations of this study. One of the major limitations is that the CBCT images evaluated were collected retrospectively from a relatively healthy population. Moreover, the patients were referred for various indications such as implant treatment planning, orthognathic surgery, impacted teeth, and cysts. Due to its retrospective nature, the number of patients with endodontic/periodontal pathologies was relatively small and not controlled in the present study. Furthermore, this study investigated the differences in MRC size between different patient groups at a single time, and the lesions were not monitored longitudinally. Therefore, it remains unknown whether the MRC size would actually decrease after patients receive endodontic treatment. Ideally, a prospective study to observe changes in MRC size in patients with different dentoalveolar pathologies, including a more even age distribution, would be needed to confirm the findings of the present study.

The present study demonstrated that the 3D-Slicer software platform is suitable for the semi-automatic volume measurements of MRCs. On the basis of the data analyzed in this retrospective study, the following 2 clinically relevant conclusions can be drawn: 1) generally, the presence of MRCs seems not to be influenced by the patient's age, sex, or dental status; and 2) for MRCs located on the maxillary sinus floor, periapical lesions of teeth in the posterior maxilla seem to have an impact on MRC presence and dimensions, as shown by associations with a larger volume, surface, and maximum diameter. Based on these findings, clinicians should assess the presence, location, and dimensions of MRCs, and also look for potential associations with the endodontic status of posterior teeth in the maxilla before surgical interventions such as SFE procedures.

Conflicts of Interest: None

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