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ORIGINAL ARTICLE

The Relationship between the Roots of Posterior Maxillary Teeth and Adjacent Maxillary Sinus Floor was Associated with Maxillary Sinus Dimension

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Background: The dimension of maxillary sinus is dynamic and might complicate the dental practice. Therefore, the purpose of this study is to analyze maxillary sinus dimension with respect to different ages, genders, tooth sites, and relationships between root of posterior maxillary teeth (RPMT) and adjacent maxillary sinus floor, using cross-sectional images from cone-beam computed tomography (CBCT). **Methods:** The 320 qualified cross-sectional posterior maxillary images of CBCT from 50 patients retrieved from the database were used to analyze the maxillary sinus area. Five types of relationship between RPMT and adjacent maxillary sinus floor were classified accordingly. The associated factors, such as age, genders, and tooth sites, were also examined. The one-way analysis of variance with Tukey's *post hoc* test was performed to compare the maxillary sinus cross-sectional area in different classifications of RPMT relative to adjacent maxillary sinus floor. **Results:** There were significant differences of mean maxillary sinus area between different genders ($P < 0.001$) and age groups ($P = 0.01$). The mean sinus area measured from cross-sectional images was greater in Type 3 classification of RPMT relative to maxillary sinus, compared to Type 2, Type 1, and Type 0 ($P < 0.001$). **Conclusions:** The RPMT relative to adjacent sinus floor may be associated with area of maxillary sinus. The maxillary sinus with greater area in cross-sectional images of CBCT would be closer to the RPMT and might complicate the dental practice.

Key words: Maxillary sinus, posterior maxillary teeth, maxillary sinus dimension, complication

INTRODUCTION

The maxillary sinuses are two bilateral pyramidal cavities located within the maxillary bone, adjacent to the nasal cavity, and below the orbits.[1] They are important anatomic structures with multiple functions, such as performing as a resonance body for the voice, contributing to the olfactory function, and adapting the temperature and humidity.[1] They are of interest to dentists for their proximity to the area where dentists' daily practices and maxillofacial surgeries involve.[2]

In addition to maxillary sinus anatomy, the knowledge of the relationship between posterior maxillary teeth and floor of the sinus is also important. Sometimes, maxillary sinus floor might approach close to the posterior maxillary teeth and even the roots of posterior maxillary teeth (RPMT) intruding into the sinus.[3] This may result in the increased opportunities of various complications when performing dental practices, including sinusitis,[4,5] sinus membrane perforation,[6] oroantral communication,[7] endoantral syndrome, or root displacement into the maxillary sinus.[8,9] Studies also reported posterior maxillary dental pathologic lesion increased the incidence of maxillary sinus abnormalities due to a close spatial relationship.[10,11] Therefore, dentists should understand the

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relationship between RPMT and the adjacent sinus floor to reduce iatrogenic damage or possible pathologic involvement in maxillary sinus before performing dental practice.[12]

The development of the maxillary sinus has been documented as early as the 17th week of the prenatal period. After birth, the maxillary sinus experiences two rapid growth phases (0–3 and 7–12 years old) and reaches adult size.[13] Previous literatures also had demonstrated that maxillary sinus dimension was still dynamic even after adulthood and possible associated with age, gender, and midfacial dimension.[2,14,15] However, the study regarding the association between sinus dimensions and position of RPMT relative to adjacent maxillary sinus floor, which might influence the dental practice, was limited. Therefore, the purpose of this study is to analyze the association between maxillary sinus area and different ages, genders, tooth sites, and positions of RPMT relative to adjacent maxillary sinus floor, using cross-sectional images from cone-beam computed tomography (CBCT).

METHODS

Image database validation, acquisition, and retrieving

The examined CBCT images (NewTom 5G; QR, Verona, Italy) were retrospectively retrieved from a database (from June 2015 to March 2016) at the Department of Dentistry, Tri-Service General Hospital. All cases were patients for dental implant therapy or other necessary dental treatment in the Tri-Service General Hospital, not specifically for this project. To achieve adequate image quality and follow the as low as reasonably achievable principle, the board-certified radiologist operated the CBCT machine according to the standard manufacturer's instruction (an accelerated potential of 110 kilovolts peak and a beam current of 11.94 milliamperes). The field of view (FOV) was fixed at 30.5 $cm^2 \times 20.3\ cm^2$ with the separation of each slice (0.15 mm). The protocols were approved by the Institutional Review Board of Tri-Service General Hospital, National Defense Medical Center (TSGHIRB 2-102-05-064).

Qualification and examination of cross-sectional images from cone-beam computed tomography

All CBCT images with 1920 × 1080 pixel resolution, displayed on a 19-inch liquid-crystal display monitor (ChiMei Innolux Corporation, Tainan, Taiwan), were inspected by a commercially available three-dimensional navigation software (ImplantMax® 4.0; Saturn Image, Taipei, Taiwan) in a dimly lit environment. Cross-sectional images of posterior maxillary teeth were aligned on the long axes of the investigated teeth at the center of their roots with the shortest distances from the center of each radiographic apex or main apical foramen to the maxillary sinus floor and inspected by two independent examiners (P.-S. C. and C.-E. S.).[12]

Inclusion and exclusion criteria

Following inclusion and exclusion criteria of the selected CBCT images were described and applied previously.[1,16]

The CBCT images meeting the inclusion criteria had to be as follows:

1. Patients were older than 20 years with fully developed maxillary sinuses
2. At least one complete maxillary sinus and corresponding posterior maxillary root apex completely was visible in the FOV
3. No pathological lesion was present in the maxillary sinus and alveolar bone
4. No implant or graft was observed in the posterior maxillary region
5. Only maxillary sinus and teeth whose root apices clearly imaged in CBCT were included in the study.

Images were excluded if:

1. The patient had a history of sinus or nasal surgeries
2. Images revealed artifacts in the maxillary sinus (acquisition or patient related)
3. Images had supernumerary or impacted tooth in the maxillary sinus or alveolar bone
4. Images were unclear or obscure due to scattering or X-ray beam-hardening effect
5. The corresponding posterior maxillary tooth was missing, so that the relationship between the teeth and floor of the maxillary sinus could not be categorized.

Area measurement of the maxillary sinus from cross-sectional images of cone-beam computed tomography

For the assessment of the maxillary sinus areas in cross-sectional images, the navigation software (ImplantMax® 4.0; Saturn Image, Taipei, Taiwan) was adopted, using the software's "calculate area" tool. The planar curve delineating the outlines of the maxillary sinus was drawn manually for each cross-sectional image of investigated tooth. Two or a maximum of three curves were drawn by the software program estimating initial surface vectors, and the curves were adjusted at interceptions [Figure 1].[1,17]

Relationship between the roots of posterior maxillary teeth and the adjacent floor of maxillary sinus

With the cross-sectional computed tomographic images, the relationship between RPMT and the maxillary sinus floor described by the previous study was classified into following five categories [Figure 2].[16]

1. Type 0: The RPMT is not in contact with the cortical borders of the sinus
2. Type 1: The RPMT is in contact with the cortical borders of the sinus with an inferiorly curving sinus floor
3. Type 2: The RPMT is projecting laterally on the sinus cavity, but its apex is outside the sinus boundaries with an inferiorly curving sinus floor
4. Type 3: The apex of RPMT is projecting into the sinus cavity with an inferiorly curving sinus floor
5. Type 4: A superiorly curving sinus floor enveloping part or all of RPMT

Calibration and reliability between intra- and interexaminers

To assess data reliability, intra- and interexaminer calibrations were performed on 10 randomly selective images from CBCT images. The Kappa statistic values for relationship between RPMT and the adjacent maxillary sinus floor were 0.934 and 0.931 for intra- and interobserver agreement, respectively. The Cronbach's α values for the measurement of maxillary sinus area were 0.999 and 0.998 for intra- and interobserver agreement, respectively. After calibration, two examiners (P.-S. C. and C.-E. S.) evaluated the images separately, and any disagreement in image interpretation was discussed until the consensus was reached.

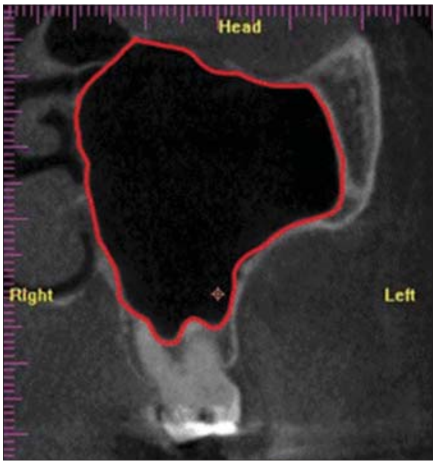

Figure 1: Representative image of the delineating the outlines of the maxillary sinus from cross-sectional image for the semi-automatic area quantification

Statistical analysis

The area of maxillary sinus measured from cross-sectional image was calculated with a mean and standard deviation. The independent samples *t*-test was used to compare the maxillary sinus dimension between male and female patients. The frequency distributions of types of the RPMT relative to the adjacent maxillary sinus floor were expressed with the percentage and number. Chi-square tests were used to examine differences of the prevalence of the classification in different tooth sites. One-way analysis of variance with Tukey's *post hoc* test was used to examine the dimension of maxillary sinus between different classifications of the RPMT relative to the adjacent maxillary sinus floor and different groups of age. All statistical analyses were performed by SPSS for Windows software (PASW Statistics, version 18.0, SPSS, Inc., Chicago, IL, USA) and the level of statistical significance was set at $P < 0.05$.

RESULTS

A total of 50 patients (320 teeth) with a mean age of 47.34 years (range from 20 to 76), who met the inclusion and exclusion criteria, were analyzed. Forty-three teeth were excluded for missing, 31 teeth for maxillary sinus not presenting in the cross-sectional image, 4 teeth for pathological lesions, and 2 teeth for impaction. The average ages of male (n = 25) and female (n = 25) patients were 44.48 ± 14.33 years (range, 20–67 years) and 50.20 ± 14.07 years (range, 20–76 years), respectively. There was no statistically significant difference between the age of male and female patients (P = 0.161).

The mean area measurements of maxillary sinus were 453.9 mm^2 from cross-sectional images. The mean sinus area (standard error [SE]) in males was 526.42 mm^2 ± 26.84 mm^2, significantly greater than the mean sinus area (SE) in females (376.60 mm^2 ± 21.37 mm^2) (P < 0.001) [Figure 3]. With respect to the age of the patients, statistically significant

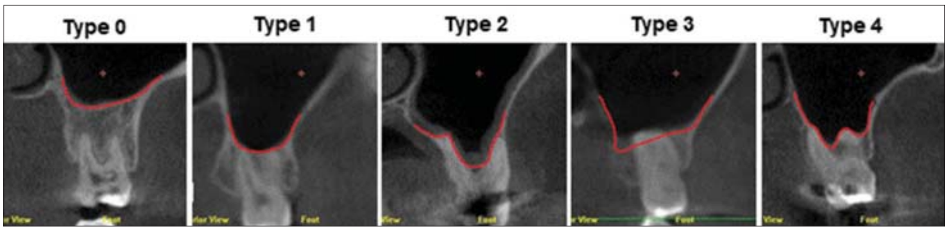

Figure 2: Cross-sectional cone-beam computed tomography images of 5 classifications of the maxillary posterior teeth roots relative to the adjacent floor of maxillary sinus[16]

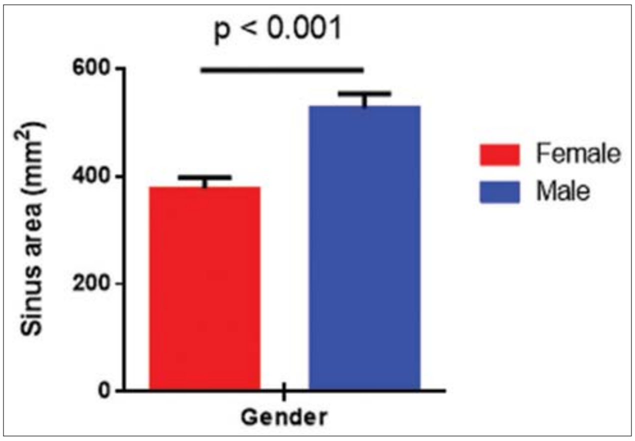

Figure 3: The comparison of the maxillary sinus area between different genders. Data represent means and standard error (mean ± standard error). The independent *t*-test was used to examine the differences of the mean maxillary sinus area

difference of mean sinus area between age groups was found ($P = 0.01$) [Figure 4].

Frequency distribution of five types of the relationship between RPMT and the maxillary sinus floor is summarized in Table 1. The first premolar had the highest probability of Type 0 (81.0%), the maxillary sinus not in contact with RPMT, compared to second premolar (69.7%), first molar (48.8%), and second molar (54.8%). In contrast, the second molar had the highest probability of Type 3 (11.9%), which means that the apex of RPMT was projecting into the sinus cavity with an inferiorly curving sinus floor. A significant different distribution of classification was observed among tooth types ($P < 0.001$), but not between different sides ($P = 0.488$) [Table 1].

Totally, the Type 3 classification of RPMT relative to maxillary sinus presented the greatest mean sinus area, followed by Type 2, Type 1, and Type 0 ($P < 0.001$) [Table 2]. The Type 3 classification also demonstrated the highest mean sinus area in second premolar and first molar tooth sites, compared to other types ($P < 0.001$). No matter which tooth site was, the mean sinus area was associated with the classification of RPMT relative to maxillary sinus (all $P < 0.001$) [Table 2].

DISCUSSION

This study attempted to investigate the sinus area of the maxillary posterior area and the relationship between RPMT and the maxillary sinus floor using images obtained by CBCT with a view to provide clinicians with insightful information for the diagnosis and management of oral pathological changes (i.e., apical periodontitis of premolar and molar region), tooth extraction, and dental implant treatment. The current study has revealed that the mean sinus area in males was significantly greater than that in females [Figure 3]. In addition to gender, there is statistically significant difference of mean sinus area among age groups [Figure 4]. Regarding the frequency distribution of different types of the relationship between RPMT and the maxillary sinus floor, significant difference among different tooth sites was noted [Table 1]. Furthermore, the mean sinus area measured from cross-sectional images was greater in Type 3 classification of RPMT relative to maxillary sinus [Table 2].

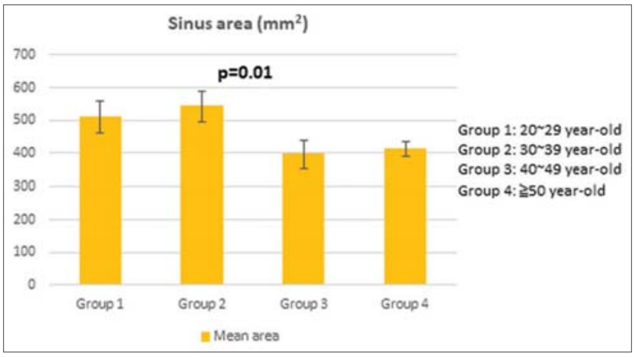

Figure 4: Maxillary sinus area measured from cross-sectional images according to different age groups. Data represent means and standard error (mean ± standard error). One-way ANOVA was used for examining the measurements of maxillary sinus area between different age groups

Our data showed that the mean sinus area was significantly smaller in older patients [Figure 4]; this was in line with other studies, which showed decreased maxillary sinus area as age increased.[18-20] In contrast, Ariji *et al.* had reported that maxillary sinus volume increased with age.[14] The patients for their research had an average age of 46.8 years and the authors did not rule out the effect of tooth loss on maxillary sinus volume in different age groups. Previous studies showed that posterior maxillary teeth extraction was related to the further maxillary sinus expansion and sinus dimension.[18,21] In the present study, the patients had an average age of 47.3 years, ranged from 20 to 76 years old, and the patients were excluded when the corresponding posterior maxillary tooth was missing [Figure 4]. As the size of the maxillary sinus is not constant over time and age might be the critical factors for the volumetric change in the maxillary sinus in adults,[2,18] attention to sinus volumetric change and sinus position relative to RPMT was suggested before dental treatment in posterior maxillary region.

According to the results obtained from the present study, the value of the mean maxillary sinus area was statistically greater among males than females, which is consistent with previous studies that reported sinus volumes being larger in males compared to females [Figure 3].[20,22] Most of the previous studies showed a significant difference in maxillary sinus volume between males and females in ages from around the

Table 1: Frequency distribution of five types of the relationship between root of posterior maxillary teeth and the maxillary sinus floor according cone-beam computed tomography cross-sectional images

Variables	Type 0, *n* (%)	Type 1, *n* (%)	Type 2, *n* (%)	Type 3, *n* (%)	Type 4, *n* (%)	*P*
Side						
Right	102 (61.8)	19 (11.5)	36 (21.8)	8 (4.8)	0	0.488
Left	98 (63.2)	15 (9.7)	28 (18.1)	13 (8.4)	1 (0.7)	
Tooth						
First premolar	51 (81.0)	5 (7.9)	6 (9.5)	1 (1.6)	0	<0.001
Second premolar	62 (69.7)	5 (5.6)	17 (19.1)	5 (5.6)	0	
First molar	41 (48.8)	8 (9.5)	30 (35.7)	5 (6.0)	0	
Second molar	46 (54.8)	16 (19.0)	11 (13.1)	10 (11.9)	1 (1.2)	
Tooth and side						
First premolar, right	27 (84.4)	2 (6.3)	3 (9.4)	0 (0)	0	0.002
Second premolar, right	32 (69.6)	1 (2.2)	11 (23.9)	2 (4.3)	0	
First molar, right	21 (48.8)	4 (9.3)	16 (37.2)	2 (4.7)	0	
Second molar, right	22 (50.0)	12 (27.3)	6 (13.6)	4 (9.1)	0	
First premolar, left	24 (77.4)	3 (9.7)	3 (9.7)	1 (3.2)	0	
Second premolar, left	30 (69.8)	4 (9.3)	6 (14.0)	3 (7.0)	0	
First molar, left	20 (48.8)	4 (9.8)	14 (34.1)	3 (7.3)	0	
Second molar, left	24 (60.0)	4 (10.0)	5 (12.5)	6 (15.0)	1 (2.5)	
Total	200 (62.5)	34 (10.6)	64 (20.0)	21 (6.6)	1 (0.3)	

The classifications were categorized according to the relationship of RPMT relative to the maxillary sinus floor. The Chi-square tests were used for comparing the distribution of classifications in different “Side”, “Tooth type” and “Side and tooth type”. The level of statistical significance was set at $P<0.05$. RPMT: Root of posterior maxillary teeth

time of growth period to prime of life. As age may affect the value of the sinus area, further longitudinal or cohort studies for investigating the influence of gender factor in patients in different ages are still needed.

We studied the position of the roots of the maxillary posterior teeth in relation to the sinus floor in different tooth sites and found a significant difference of the frequency distribution of the five types of the topographic relationship imaged by CBCT. Our data showed that classification Type 0 was the most frequent relationship for all maxillary posterior tooth roots, indicating that the roots of the teeth are away from the cortical border of the sinus [Table 1]. These data agreed with findings of previous studies.[16,23] In the present study, for the premolars, Type 0 was the most common relationship between root apex and sinus (81%) and the total incidence of Types 1, 2, and 3 relationship was 19%. For the second premolars, the frequencies of Type 0 accounted for 69.7%, and frequencies of Type 2 and Type 3 were observed more than the first premolars. These data were consistent with previous studies in different ethnic populations, which shows that the root position of the second premolar is relatively close to the maxillary sinus floor.[3,23-25]

For the molars, Type 0 was more common in both the first and second molars (48.8% and 54.8%, respectively), which is consistent with previous reports [Table 1].[3,26] Our data further showed that Type 2 occurred more often in the maxillary first molar than that in the second molar (35.7% vs. 13.1%). On the other hand, second molars had the highest probability of Type 3 (11.9%) when compared to first premolars (1.6%), second premolar (5.6%), and first molars (6.0%). These data suggested that the apices which protrude into the sinus were more common in the second molar and this also indicated the complications including development of odontogenic maxillary sinusitis and endoantral syndrome during tooth extraction and dental implant perforation in the second molars is more likely to occur.[16] Therefore, the dental clinicians should be more aware of the possible occurred complication of dental treatment in second molar region when performing dental practice.

Previous studies on the relationship between maxillary posterior teeth and the maxillary sinus floor did not consider the value of maxillary sinus area. In the present study, the data showed significant difference of the value of sinus area between different relationships of RPMT relative to the maxillary sinus floor. In general, the value of sinus area increased from first premolars to second molars in different relationships, except for Type 1, where the first premolar had greater mean value of

Table 2: The comparison of cross-sectional area measurement of the maxillary sinus in different relationships of root of posterior maxillary teeth relative to the maxillary sinus floor

Cross-sectional area (mm^2)	Type 0		Type 1		Type 2		Type 3		Type 4		P
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Side											
Right	313.2^{a}	246.1	699.8^{b,c}	194.9	598.5^{b}	301.3	891.4^{c}	418.5	-	-	<0.001
Left	339.9^{a}	261.9	596.2^{b}	286.7	591.2^{b}	240.9	887.8^{c}	334.6	965.3*	-	<0.001
Tooth											
First premolar	122.5^{a}	80.6	400.5^{b}	218.7	201.7^{a}	138.4	221.4*	-	-	-	<0.001
Second premolar	215.0^{a}	121.7	366.8^{a}	74.3	358.6^{a}	181.8	712.4^{c}	317.9	-	-	<0.001
First molar	416.7^{a}	220.9	642.9^{a,b}	166.4	714.6^{b}	176.6	1046.2^{c}	388.2	-	-	<0.001
Second molar	621.8^{a}	230.4	828.7^{a,b}	140.0	850.3^{b}	137.8	965.8^{b}	294.1	965.3*	-	<0.001
Tooth and side											
First premolar, right	127.8	81.2^{a}	492.4^{b}	80.8	122.8^{a}	74.6	-	-	-	-	<0.001
Second premolar, right	202.7	124.2^{a}	361.3*	-	368.8^{a,b}	212.9	626.8^{b}	496.2	-	-	0.002
First molar, right	399.8^{a}	194.8	575.9^{a,b}	144.6	745.2^{a,b}	189.1	934.5^{c}	674.2	-	-	<0.001
Second molar, right	618.8^{a}	236.7	803.9^{a,b}	142.3	866.1^{a,b}	169.1	1002.2^{c}	333.0	-	-	0.004
First premolar, left	116.4^{a}	81.2	339.2^{b}	279.9	280.6^{a,b}	153.9	221.4*	-	-	-	0.008
Second premolar, left	228.0^{a}	119.7	368.1^{a}	85.7	339.7^{a}	120.3	769.4^{c}	258.4	-	-	<0.001
First molar, left	434.4^{a}	249.2	710.0^{a}	178.0	679.7^{a}	160.8	1120.7^{c}	231.1	-	-	<0.001
Second molar, left	624.5^{a}	229.4	903.3^{a}	117.7	831.4^{a}	104.3	941.5^{a}	295.7	965.3*	-	0.011
Total	326.3^{a}	253.7	654.1^{b}	241.5	595.3^{b}	274.4	889.1^{c}	358.5	965.3*		<0.001

The one-way analysis of variance with Tukey's *post hoc* test was used for comparing the sinus area measurement of maxillary sinus between different classifications of the RPMT relative to the floor of maxillary sinus. a, b and c designate significantly distinct data subsets with the Tukey's *post hoc* analysis. The level of statistical significance was set at $P<0.05$. *Denote the tooth excluded from the calculation for <2 samples. RPMT: Root of posterior maxillary teeth, SD: Standard deviation

sinus area than second premolars [Table 2]. For the value of sinus area of each relationship type in first and second molars, the Type 3 relationship had the greatest value followed by Type 2, 1, and 0. However, for the value of sinus area of each relationship type in first premolars, the Type 1 relationship had the greatest value followed by Type 3, 2, and 0. For the second premolar, the greatest mean value of sinus area was observed in Type 3, followed by Type 1, 2, and 0. These data indicated that the RPMT relative to adjacent sinus floor may be associated with dimension of maxillary sinus, and the maxillary sinus with greater dimension would be closer to the RPMT. As our data suggested that maxillary sinus area decreased as age increased, it is also important to evaluate the influence of age on the relationship between the maxillary sinus floor and the maxillary posterior teeth in adults.

The close relationship between teeth roots and maxillary sinus could lead to the increased risks of sinusitis, sinus membrane perforation, oroantral communication, endoantral syndrome, or root displacement into the maxillary sinus when performing dental practice. Therefore, the area of maxillary sinuses and relationships of RPMT relative to the maxillary sinus floor in the CBCT image play important roles in the dental treatment plan. When using dental images for diagnosis and treatment plan, the cross-sectional image of the CBCT allows an accurate interpretation of the true relationships between the teeth roots and the sinus, especially an investigation of tooth root proximity to the maxillary sinus, compared to a panoramic radiograph.[16,27,28] Although the accessibility of CBCT and the cost and radiation dose from CBCT are higher than panoramic radiography, a CBCT for roots in proximity to the sinus, not identified on panoramic radiographs, might be considered by the clinician on a case-by-case basis.

In this study, the association between maxillary sinus area and position of RPMT relative to maxillary sinus was investigated to demonstrate the impact of dynamic change of maxillary sinus on the risk of clinical dental practice. However, with the meticulous assessment before dental treatment and postoperative care, the risk of possible complications in the maxillary sinus might be decreased, even though the maxillary sinus was so close to the posterior teeth. For example, raising of a mucoperiosteal vestibular flap and covering the defect by rotating and suturing the flap had been proposed to achieve primary closure after tooth extraction for reducing the risk of oral sinus communications.[29,30] Moreover, further researches focus on the spatial and temporal changes of sinus dimension and its associated factors are still required in future.

CONCLUSIONS

Our data showed that age was an important influencing factor to the value of the maxillary sinus area as well as gender had effects. The Type 3 classification of RPMT relative to maxillary sinus presented the greatest mean sinus area. The mean sinus area was associated with the classification of RPMT relative to maxillary sinus. These findings may demonstrate that the maxillary sinus with greater dimension would be closer to the RPMT and might complicate the dental practice.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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