Journal of Dental Sciences 19 (2024) 1972–1982

Available online at www.sciencedirect.com

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journal homepage: www.e-jds.com

Original Article

An analysis of the relevance and proximity between maxillary posterior root apices to the maxillary sinus and the buccal cortical bone plate

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Received 23 June 2024; Final revision received 18 July 2024
Available online 25 July 2024

KEYWORDS
Cone-beam computed tomography;
Maxillary sinus;
Root apex;
Sinus proximity;
Buccal bone thickness

Abstract *Background/purpose:* Understanding the relationship between maxillary sinus and posterior root apices is critical in preventing dental treatment complications. This study aimed to analyze and showcase the relationship between the posterior root apices and the maxillary sinus floor, the distance to the buccal cortical bone, and their correlation with age, gender, and sides.
Materials and methods: Cone-beam computed tomography images were collected from 94 patients with a total of 478 maxillary posterior teeth and 997 roots. The shortest distance from root apices to the closest border of maxillary sinus and the outer buccal cortical bone margin were measured and grouped for statistical analysis for the differences ($P < 0.05$).
Results: The root apices of maxillary molars and single-rooted second premolars were located closer to the maxillary sinus compared to first premolars ($P < 0.01$). The buccal root of two-

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https://doi.org/10.1016/j.jds.2024.07.019

rooted first premolar had the shortest horizontal distance to the buccal cortical bone among all roots ($P < 0.01$). The lowest position of the maxillary sinus floor was mostly located at the palatal side ($P < 0.01$) and between the buccal and palatal root apices ($P < 0.01$) in the maxillary premolars and molars, respectively. Increasing age would lead to longer distances between the root apices and the maxillary sinus ($P < 0.01$). Additionally, male patients had thicker buccal cortical bone than female patients ($P < 0.01$).

Conclusion: Different tooth positions, age, and gender significantly impact the relationships between root apices and the maxillary sinus and buccal cortical plates, informing patient-centered and individually tailored approaches for more effective and safer surgical endodontic treatment.

Introduction

Maxillary sinus, located above the maxillary posterior teeth and adjacent to the nasal cavity, exhibits variable dimensions, typically averaging 40 × 26 × 28 mm with a volume of approximately 15 ml in adults.[1] In about half of the population, the maxillary sinus extends into the alveolar process,[1] with its floor position varying with age.[2] Maxillary sinus development progresses until the third decade in males and the second decade in females.[3] Expansion of the maxillary sinus floor may further result in the closer proximity of root apices to the sinus.[4]

The thickness of buccal cortical bone covering root apices is crucial for surgical endodontic treatment. The thickness value impacts treatment planning, surgical access design, instrument selection and utilization, and determines the depth and complexity of surgical approaches in limited space.[5] In a retrospective cohort study involving 143 patients undergoing endodontic microsurgery, the correlation between radiographic healing outcomes and preoperative buccal plate thickness was assessed. The study found significant benefits from guided tissue regeneration for patients with buccal plate thicknesses ≤1.0 mm, highlighting the critical role and impact of thickness values in crafting treatment strategies and influencing healing outcomes.[6] Furthermore, metrics of buccal cortical bone thickness provide valuable information regarding the spread and extent of infection, as well as the possible location of sinus tracts.[7] Accurate estimation of these values is essential to ensure successful surgical procedures.

Cone-beam computed tomography (CBCT) imaging is invaluable for evaluating anatomical structures, offering high spatial resolution in three-dimensional planes while minimizing issues like distortion and superimposition. A strong correlation (Pearson correlation coefficient of 0.85) was found between the values measured from the CBCT images and those from cadaver specimens, suggesting that CBCT can be used as a clinical tool for examination and measurement.[8] CBCT images have been utilized to assess the proximity of root apices and the maxillary sinus, facilitating successful dental treatments and reducing the risks of injury to vital structures.[2,4,5,9]

Although some previous studies have investigated the relationship between the maxillary sinus and root apices in posterior teeth across different regions, there is limited data exploring correlations with age, gender, or various tooth and root configurations.[4,7,8,10–16] Several published articles have focused only on molar teeth without information on premolars.[7,8,16] Additionally, different ethnicities may exhibit anatomical variances. There is an urgent need to address these knowledge gaps. The aim of this study is to investigate the relationship between the root apices of maxillary premolars and molars with the maxillary sinus and outer buccal cortical bone margin, classify the horizontal and vertical relationships between the root apices and the maxillary sinus floor, and explore correlations with age, gender, and sides.

Materials and methods

Patient subjects

This study was approved by the Ethics Committee, National Taiwan University Hospital. The images were obtained from the CBCT scanner 3D Accuitomo 170 (J. Morita MFG. Corp., Kyoto, Japan). The cases were collected retrospectively from August, 2020 to January, 2023 in the dental department of National Taiwan University Hospital. Totally 94 patients and 478 maxillary posterior teeth with 997 roots were recruited based on inclusion and exclusion criteria.

Inclusion and exclusion criteria

The inclusion and exclusion criteria of this study were based on relevant articles that had been previously utilized, validated, and published.[4,5,9,16] The inclusion criteria were as follows: patients must be aged ≥18 years old, have fully erupted maxillary permanent premolars or molars with closed apices on the CBCT scan, show no signs of apical radiolucency or definitive root resorption, and have an intact and complete sinus floor. The CBCT material used must meet the following criteria for the field of view: 100 mm × 100 mm x 51 mm, 140 mm × 140 mm x 51 mm, 140 mm × 140 mm x 101 mm, or 170 mm × 170 mm x 121 mm. The operating parameters should be set at 84–90 kVp and 3.5～8 mA, with a scanning time of 17.5 s, and images should have a voxel size of 0.25 mm.

The exclusion criteria included the presence of periapical or periradicular radiolucency or bony destruction, patients who received treatment for sinus floor elevation with/without grafting, patients who underwent orthodontic treatment, identification of foreign materials within the maxillary sinus, and CBCT images with scatter artifacts.

Radiographic evaluations

The re-formatted images were analyzed and reviewed using i-Dixel imaging software (J. Morita MFG. Corp.) with a 0.5 mm slice interval and 1 mm slice thickness. The distances were measured using the tools built into the imaging software, and the parameters of images were assessed according to the following descriptions and categories.

The shortest distance from root apices to the closest border of maxillary sinus

The shortest distance from root apices to the closest border of maxillary sinus were measured at the sagittal and coronal views. The smaller value in these 2 measurements were recorded. If the root apices were located inside the maxillary sinus, then the distance was marked with a negative value (Fig. 1).[4]

The shortest horizontal distance from root apices to the outer buccal cortical bone margin

The shortest horizontal distance from root apices to the outer buccal cortical bone margin were measured at the axial view. If the mesiobuccal root of maxillary molar had two canals, then the midpoint of the two canals were considered as the root apex for evaluation (Fig. 2).[5]

The horizontal relationships between root apices of maxillary posterior teeth and the maxillary sinus floor

The CBCT images were evaluated at the coronal view. The horizontal relationships can be categorized into three types: Type B, where the lowest point of sinus floor is located on the buccal side; Type BP, where it appears between the buccal and palatal roots; and Type P, where it is situated on the palatal side of the palatal root (Fig. 3).[5]

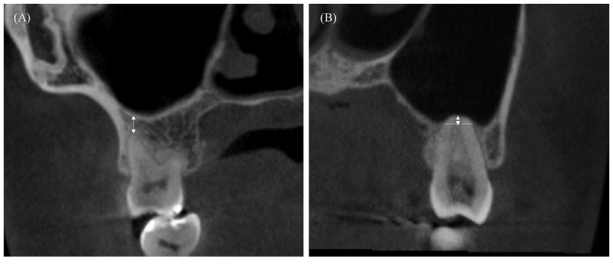

Figure 1 Coronal views of the cone-beam computed tomography show the measurements of the shortest distances (white double-headed arrows) between the root apices and the maxillary sinus floor in (A) a posterior tooth with roots located outside the maxillary sinus and (B) a posterior tooth with roots situated inside the maxillary sinus.

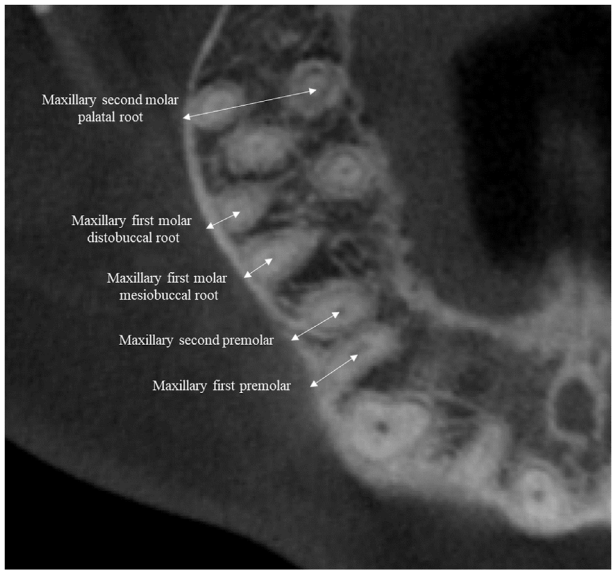

Figure 2 An axial view of the cone-beam computed tomography presents measurements of the shortest horizontal distance from the maxillary posterior root apices to the outer buccal cortical bone plate (indicated by white double-headed arrows) in the maxillary first premolar, second premolar, first molar, and second molar. If two canals existed within one root, the midpoint of the two canals was considered as the landmark for evaluation.

The vertical relationships between root apices of maxillary posterior teeth and the maxillary sinus floor

The CBCT images were examined in sagittal and coronal views and classified into three categories based on the position of root apices with respect to the maxillary sinus: Type OS for apices outside the sinus, Type CO for apices in contact with the sinus floor, and Type IS for apices inside the sinus (Fig. 4).[2] If the images from the sagittal and coronal views showed inconsistent result, the priority of these 3 groups was in the order of Type IS, Type CO, and Type OS.[2]

Serial axial, coronal, and sagittal slices were reviewed. All data were measured at an interval of 1 week. The *t* test was used to examine the replicate measurements by Statistical Package for Social Sciences (SPSS) software version 21 (SPSS Inc., Chicago, IL, USA).[2] No statistical difference was found in the shortest distance from root apices to the closest border of maxillary sinus and the outer buccal cortical bone margin.

Statistical analysis

The measurement and category data were presented through descriptive statistics and tables. The distribution among groups was analyzed using the multinomial test. The differences in the distance of posterior tooth apices to

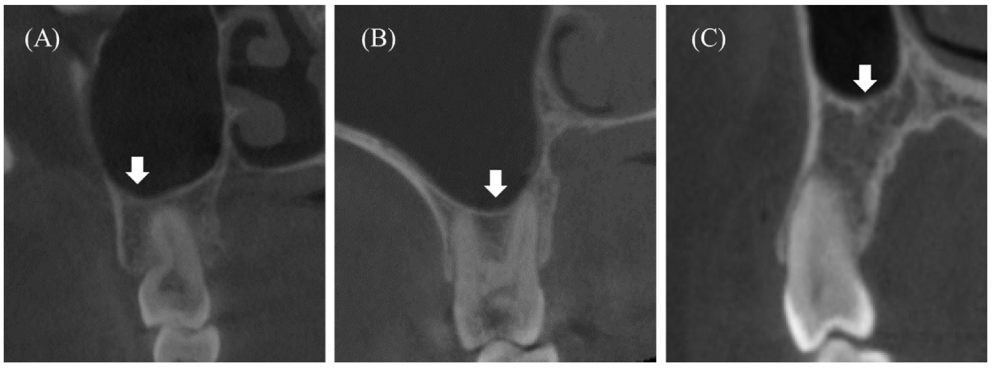

Figure 3 Coronal views of the cone-beam computed tomography demonstrate the horizontal relationships between the lowest point of the maxillary sinus floor (arrowhead) and the root apices of maxillary posterior teeth, grouped into (A) Type B, where the lowest point of the sinus floor is located on the buccal side of the root apex; (B) Type BP, where it appears between the buccal and palatal roots; and (C) Type P, where it is situated on the palatal side of the root apex.

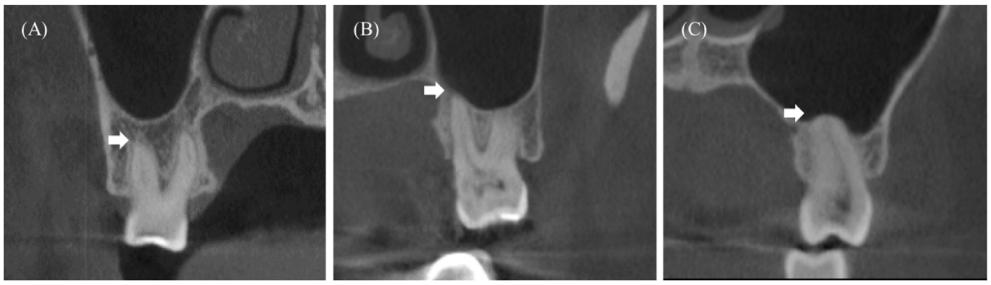

Figure 4 Coronal views of the cone-beam computed tomography showcase the vertical relationships between the root apices of maxillary posterior teeth and the maxillary sinus floor (arrowhead), categorized into: (A) Type OS for root apices located outside the sinus, (B) Type CO for root apices in contact with the sinus floor, and (C) Type IS for root apices situated inside the sinus.

maxillary sinus and the outer buccal cortical bone between individual roots were calculated using analysis of variance followed by the Tukey multiple comparison test. Fisher exact test was utilized to evaluate the distribution of vertical relationships of root apices with respect to the maxillary sinus floor in different tooth positions. Pearson correlation coefficient was used to investigate the association between the distance to the maxillary sinus and the outer buccal cortical bone in bilateral sides. Univariate and multiple linear regression analyses were then applied to analyze the correlation with age, gender, and distances simultaneously. The statistical analysis was conducted using R Studio Version 0.99.902 (The R Foundation for Statistical Computing, Vienna, Austria) and Statistical Package for Social Sciences software version 21 (SPSS Inc.). Differences were considered significant at $P < 0.05$.

Results

The study assessed 94 patients and 478 maxillary posterior teeth with 997 roots. Among the patients, 37 (39.36%) were male and 57 (60.64%) were female, with a mean age of 49.33 ± 16.95 years (range: 18–82 years). The data included 130 maxillary first premolars, 120 maxillary second premolars, 103 maxillary first molars, and 125 maxillary second molars.

The shortest distance from root apices to the closest border of maxillary sinus

The shortest distances from root apices of single-rooted premolars to the maxillary sinus were 6.69 ± 3.87 mm (right maxillary first premolars), 5.89 ± 4.16 mm (left maxillary first premolars), 3.07 ± 3.44 mm (right maxillary second premolars), and 2.44 ± 3.36 mm (left maxillary second premolars). For two-rooted premolars, the shortest distances to the maxillary sinus were 6.28 ± 4.25 mm (buccal) and 5.62 ± 4.32 mm (palatal) for right maxillary first premolars, 5.85 ± 3.70 mm (buccal) and 4.80 ± 3.51 mm (palatal) for left maxillary first premolars, 4.45 ± 6.66 mm (buccal) and 4.35 ± 7.53 mm (palatal) for right maxillary right second premolars, and 1.38 ± 2.39 mm (buccal) and 0.26 ± 2.56 mm (palatal) for left maxillary second premolars (Table 1).

The measurements in right and left maxillary first molars were 1.62 ± 2.90 mm (mesiobuccal), 1.71 ± 2.69 mm (distobuccal), and 1.34 ± 2.54 mm (palatal), and 1.67 ± 2.87 mm (mesiobuccal), 1.65 ± 2.73 mm (distobuccal), and 1.06 ± 2.66 mm (palatal), respectively. The measurements in the three-rooted second molars were 0.60 ± 2.18 mm (mesiobuccal), 0.86 ± 2.37 mm (distobuccal), and 1.24 ± 2.31 mm (palatal) for right maxillary second molars, and 0.36 ± 1.15 mm (mesiobuccal),

Table 1 The shortest distance from the right and left maxillary posterior teeth root apices to the maxillary sinus and outer buccal cortical bone margin (mm).

Tooth		Right maxillary first premolar			Right maxillary second premolar			Right maxillary first molar			Right maxillary second molar					
Root numbers		1	2		1	2		3			1	2		3		
Root		Single	B	P	Single	B	P	MB	DB	P	Single	B	P	MB	DB	P
N		25	38	38	56	3	3	60	60	60	1	5	5	60	60	60
Shortest distance to the maxillary sinus	Mean	6.69	6.28	5.62	3.07	4.45	4.35	1.62	1.71	1.34	1.03	1.65	1.60	0.60	0.86	1.24
	SD	±3.87	±4.25	±4.32	±3.44	±6.66	±7.53	±2.90	±2.69	±2.54	NA	±2.25	±2.89	±2.18	±2.37	±2.31
	Median	6.48	6.29	5.43	1.57	1.24	0.00	0.00	0.37	0.49	1.03	0.45	0.41	0.00	0.00	0.71
	Min to Max	0.34～13.69	0～14.89	0～14.93	−2～12.78	0～12.11	0～13.04	−4～11.11	−1.58～10.78	−3～9.68	1.03	0–5.15	0–6.76	−4.99–11.92	−4.27–12.91	−2.01–10.45
Shortest distance to buccal cortical bone	Mean	3.22	2.33	5.91	3.78	4.90	9.26	3.29	3.36	10.46	7.49	3.48	7.86	4.75	3.66	9.96
	SD	±1.31	±0.82	±1.48	±1.31	±1.74	±0.57	±1.15	±1.50	±1.74	±NA	±1.21	±1.51	±1.55	±1.50	±1.86
	Median	3.17	2.28	5.81	3.52	4.02	9.49	3.09	3.15	10.43	7.49	3.36	7.63	4.49	3.61	9.87
	Min to Max	0–5.75	0.71–4.12	3.33–9.29	0–6.99	3.77–6.9	8.62–9.68	0.86–5.79	0.53–6.53	3.28–13.64	7.49	1.91–5.02	6.1–10.29	2.07–8.94	0.85–9.15	5.51–14.04

Tooth		Left maxillary first premolar						Left maxillary second premolar			Left maxillary first molar			Left maxillary second molar					
Root numbers		1	2		3			1	2		3			1	2		3		
Root		Single	B	P	MB	DB	P	Single	B	P	MB	DB	P	Single	B	P	MB	DB	P
N		27	39	39	1	1	1	58	3	3	43	43	43	6	3	3	50	50	50
Shortest distance to the maxillary sinus	Mean	5.89	5.85	4.80	0	0	0.9	2.44	1.38	0.26	1.67	1.65	1.06	1.13	1.19	0.87	0.36	0.65	1.25
	SD	±4.16	±3.70	±3.51	NA	NA	NA	±3.36	±2.39	±2.56	±2.87	±2.73	±2.66	±1.76	±1.67	±0.76	±1.15	±1.29	±1.91
	Median	6.05	6.05	4.36	0	0	0.9	1.83	0.00	0.00	0.00	0.00	0.00	0.68	0.47	1.19	0.00	0.00	0.54
	Min to Max	0.34～17.09	0.61～13.57	0～11.6	0	0	0.9	−2.79～16.77	0～4.14	−2.15～2.94	−2.92～12.05	−1.03～11.37	−4.25～10.31	0～4.66	0～3.09	0～1.42	−2.86 ～5.22	−2.23 ～5.05	−1.83 ～8.24
Shortest distance to buccal cortical bone	Mean	3.08	2.06	5.58	1.80	1.74	7.96	3.77	4.43	8.18	3.23	3.26	10.28	4.95	4.38	8.69	4.71	3.73	10.37
	SD	±0.81	±0.89	±1.33	NA	NA	NA	±1.56	±2.32	±1.71	±1.39	±1.66	±1.52	±1.30	±1.49	±2.12	±1.33	±1.53	±1.59
	Median	3.21	1.87	5.86	1.80	1.74	7.96	3.52	3.35	9.06	2.96	3.01	10.21	4.89	4.99	9.13	4.69	3.60	10.22
	Min to Max	1.73–5.15	0.53–4.12	0.67–7.44	1.8	1.74	7.96	1.38–9.3	2.85–7.1	6.21–9.28	1.12–8.72	0.7–8.96	7.05–14.78	3.46–6.42	2.68–5.47	6.38–10.56	2.14–8.34	1.42–8.05	6.66–13.65

B: buccal; P: palatal; MB: mesiobuccal; DB: distobuccal; NA: not applicable; SD: standard deviation.

0.65 ± 1.29 mm (distobuccal), and 1.25 ± 1.91 mm (palatal) for left maxillary second molars (Table 1).

Maxillary molars and single-rooted second premolars were closer to the maxillary sinus than first premolars ($P < 0.01$). There was no significant difference between the distance to the maxillary sinus and the different root apices within first premolars, second premolars, and first molars, respectively. Only the mesiobuccal root of second molar was significantly closer to the maxillary sinus than the palatal root ($P < 0.05$).

The shortest horizontal distance from root apices to the outer buccal cortical bone margin

The shortest horizontal distances from root apices to the outer buccal cortical bone were 3.22 ± 1.31 mm (right first), 3.08 ± 0.81 mm (left first), 3.78 ± 1.31 mm (right second), and 3.77 ± 1.56 mm (left second) in single-rooted maxillary premolars. For buccal roots of two-rooted maxillary first premolars, values were 2.33 ± 0.82 mm (right) and 2.06 ± 0.89 mm (left), and for palatal roots, measurements were 5.91 ± 1.48 mm (right) and 5.58 ± 1.33 mm (left) (Table 1).

Maxillary first molars have mesiobuccal roots at 3.29 ± 1.15 mm (right) and 3.23 ± 1.39 (left), distobuccal roots at 3.36 ± 1.50 mm (right) and 3.26 ± 1.66 mm (left), and palatal roots at 10.46 ± 1.74 mm (right) and 10.28 ± 1.52 mm (left) from the buccal cortical bone. In three-rooted maxillary second molars, mesiobuccal roots are 4.75 ± 1.55 mm (right) and 4.71 ± 1.33 mm (left), distobuccal roots are 3.66 ± 1.50 mm (right) and 3.73 ± 1.53 mm (left), and palatal roots are 9.96 ± 1.86 mm (right) and 10.37 ± 1.59 mm (left) (Table 1).

Excluding the only three-rooted premolar, buccal root of the two-rooted first premolar demonstrated the shortest horizontal distance to buccal cortical bone ($P < 0.01$). The thickness of the buccal cortical bone did not exhibit a significant difference between the mesiobuccal and distobuccal roots in three-rooted first molars. However, in three-rooted second molars, mesiobuccal root exhibited a significantly thicker buccal cortical bone than distobuccal root ($P < 0.01$).

Horizontal relationships between root apices of maxillary posterior teeth and the maxillary sinus floor

In premolars, the lowest point of the maxillary sinus floor was located on the palatal side of palatal root (Type P). The percentage was 93.65% (right) and 92.54% (left) for maxillary first premolars, and 96.61% (right) and 93.44% (left) for maxillary second premolars. In molars, the lowest point of maxillary sinus floor was situated between the buccal and palatal roots (Type BP). The corresponding percentages were 91.67% (right) and 86.05% (left) for maxillary first molars, and 60.61% (right) and 61.02% (left) for maxillary second molars (Table 2).

Maxillary premolars had the lowest point of maxillary sinus floor on the palatal side of the root apices, while maxillary molars had it between the buccal and palatal root apices with significant difference ($P < 0.01$). Maxillary second molars have the deepest point of maxillary sinus floor on the buccal side of root apices (Table 2).

Vertical relationships between root apices of maxillary posterior teeth and the maxillary sinus floor

The majorities of root apices of premolars were located outside the maxillary sinus (Type OS), while in molars, more root apices contacted the maxillary sinus floor (Type CO). None of the root apices of maxillary first premolars were found to extend inside the maxillary sinus (Type IS) (Table 3).

Premolars had most root apices outside the maxillary sinus, while molars had more root apices contacting or extending inside the maxillary sinus floor ($P < 0.01$).

Bilateral correlation analysis

The distance between posterior root apices and the closest border of maxillary sinus demonstrated a moderate to strong positive correlation, as indicated by Pearson correlation coefficients ranging from 0.46 to 0.88 for different tooth positions on both sides. Similarly, the shortest horizontal distance from posterior root apices to the outer buccal cortical bone margin displayed a moderate positive correlation, with Pearson correlation coefficients ranging from 0.57 to 0.79 for different tooth positions on both sides, except for the maxillary second premolar which showed a lower correlation coefficient of 0.38.

Age and gender analysis

The univariate and multiple linear regression analyses showed a significant correlation between the distance from the posterior root apices to the closest border of the maxillary sinus and age, indicating that as age increases, the measured distances also increase ($P < 0.01$). In the multiple linear regression model, for each additional year of age, the shortest distance from the root apices to the closest border of the maxillary sinus increases by 0.06 mm. However, there was no significant correlation between gender and the values (Table 4).

The univariate and multiple linear regression models showed a significant decrease in the measurements between the posterior root apices and the buccal cortical bone with increasing age ($P < 0.01$). In the multiple linear regression model, for each additional year of age, the shortest horizontal distance from the root apices to the outer buccal cortical bone margin decreases by 0.02 mm. Moreover, male patients had significantly thicker buccal cortical bone than female patients ($P < 0.01$) (Table 4).

Discussion

The anatomic relationship of the maxillary sinus and maxillary posterior root apices is related to dental complications during endodontic, periodontal, or orthodontic treatment.[7,17] Distinctive genetic and anatomic characteristics exist in different populations. Our study investigated and showcased valuable data from Taiwanese adults,

Table 2 The horizontal relationships between the root apices of maxillary posterior teeth and the maxillary sinus floor (case number and percentage).

Tooth		Right maxillary first premolar			Right maxillary second premolar			Right maxillary first molar			Right maxillary second molar			
Lowest point of the maxillary sinus floor		B	BP	P	B	BP	P	B	BP	P	B	BP	P	
Root numbers	1	0 (0.00%)	0 (0.00%)	25 (39.68%)	1 (1.69%)	0 (0.00%)	55 (93.22%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (1.52%)	0 (0.00%)	0 (0.00%)	
	2	1 (1.59%)	3 (4.76%)	34 (53.97%)	0 (0.00%)	1 (1.69%)	2 (3.39%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (1.52%)	2 (3.03%)	2 (3.03%)	
	3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	4 (6.67%)	55 (91.67%)	1 (1.67%)	17 (25.76%)	38 (57.58%)	5 (7.58%)	
Total		1 (1.59%)	3 (4.76%)	59 (93.65%)	1 (1.69%)	1 (1.69%)	57 (96.61%)	4 (6.67%)	55 (91.67%)	1 (1.67%)	19 (28.79%)	40 (60.61%)	7 (10.61%)	248
Multinomial test (*P* value)		**< 0.01**			**< 0.01**			**< 0.01**			**< 0.01**			
Tooth		**Left maxillary first premolar**			**Left maxillary second premolar**			**Left maxillary first molar**			**Left maxillary second molar**			
Lowest point of the maxillary sinus floor		**B**	**BP**	**P**	**B**	**BP**	**P**	**B**	**BP**	**P**	**B**	**BP**	**P**	
Root numbers	1	0 (0.00%)	0 (0.00%)	27 (40.30%)	3 (4.92%)	0 (0.00%)	55 (90.16%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	4 (6.78%)	0 (0.00%)	2 (3.39%)	
	2	1 (1.49%)	3 (4.48%)	35 (52.24%)	0 (0.00%)	1 (1.64%)	2 (3.28%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (1.69%)	1 (1.69%)	1 (1.69%)	
	3	1 (1.49%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	3 (6.98%)	37 (86.05%)	3 (6.98%)	14 (23.73%)	35 (59.32%)	1 (1.69%)	
Total		2 (2.99%)	3 (4.48%)	62 (92.54%)	3 (4.92%)	1 (1.64%)	57 (93.44%)	3 (6.98%)	37 (86.05%)	3 (6.98%)	19 (32.20%)	36 (61.02%)	4 (6.78%)	230
Multinomial test (*P* value)		**< 0.01**			**< 0.01**			**< 0.01**			**< 0.01**			

B: The lowest point of the maxillary sinus floor was located on the buccal side.
BP: The lowest point of the maxillary sinus floor was appeared between the buccal and palatal roots.
P: The lowest point of the maxillary sinus floor was situated on the palatal side of the palatal root.

Table 3 The vertical relationships between the root apices of maxillary posterior teeth and the maxillary sinus floor (case number and percentage).

Tooth	Right maxillary first premolar			Right maxillary second premolar			Right maxillary first molar			Right maxillary second molar					
Root	Single	B	P	Single	B	P	MB	DB	P	Single	B	P	MB	DB	P
Root numbers	25	38	38	56	3	3	60	60	60	1	5	5	60	60	60
OS	25 (100.00%)	36 (94.74%)	35 (92.11%)	48 (85.71%)	2 (66.67%)	1 (33.33%)	26 (43.33%)	31 (51.67%)	32 (53.33%)	1 (100.00%)	3 (60.00%)	4 (80.00%)	23 (38.33%)	24 (40.00%)	35 (58.33%)
CO	0 (0.00%)	2 (5.26%)	3 (7.89%)	6 (10.71%)	1 (33.33%)	2 (66.67%)	28 (46.67%)	25 (41.67%)	20 (33.33%)	0 (0.00%)	2 (40.00%)	1 (20.00%)	32 (53.33%)	33 (55.00%)	17 (28.33%)
IS	0 (0.00%)	0 (0.00%)	0 (0.00%)	2 (3.57%)	0 (0.00%)	0 (0.00%)	6 (10.00%)	4 (6.67%)	8 (13.33%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	5 (8.33%)	3 (5.00%)	8 (13.33%)

Tooth	Left maxillary first premolar						Left maxillary second premolar			Left maxillary first molar			Left maxillary second molar					
Root	Single	B	P	MB	DB	P	Single	B	P	MB	DB	P	Single	B	P	MB	DB	P
Root numbers	27	39	39	1	1	1	58	3	3	43	43	43	6	3	3	50	50	50
OS	27 (100.00%)	38 (97.44%)	37 (95.87%)	0 (0.00%)	0 (0.00%)	1 (100.00%)	40 (68.97%)	1 (33.33%)	1 (33.33%)	21 (48.84%)	20 (46.51%)	19 (44.19%)	4 (66.67%)	2 (66.67%)	2 (66.67%)	16 (32.00%)	23 (46.00%)	29 (58.00%)
CO	0 (0.00%)	1 (2.56%)	2 (5.13%)	1 (100.00%)	1 (100.00%)	0 (0.00%)	15 (25.86%)	2 (66.67%)	1 (33.33%)	18 (41.86%)	21 (48.84%)	16 (37.21%)	2 (33.33%)	1 (33.33%)	1 (33.33%)	30 (60.00%)	24 (48.00%)	20 (40.00%)
IS	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	3 (5.17%)	0 (0.00%)	1 (33.33%)	4 (9.30%)	2 (4.65%)	8 (18.60%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	4 (8.00%)	3 (6.00%)	1 (2.00%)

B: buccal; P: palatal; MB: mesiobuccal; DB: distobuccal.
Type OS: The root apices which were situated outside the maxillary sinus.
Type CO: The root apices which were contacted with the maxillary sinus floor.
Type IS: The root apices which were located inside the maxillary sinus.

Table 4 Univariate and multiple linear regression model were used to evaluate the correlation between the age, gender and the shortest distance from the root apices to the closest border of the maxillary sinus and outer buccal cortical bone margin.

	The shortest distance from the root apices to the closest border of the maxillary sinus								The shortest distance from the root apices to the outer buccal cortical bone margin							
	Univariate linear regression analysis				Multiple linear regression analysis				Univariate linear regression analysis				Multiple linear regression analysis			
	Coefficient	95%CI		P value	Coefficient	95%CI		P value	Coefficient	95%CI		P value	Coefficient	95%CI		P value
Age	0.06	0.04	0.07	<0.01	0.06	0.04	0.07	<0.01	−0.03	−0.04	−0.01	<0.01	−0.02	−0.03	−0.01	<0.01
Gender	0.21	−0.23	0.65	0.35	0.37	−0.05	0.79	0.08	0.97	0.57	1.36	<0.01	0.90	0.51	1.30	<0.01

CI: confidence interval.

including teeth with anatomical variations and their correlation with age, gender, and sides. We included patients aged over 18 years old, as maxillary sinus gasification is completed at this age.[18] In addition, CBCT is a valuable diagnostic technique for effective treatments, providing high-quality 3D images with reliable measurements between the target and neighboring anatomic structures.[5,8,15,19]

In this study, root apices of maxillary molars and single-rooted second premolars were found to be closer to maxillary sinus than the first premolars. Previous studies also showed that molar roots are typically closer to the sinus than premolars.[2,11,19,20] The distances between the root apices to the maxillary sinus showed a tendency of decreasing toward the posterior teeth.[5,21,22] Interestingly, mesiobuccal root of the second molar was found to be closer to the sinus than the palatal root, which is in line with studies from various countries.[2,9,11,14,19,22] However, some studies have shown that distobuccal root of the second molar,[12,20,21] or palatal root of the first or second molar,[13,23] can also be the closest to the sinus. These discrepancies may be due to ethnic or genetic differences.[2,24,25]

This study found a significant correlation between the distance from root apices to the closest border of maxillary sinus and age. Similarly the average distances increase with aging due to changes in the level of maxillary sinus floor.[2] However, gender did not show significance in the distance to the maxillary sinus in this study, which is inconsistent with some other research showing a closer proximity in male patients.[4,5] Extrusion of foreign bodies or periapical disease with maxillary sinus communication can lead to sinusitis, infection, traumatic alterations, iatrogenic damage, or sinus mucosal hyperplasia.[4,9,15,19] Therefore, dental practitioners should avoid such scenarios during treatment. The study's results are valuable for determining optimal treatment modalities and estimating possible risk factors. Age is a crucial factor that clinicians should consider when treating maxillary posterior teeth as it can affect the level and relationship of the maxillary sinus with the root apices.

The two-rooted first premolar's buccal root apices were the closest to the buccal cortical bone among all the teeth studied in this research. Buccal cortical bone was thicker at the mesiobuccal root than distobuccal root in the three-rooted second molar. Previous studies have also reported similar results,[5,19,21,22,26] suggesting that maxillary first premolar may be more vulnerable to root fenestration or sinus tract from pulpal or periapical pathosis.[19] In addition, limited vestibular space and thicker buccal cortical bone make surgical approaches in the maxillary second molars more complex.[5]

This study found a significant decrease in measurements between the root apices and buccal cortical bone with increasing age, which is consistent with a previous study.[19] Additionally, the thickness of buccal cortical bone was found to be significantly thicker in male patients than in female patients, possibly due to differences in skeletal size and dimensions.[5] Given that most endodontic surgery approach from the buccal side, these findings can guide practitioners in managing periapical and periodontal surgery for maxillary posterior teeth.

The lowest position of the maxillary sinus floor was mainly located at the palatal side for premolars and between the buccal and palatal roots for molars, consistent with previous research.[5,7] Maxillary second molars were found to have the lowest point of maxillary sinus located more buccally than the root apices, which is consistent with findings from other studies.[5,7] This is likely due to the more buccal tilted crowns of the second molars resulting in palatal-directed roots.[5] Clinicians should be aware of this when performing surgical approaches in the maxillary second molars. The study provides valuable information for a comprehensive understanding of the lowest point of the maxillary sinus in each tooth position.

In this study, most of the root apices of maxillary premolars were located outside maxillary sinus floor. However, in maxillary molars, a higher percentage of root apices were found to either contact or extend into the sinus floor. Previous studies have suggested that root protrusion into the maxillary sinus is rare in maxillary premolars,[4,7,9,10,12,21,27] with only 0—7.2% of first premolars and 2.5—13.6% of second premolars showing this phenomenon.[4,5,27] One study reported that 91.9% of the first premolar root apices were located outside the maxillary sinus.[15] On the other hand, the frequency of root protrusion was found to be higher in maxillary molars, with 26.1—36.7% of the root apices protruding into the sinus.[7,10,27] Some articles also reported higher percentages of 40% and 46% of maxillary molars communicating with the sinus.[28,29] Palatal root of the first molar was found to have the highest incidence of root protrusion in one study,[19] while others have reported the greatest occurrence in the palatal root of upper first molar and mesiobuccal root of upper second molar.[9,29] The maxillary sinus has a convex shape with the lowest point around the first and second molars.[1] Root apices that extend into or contact the sinus can prone to odontogenic sinusitis.[15] The first and second molars are the most susceptible to oroantral communication,[4,30] so practitioners should be aware of their root location when treating maxillary molars.

Our study identified a positive correlation between the shortest distance from posterior root apices to the closest border of maxillary sinus and the outer buccal cortical bone margin on both sides. Additionally, previous research has indicated no statistically significant difference between the right and left teeth.[4,5] These results provide valuable insights into the morphology of each tooth, suggesting potential similarities in features and metrics between both sides in posterior teeth.

The strength of this study lies in its comprehensive measurements of maxillary premolars and molars with various configurations of one-, two-, and three-rooted teeth, providing important statistics for clinical dentistry. We used three-dimensional CBCT images as a non-invasive tool to investigate and verify anatomical structures, avoiding superimposition and distortion observed in conventional radiographs. A multiple linear regression model was employed to analyze more than one independent variable (age and gender) together to predict the shortest distance from the root apices to the maxillary sinus and the buccal cortical bone margin. Although CBCT scans are readily available nowadays, they should only be performed when necessary, following the As Low As Reasonably

Achievable principle.[5] Therefore, the findings and statistics from our study can be utilized as valuable data and references for clinical endodontics. However, we acknowledge some limitations in our study. The sample size might be too small. In addition, facial and dental anatomical structures may vary among different ethnicities, which could affect the generalizability of our results.

There were several clinical implications and practical recommendations that emerged based on the results of this study. When performing apical surgeries on the root apices of maxillary molars and single-rooted second premolars, pre-surgical CBCT may be indicated due to their proximity to the maxillary sinus. Dental practitioners may find it safer to operate on the buccal root of two-rooted first premolars, as it is more accessible from the buccal side during surgery compared to other teeth. Treating maxillary premolars from a buccal access route is safer, as the lowest position of the maxillary sinus floor is typically located on the palatal side of the root. Clinicians may expect that root apices are further from the maxillary sinus and therefore safer to operate on in elderly patients. Male patients generally have thicker buccal cortical bone, which can complicate accurate location of the root apices. These results will benefit clinicians in tailoring individual patient-centered treatment planning, classifying cases based on difficulty, and strategizing to minimize complications in endodontic surgery.

In conclusion, root apices of maxillary molars and second premolars were closer to the maxillary sinus than first premolars. The distance between root apices and maxillary sinus increased with age. The distance between buccal root of the two-rooted first premolar and the buccal cortical bone was found to be the shortest, with larger distances observed in younger and male patients. The study also found that in maxillary premolars, the lowest position of maxillary sinus floor was located on the palatal side of palatal root. However, in maxillary molars, the deepest position was located between the buccal and palatal roots, with many root apices extending into or contacting the maxillary sinus floor. These findings have significant clinical implications for improving the planning and guidance of endodontic treatments in the maxillary posterior region **(Sketch graph)**.

Declaration of competing interest

All authors declare no conflict of interest related to this article.

Acknowledgements

This study was supported by Chang Gung Memorial Hospital (CMRPF1M0081, CMRPF1F0071, CMRPF1H0063, CMRPF3E0023, NMRPF3E0041, NMRPF3E0042, NMRPF3E0043, NMRPF3H0061, NMRPF3H0062, NMRPF3H0071, NMRPF3H0072, NMRPF3H0073, CMRPF1K0071, CMRPF1K0072, NMRPF3L0031, NMRPF3L0032, NMRPF3L0041, NMRPF3L0042, ZMRPF3L0111, ZMRPF3L0121, ZMRPF3M0051, ZMRPF3M0061, CMRPF1M0081), the National Science and Technology Council, Taiwan (MOST104-2314- B-255-010-MY3, MOST106-2314-B-002-033-MY2, MOST106-2314-B-002-034-MY2, MOST107-2314-B-255-009-MY3, MOST107-2314-B-255-008-MY2, MOST108-2314-B-002-043-MY3, MOST 110-2314-B255-002-MY3. MOST110-2314-B-255-003-MY3; MO ST111-2314-B002-109-MY3, MOST111-2314-B002-107-MY3), National Taiwan University Hospital (NTUH101-S1862, NTU H102-S2180, NTUH103- S2368, NTUH104-S2658, NTUH106-S3467, NTUH106-UN-001, NTUH107-003875, NTUH108-004156, NTUH110-S4815, NTUH113-UN0012) & Kaohsiung Medical University (KMU-Q111004, KMU-110KK040, KMU-112KK017, KMU-DK(A)-110002, KMUH111-1T09).

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