Evaluation of the Relationship Between Maxillary Sinus Wall and Maxillary Canines and Posterior Teeth Using Cone-Beam Computed Tomography

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: The proximity between the maxillary sinus and dental roots may impede orthodontic tooth movement. This study aimed to explore the relationship between the maxillary sinus wall (MSW) and maxillary canines and posterior teeth using cone-beam computed tomography (CBCT).

Material/Methods: CBCT images (317) were examined for whether the mesial, distal, buccal, and palatal surfaces of the examined root contacted the MSW, and the contact distance of each root surface with the MSW was measured. The effects of age and sex were analyzed using logistic regression and linear regression analyses.

Results: The highest contact ratios with the MSW (ranging from 62.0% to 73.2%) were observed at the palatal root surfaces of the first molar mesiobuccal and distobuccal roots (1M MB and DB), the buccal root surface of the first molar palatal roots (1M P), and the mesial and buccal root surfaces of the second molars (2M), followed by the distal root surface of the second premolars (2PM) and the mesial root surfaces of the 1M MB and P (ranging from 49.2% to 59.3%). At these root surfaces, the contact ratios decreased with age (*P*<0.05), but the lowest still reached a range of 29.4% to 57.9% in the 30- to 47-year-old group.

Conclusions: The 2PM distal root surface, the 1M MB mesial and palatal root surfaces, the 1M DB palatal root surface, and the 1M P and 2M mesial and buccal root surfaces most frequently contacted the MSW. Clinicians should observe the contact of root surfaces with the MSW, even in aged patients.

MeSH Keywords: **Bicuspid • Cone-Beam Computed Tomography • Cuspid • Maxillary Sinus • Molar • Orthodontics**

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/925384

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Background

The maxillary sinus wall (MSW) is a layer of cortical bone lined with periosteum [1,2], which is a natural barrier for orthodontic tooth movement [2,3]. The distance between the maxillary sinus (MS) and maxillary posterior teeth has been known to cause greater tipping, and moving teeth against the MSW can induce root resorption [3]. It is generally believed that moving teeth against the cortical bone is very difficult and will increase the complexity and duration of orthodontic treatment in adult patients [1,2,4,5]. Generally, an inverse relationship exists between bone density and the rate of tooth movement [6]. The rate of teeth moving through dense cortical bone has been reported to be approximately 0.3 mm per month [6]. Nevertheless, in previous histomorphometric studies using mice, teeth could be moved into the MS without losing bone because mechanical stress induced bone deposition on the MS side before bone resorption on the periodontal ligament side [7,8]. Previous case reports have shown that teeth were successfully moved through the MS in adult patients without significant postoperative complications [1,2,9–14]. Therefore, evaluating the position of the maxillary teeth in relation to the MS is important for a comprehensive orthodontic diagnosis and treatment plan [15].

Cone-beam computed tomography (CBCT) avoids image distortion and overlapping and has multiple applications in dentistry [16,17]. The precision of 3-dimensional (3D) measurements could help clinicians choose suitable sizes of implants and miniscrews [18,19]. Additionally, this radiologic exam is useful for periodontal and endodontic treatments [20,21]. In orthodontics, CBCT is used mainly to evaluate the position of unerupted teeth to improve the accuracy of surgical exposure and to reduce bleeding that can alter bond efficacy [22].

There have been many studies concerning the vertical and horizontal relationships between maxillary posterior root apices and the inferior wall of the MS and their effect on endodontic process, implant, alveolar surgery, and sinusitis [17,21,23–28]. However, no study has evaluated the anatomical relationship between the MSW and maxillary teeth from mesial, distal, buccal, and palatal root surfaces. In orthodontic treatment, cortical bone in the direction of tooth advancement may have the most significant impact. Furthermore, the MSW is curved, which results in different three-dimensional relationships with the dental roots [15,29].

Hence, the aim of the present study was to evaluate the relationships between the MSW and maxillary canines and posterior teeth bilaterally from mesial, distal, buccal, and palatal root surfaces in the Chinese population using CBCT and to examine if the data were correlated with age or sex.

Material and Methods

This study was approved by the Institutional Review Board of Peking University Hospital of Stomatology (PKUSSIRB-201734033). Pretreated orthodontic CBCT images from 2014 to 2016, including dentition and nearby MSW, were evaluated retrospectively. The present study included patients (1) with clear CBCT images; (2) without missing posterior teeth (excluding the third molars); (3) without radiographic signs of bone, root, and MS abnormalities or embedded teeth; and (4) without a history of trauma, surgery, or orthodontic treatment. A total of 317 patients from 10 to 47 years old were selected for the study (Table 1).

CBCT scans (DCT pro; Vatech & EWOO Group, Seoul, Korea) were taken at 90 kVp and 7 mA with an exposure time of 24 s and a voxel size of 0.3 mm [30]. The field of view was 16×10 cm or 16×7 cm according to the clinician's prescription. Images were reconstructed and evaluated using Ez3D 2009 Premium software (version 1.2.4.1 for Windows; Vatech & EWOO Group). The sagittal plane for measurements was determined through the mesiodistal axis of the examined crown, and the coronal

Table 1. Demographic data.

|	10–19 y	20–29 y	30–47 y	Total
Canine				
Female	120	192	92	404
Male	139	52	32	223
Total	259	244	124	627
1PM/2PM/1M/2M				
Female	124	192	94	410
Male	140	52	32	224
Total	264	244	126	634

1PM – first premolars; 2PM – second premolars; 1M – first molars; 2M – second molars.
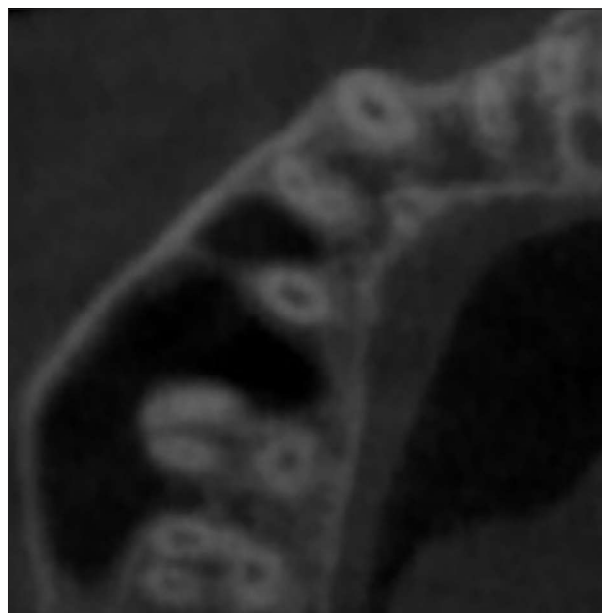
Figure 1. Distal root surface of 1PM, the mesial root surface of 2PM, mesial and buccal root surfaces of 1M MB, distal and buccal root surfaces of 1M DB, and mesial and buccal root surfaces of 2M that contact the MSW. The axial plane was adjusted during evaluation according to every examined root.

and axial planes were determined through the central long axis of the examined root.

Whether the mesial, distal, buccal, or palatal root surface of the examined root contacted the MSW was identified on the axial plane from the tooth cervix to the root apex (Figure 1). The contact distance of each root surface was measured along the central long root axis and assigned a negative value (Figure 2). If the examined root did not contact the MSW (type NC), the shortest distance from the root to the MSW was measured and assigned a positive value. The examined root with only the apex contacting the MSW was classified as type AC.
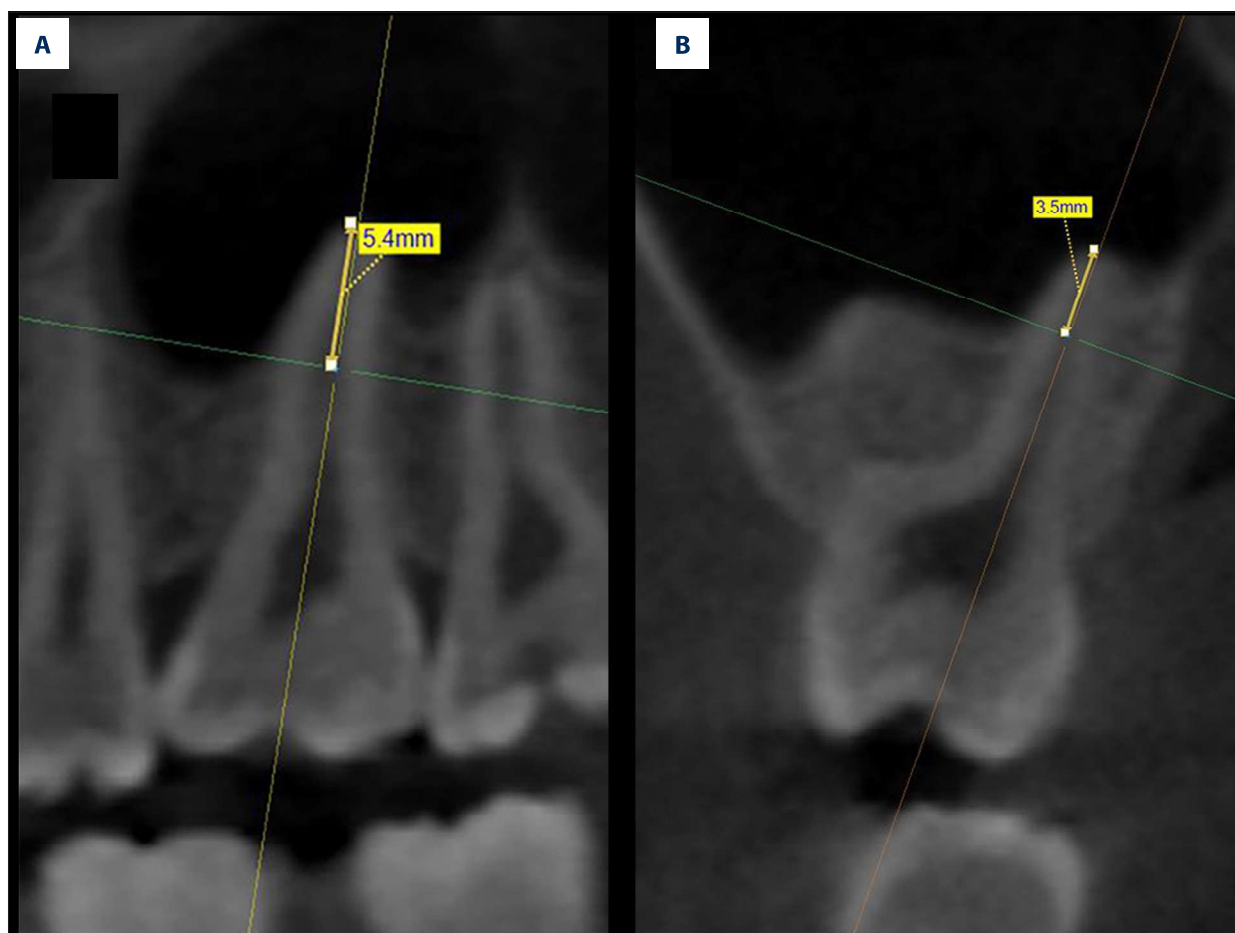
Figure 2. (**A**) Contact distance of the mesial root surface of 1M P with the MSW measured on the sagittal plane. (**B**) Contact distance of the buccal root surface of 1M P with the MSW measured on the coronal plane.

Table 2. Contact ratios of the 4 root surfaces of the maxillary canines and posterior teeth with the MSW.

	Mesial root surface		Distal root surface		Buccal root surface		Palatal root surface		p
	n	(%)	n	(%)	n	(%)	n	(%)	
Canine	3	(0.5%)$_a$	85	(13.6%)$_{b,c}$	7	(1.1%)$_a$	47	(7.5%)$_c$	
1PM	16	(2.5%)$_a$	99	(15.6%)$_{b,d}$	14	(2.2%)$_a$	88	(13.9%)$_{b,c}$	
2PM	68	(10.7%)$_{b,c}$	312	(49.2%)$_{e,f}$	86	(13.6%)$_{b,c}$	236	(37.2%)$_{g,h,i,j,k,l,m,n,o}$	
1M MB	328	(51.7%)$_{e,f,q}$	203	(32.0%)$_{l,m,n,o,p}$	156	(24.6%)$_p$	428	(67.5%)$_{r,s,t}$	0.000**
1M DB	227	(35.8%)$_{i,k,m,o}$	187	(29.5%)$_{j,k,n,o,p}$	149	(23.5%)$_{d,p}$	403	(63.6%)$_{r,s,t}$	
1M P	376	(59.3%)$_{e,q,s}$	294	(46.4%)$_{f,h}$	464	(73.2%)$_t$	69	(10.9%)$_{b,c}$	
2M	451	(71.1%)$_{r,t}$	180	(28.3%)$_{g,i,j,k,l,m,n,o,p}$	393	(62.0%)$_{q,r,s}$	226	(35.6%)$_{g,i,j,k,l,m,n,o}$	

Each subscript letter denotes a subset of root surface categories whose contact proportions do not differ significantly from each other at the $P<0.05$ level. 1PM – first premolars; 2PM – second premolars; 1M MB – first molar mesiobuccal roots; 1M DB – first molar distobuccal roots; 1M P – first molar palatal roots; 2M – second molars.

Because root fusion was common for premolars and the second molars (2M), these teeth were evaluated as 1 root. Age was divided into 3 groups using 10-year intervals, except for the 30- to 47-year-old group because the sample size of this group was inadequate to be divided into 2 groups.

Statistical analysis

All measurements were done by 1 examiner (Y.Q.). The intraobserver reliability was assessed by repeating the evaluation of 30 CBCT images after a 2-week interval. Kendall's tau test was used to evaluate replicate classifications, and the interclass correlation coefficient (ICC) was applied to evaluate replicate linear measurements. The Kendall's tau coefficient was 0.741, and the ICC was 0.929. Both were statistically significant ($P<0.001$) and showed high reliability.

A descriptive analysis of the data was presented as the contact ratios of 4 root surfaces with the MSW (e.g., the contact ratio of the mesial root surface of canines was the number of mesial root surfaces of canines that contacted the MSW divided by the number of canines), the frequencies of type AC and type NC, and the means and standard deviations of the corresponding measurements from canines to 2M. Data categorized for age and sex were provided. Whether the contact ratios differed among 4 root surfaces of maxillary canines and posterior teeth was tested by chi-square test with post hoc analysis. The correlations between the frequencies and age group and sex were analyzed using multivariate logistic regression. The correlations between the linear measurements and age group and sex were analyzed using multivariate linear regression. All statistical analyses were performed using SPSS Statistics 22.0 (IBM Corp., Armonk, NY, USA) and $P<0.05$ was considered statistically significant.

Results

The contact ratios of the 4 root surfaces of the maxillary canines and posterior teeth with the MSW are shown in Table 2. There was a statistically significant difference in contact ratios among the 4 root surfaces of the maxillary canines and posterior teeth ($P<0.001$). The highest contact ratios were observed at the palatal root surfaces of the first molar mesiobuccal and distobuccal roots (1M MB and DB), the buccal root surface of the first molar palatal roots (1M P), and the 2M mesial and buccal root surfaces (ranging from 62.0% to 73.2%), followed by the distal root surface of the second premolars (2PM) and the mesial root surfaces of the 1M MB and P (ranging from 49.2% to 59.3%).

Data of contact ratio and distance categorized by age and sex are illustrated in Table 3. The events per variable (EPV) were <5 for the mesial and buccal root surfaces in canines; therefore, the regression analyses were not applied. The contact ratios decreased significantly with age at the distal and palatal root surfaces of the first premolars (1PM), the distal and buccal root surfaces of the 2PM, the 4 root surfaces of the 1M 3 roots except for the distal root surface of the 1M P, and the 2M mesial and buccal root surfaces, whereas the contact ratio increased at the 2M distal root surface ($P<0.05$). The contact distances significantly decreased with age at the distal and palatal root surfaces of the 1PM, the palatal root surface of the 2PM, the mesial root surfaces of the 1M 3 roots, the buccal root surfaces of the 1M buccal roots, and the distal root surface of the 2M ($P<0.05$).

Regarding sex, significant differences were found for contact ratios at the palatal root surface of the canines, the 4 root surfaces of the 2PM except for the buccal root surface, and the distal root surface of the 2M, as well as for contact distances

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Table 3. Contact ratios and contact distances (mm) of the 4 root surfaces of the maxillary canines and posterior teeth by age and sex.

	Mesial root surface		Distal root surface		Buccal root surface		Palatal root surface	
	n (%)	Mean (SD)	n (%)	Mean (SD)	n (%)	Mean (SD)	n (%)	Mean (SD)
Canine								
10–19	2 (0.8%)	−2.2 (0.0)	44 (17.0%)	−2.2 (1.6)	4 (1.5%)	−1.8 (0.9)	27 (10.4%)	−3.0 (1.4)
20–29	1 (0.4%)	−2.3 (−)	29 (11.9%)	−1.8 (0.6)	2 (0.8%)	−0.8 (0.4)	15 (6.1%)	−1.9 (1.3)
30–47	0 (0%)	−	12 (9.7%)	−3.2 (2.0)	1 (0.8%)	−4.0 (−)	5 (4.0%)	−3.8 (2.1)
P	−	−	0.081	0.112	−	−	0.112	0.977
Female	1 (0.2%)	−2.3 (−)	49 (12.1%)	−1.9 (0.8)	4 (1.0%)	−1.7 (1.6)	20 (5.0%)	−2.3 (1.6)
Male	2 (0.9%)	−2.2 (0.0)	36 (16.1%)	−2.7 (2.0)	3 (1.3%)	−2.0 (1.0)	27 (12.1%)	−3.0 (1.6)
P	−	−	0.361	0.004**	−	−	0.008**	0.139
1PM								
10–19	11 (4.2%)	−1.0 (0.7)	52 (19.7%)	−2.2 (1.4)	10 (3.8%)	−1.0 (0.6)	46 (17.4%)	−2.2 (1.1)
20–29	4 (1.6%)	−0.6 (0.3)	38 (15.6%)	−1.2 (0.7)	3 (1.2%)	−0.6 (0.3)	34 (13.9%)	−1.7 (1.0)
30–47	1 (0.8%)	−0.9 (−)	9 (0.7%)	−1.3 (0.6)	1 (0.8%)	−1.6 (−)	8 (6.3%)	−1.6 (1.2)
P	0.082	0.508	0.007**	0.001**	0.091	0.858	0.017*	0.010*
Female	7 (1.7%)	−0.9 (0.7)	56 (13.7%)	−1.6 (1.1)	6 (1.4%)	−1.0 (0.7)	48 (11.7%)	−2.0 (1.2)
Male	9 (4.0%)	−0.8 (0.6)	43 (19.2%)	−2.0 (1.3)	8 (3.6%)	−1.0 (0.5)	40 (17.9%)	−1.9 (0.9)
P	0.269	0.621	0.319	0.381	0.285	0.995	0.169	0.171
2PM								
10–19	34 (12.9%)	−2.0 (1.6)	144 (54.5%)	−2.7 (2.0)	45 (17.0%)	−2.1 (1.4)	103 (39.0%)	−2.3 (1.4)
20–29	29 (11.2%)	−1.3 (0.9)	121 (49.6%)	−2.7 (1.4)	38 (15.6%)	−1.6 (1.2)	103 (42.2%)	−1.7 (1.0)
30–47	5 (4.0%)	−1.7 (1.3)	47 (37.3%)	−2.1 (1.4)	3 (2.4%)	−1.4 (0.7)	30 (23.8%)	−1.4 (0.9)
P	0.087	0.105	0.015*	0.072	0.003**	0.064	0.084	0.000**
Female	33 (8.0%)	−1.6 (1.5)	185 (45.1%)	−2.6 (1.6)	45 (11.0%)	−1.9 (1.4)	137 (33.4%)	−1.9 (1.2)
Male	35 (15.6%)	−1.7 (1.3)	127 (56.7%)	−2.6 (1.9)	41 (18.3%)	−1.8 (1.2)	99 (44.2%)	−2.0 (1.2)
P	0.021*	0.924	0.038*	0.954	0.111	0.339	0.033*	60.637
1M MB								
10–19	173 (65.5%)	−2.8 (1.9)	105 (39.8%)	−1.5 (1.1)	94 (35.6%)	−1.9 (1.4)	207 (78.4%)	−2.6 (1.8)
20–29	118 (48.4%)	−2.1 (1.3)	71 (29.1%)	−1.3 (0.9)	53 (21.7%)	−1.2 (1.3)	160 (65.6%)	−2.3 (1.3)
30–47	37 (29.4%)	−2.2 (1.3)	27 (21.4%)	−1.4 (1.1)	9 (7.1%)	−1.2 (0.4)	61 (48.4%)	−2.3 (1.7)
P	0.000**	0.005**	0.001**	0.255	0.000**	0.023*	0.000**	0.16
Female	192 (46.8%)	−2.4 (1.5)	116 (28.3%)	−1.4 (1.0)	87 (21.2%)	−1.5 (1.3)	260 (63.4%)	−2.3 (1.5)
Male	136 (60.7%)	−2.6 (1.8)	87 (38.9%)	−1.4 (1.1)	69 (30.8%)	−1.8 (1.4)	168 (75.0%)	−2.7 (1.7)
P	0.092	0.978	0.079	0.935	0.349	0.444	0.106	0.027*

Table 3 continued. Contact ratios and contact distances (mm) of the 4 root surfaces of the maxillary canines and posterior teeth by age and sex.

	Mesial root surface		Distal root surface		Buccal root surface		Palatal root surface	
	n (%)	Mean (SD)	n (%)	Mean (SD)	n (%)	Mean (SD)	n (%)	Mean (SD)
1M DB								
10–19	125 (47.3%)	−2.1 (1.5)	93 (35.2%)	−1.3 (0.9)	98 (37.1%)	−2.2(1.4)	195 (73.9%)	−2.6 (1.7)
20–29	75 (30.7%)	−1.4 (1.2)	76 (31.1%)	−1.3 (0.8)	42 (17.2%)	−1.4(0.9)	155 (63.5%)	−2.3 (1.4)
30–47	27 (21.4%)	−1.4 (0.9)	18 (14.3%)	−1.2 (0.8)	9 (7.1%)	−1.1(0.7)	53 (42.1%)	−2.3 (1.5)
P	0.000**	0.001**	0.001**	0.701	0.000**	0.000**	0.000**	0.151
Female	129 (31.5%)	−2.4 (1.5)	108 (26.3%)	−1.4 (1.0)	77 (18.8%)	−1.5(1.3)	258 (62.9%)	−2.3 (1.5)
Male	98 (43.8%)	−2.6 (1.8)	79 (35.3%)	−1.4 (1.1)	72 (32.1%)	−1.8(1.4)	145 (64.7%)	−2.7 (1.7)
P	0.086	0.75	0.183	0.66	0.067	0.346	0.262	0.017*
1M P								
10–19	183 (69.3%)	−3.6 (2.1)	127 (48.1%)	−2.7 (1.7)	218 (82.6%)	−3.7(2.0)	42 (15.9%)	−1.8 (1.3)
20–29	147 (60.2%)	−2.7 (1.5)	124 (50.8%)	−2.4 (1.5)	177 (72.5%)	−3.4(1.7)	15 (6.1%)	−1.9 (1.9)
30–47	46 (36.5%)	−2.9 (1.7)	43 (34.1%)	−2.5 (1.5)	69 (54.8%)	−3.4(2.2)	12 (9.5%)	−2.5 (1.4)
P	0.000**	0.001**	0.062	0.736	0.000**	0.263	0.011*	0.342
Female	231 (56.3%)	−3.0 (1.7)	183 (44.6%)	−2.4 (1.5)	294 (71.7%)	−3.4(1.8)	44 (10.7%)	−2.2 (1.5)
Male	145 (64.7%)	−3.4 (2.1)	111 (49.6%)	−2.9 (1.8)	170 (75.9%)	−3.9(2.1)	25 (11.2%)	−1.5 (1.1)
P	0.558	0.121	0.509	0.005*	0.784	0.015*	0.578	0.109
2M								
10–19	202 (76.5%)	−2.9 (1.5)	48 (19.7%)	−2.7 (1.7)	180 (68.2%)	−2.7(1.7)	80 (30.3%)	−1.8 (1.2)
20–29	176 (72.1%)	−2.7 (1.4)	94 (38.5%)	−1.9 (1.2)	75 (64.3%)	−2.3(1.5)	43 (42.2%)	−1.6 (1.1)
30–47	73 (57.9%)	−2.6 (1.6)	38 (30.2%)	−1.9 (1.3)	56 (44.4%)	−2.3(1.5)	43 (34.1%)	−1.6 (1.4)
P	0.001**	0.17	0.000**	0.042*	0.000**	0.277	0.104	0.162
Female	286 (69.8%)	−2.6 (1.3)	108 (26.3%)	−1.8 (1.2)	247 (60.2%)	−2.2(1.6)	141 (34.4%)	−1.6 (1.1)
Male	165 (73.7%)	−3.0 (1.7)	72 (32.1%)	−2.4 (1.7)	146 (65.2%)	−2.8(1.6)	85 (37.9%)	−1.7 (1.4)
P	0.883	0.012*	0.012*	0.038*	0.865	0.002**	0.199	0.625

SD – standard deviation; 1PM – the first premolars; 2PM – the second premolars; 1M MB – the first molar mesiobuccal roots; 1M DB – the first molar distobuccal roots; 1M P – the first molar palatal roots; 2M – the second molars.

at the distal root surface of the canines, the palatal root surfaces of the 1M buccal roots, the distal and buccal root surfaces of the 1M P, and the 4 root surfaces of the 2M except for the palatal root surface (*P*<0.05). Male subjects showed higher contact ratios and distances compared with female subjects at these root surfaces.

The frequencies of type AC in the maxillary canines and posterior teeth ranged from 2.5% to 12.5% (Table 4). The frequencies of type AC in the maxillary canines and premolars significantly

decreased with age (*P*<0.05). Male subjects showed a higher frequency of type AC compared with female subjects at the 1M P (*P*<0.05, 5<EPV<10).

The frequencies and distances of type NC in the maxillary canines and posterior teeth are shown in Table 5. Both the frequencies and distances of type NC in the maxillary canines and posterior teeth significantly increased with age (*P*<0.05) except for the 2M, in which the distance did not increase with age, but the frequency did. Female subjects showed a

Table 4. Frequencies of type AC in the maxillary canines and posterior teeth by age and sex.

	Canine	1PM	2PM	1M MB	1M DB	1M P	2M
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
10–19	33 (12.7%)	42 (15.9%)	44 (16.7%)	27 (10.2%)	40 (15.2%)	8 (3.0%)	32 (12.1%)
20–29	13 (5.3%)	26 (10.7%)	21 (8.6%)	22 (9.0%)	24 (9.8%)	5 (2.0%)	28 (11.5%)
30–47	3 (2.4%)	11 (8.7%)	4 (3.2%)	10 (7.9%)	15 (11.9%)	3 (2.4%)	12 (9.5%)
p	0.000**	.046*	0.000**	0.282	0.417	0.928	0.398
Female	28 (6.9%)	47 (11.5%)	38 (9.3%)	42 (10.2%)	44 (10.7%)	6 (1.5%)	48 (11.7%)
Male	21 (9.4%)	32 (14.3%)	31 (13.8%)	17 (7.6%)	35 (15.6%)	10 (4.5%)	24 (10.7%)
p	0.966	0.664	0.594	0.182	0.137	.033*	0.559
Total	49 (7.8%)	79 (12.5%)	69 (10.9%)	59 (9.3%)	79 (12.4%)	16 (2.5%)	72 (11.4%)

1PM – first premolars; 2PM – second premolars; 1M MB – first molar mesiobuccal roots; 1M DB – first molar distobuccal roots; 1M P – first molar palatal roots; 2M – second molars.

Table 5. Frequencies and distances (mm) of type NC in the maxillary canines and posterior teeth by age and sex.

	10–19	20–29	30–47	P	Female	Male	P	Total
Canine								
n (%)	179 (69.1%)	199 (81.6%)	108 (87.1%)	0.000**	322 (79.7%)	164 (73.5%)	0.568	486 (77.5%)
Mean (SD)	4.5 (2.7)	5.7 (3.5)	6.9 (3.7)	0.000**	5.8 (3.5)	5.0 (3.2)	0.487	5.5 (3.4)
1PM								
n (%)	162 (61.4%)	169 (69.3%)	105 (83.3%)	0.000**	294 (71.7%)	142 (63.4%)	0.302	436 (68.8%)
Mean (SD)	3.5 (1.9)	4.6 (3.3)	6.6 (3.7)	0.000**	4.9 (3.4)	4.2 (2.7)	0.752	4.7 (3.2)
2PM								
n (%)	69 (26.1%)	90 (36.9%)	72 (57.1%)	0.000**	173 (42.2%)	58 (25.9%)	0.005**	231 (36.4%)
Mean (SD)	2.2 (1.5)	4.1 (3.0)	4.6 (3.2)	0.000**	3.7 (2.8)	3.6 (3.2)	0.179	3.7 (2.9)
1M MB								
n (%)	14 (5.3%)	51 (20.9%)	53 (42.1%)	0.000**	91 (22.2%)	27 (12.1%)	0.164	118 (18.6%)
Mean (SD)	2.2 (1.0)	3.5 (2.6)	4.4 (3.2)	0.002**	3.6 (2.7)	4.3 (3.2)	0.038*	3.7 (2.9)
1M DB								
n (%)	16 (6.1%)	54 (22.1%)	53 (42.1%)	0.000**	91 (22.2%)	32 (14.3%)	0.555	123 (19.4%)
Mean (SD)	2.3 (1.5)	3.3 (2.2)	4.4 (3.0)	0.001**	3.6 (2.4)	3.8 (3.2)	0.14	3.6 (2.6)
1M P								
n (%)	22 (8.3%)	56 (23.0%)	47 (37.3%)	0.000**	90 (22.0%)	35 (15.6%)	0.722	125 (19.7%)
Mean (SD)	2.6 (1.5)	3.7 (2.3)	4.4 (2.9)	0.002**	3.7 (2.4)	3.9 (2.8)	0.179	3.8 (2.5)
2M								
n (%)	9 (3.4%)	22 (9.0%)	35 (27.8%)	0.000**	49 (12.0%)	17 (7.6%)	0.754	66 (10.4%)
Mean (SD)	1.7 (1.2)	3.3 (1.9)	3.4 (2.6)	0.062	3.1 (1.9)	3.3 (3.3)	0.393	3.1 (2.3)

SD – standard deviation; 1PM – first premolars; 2PM – second premolars; 1M MB – first molar mesiobuccal roots; 1M DB – first molar distobuccal roots; 1M P – first molar palatal roots; 2M – the second molars.
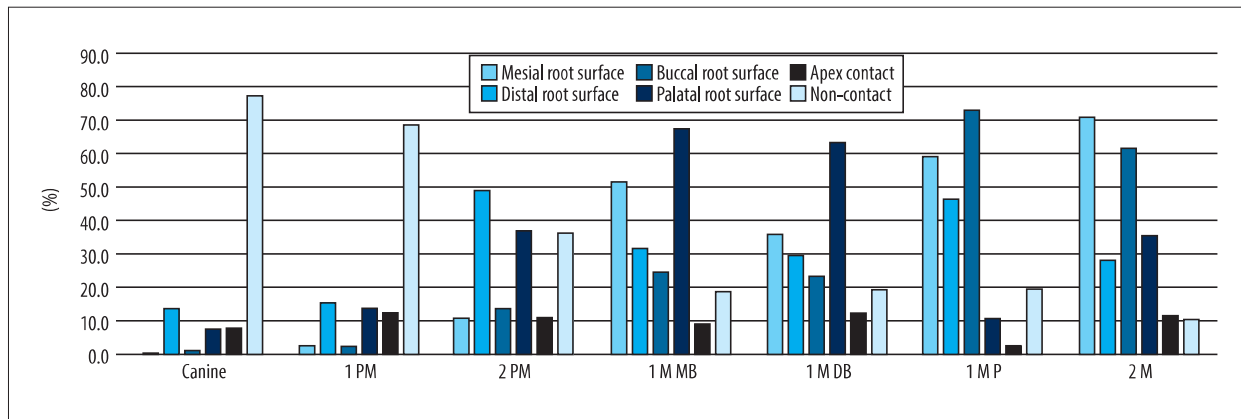
Figure 3. Contact ratios of the 4 root surfaces and the frequencies of type AC and type NC in the maxillary canines and posterior teeth.

higher frequency of type NC compared with male subjects at the 2PM, whereas male subjects showed a longer distance at the 1M MB ($P<0.05$).

Discussion

Awareness of the three-dimensional position of the maxillary dental roots in relationship to the MSW at the beginning of orthodontic treatment can help clinicians estimate its influence on anchorage and treatment duration as well as minimize the risk of roots moving against the MSW [2].

In the present study, the 1M MB and DB palatal root surfaces, the 1M P buccal root surface, and the 2M mesial and buccal root surfaces most frequently contacted the MSW, followed by the 2PM distal root surface and the 1M MB and P mesial root surfaces (Figure 3), indicating that when planning tooth movements in these directions, more attention should be given to the impact of the MSW. At these root surfaces, the contact ratios significantly decreased with increasing age (Figure 4; the influence of sex as a confounding factor was controlled by using the multivariate analysis). The highest reached a range of 54.5% to 82.6% in the 10- to 19-year-old group. Considering the popularity of orthodontic treatment in adolescents, the remodeling of the MSW should be common in the young population. Although the older age groups showed a decreased MSW–root relationship, the lowest contact ratios still reached a range of 29.4% to 57.9% in the 30- to 47-year-old group, which should not go unnoticed. Furthermore, among these root surfaces, the contact distances significantly decreased with age only at the mesial root surfaces of the 1M MB and P. Therefore, clinicians should take into account these results when determining the amount and direction of movement in posterior teeth for adult patients. Additionally, three-dimensional diagnostic imaging may have the advantage of providing more detailed information when planning posterior tooth movement for aged patients.

It is difficult to compare our findings of contact ratios and distances with those of earlier studies because our study was the first to evaluate contact ratios and distances at the 4 root surfaces. Reportedly, canines and 1PM rarely protruded into the MS [1,21,24,25,31]. In our study, the mesial and buccal root surfaces of canines and 1PM rarely contacted the MSW, whereas their distal and palatal root surfaces showed higher contact ratios with the MSW (Figure 3). Although canines and 1PM rarely protrude into the MS, they could be impeded by the MSW during their distal and palatal orthodontic movements in certain patients. Regarding 2M, our results partially agree with the findings of Kwak et al. [24] and Jung and Cho [32]. These studies showed that the lowest level of the MS was most frequently located at the buccal side of 2M in the coronal plane.

In the present study, the frequencies of type AC were not significantly associated with age in molars and were associated with sex only at the 1M P, indicating that the molar intrusion was mainly dependent on the contact of root surfaces with the MSW.

In the present study, male subjects showed a closer MSW–root relationship compared with female subjects (Figure 4). This difference was statistically significant for the contact ratios and distances at a few of the root surfaces in maxillary canines and posterior teeth except for the 1PM, as well as for the frequencies of types AC and NC in the 1M P and 2M, respectively (the influence of age as a confounding factor was controlled by using the multivariate analysis). This result agrees with previous studies by Kang et al. [23], Ok et al. [25], and Ahn and Park [16] for posterior teeth; however, some studies found no sex-related difference [17,31].

Tian et al. [33] reported noncontact ratios of 83.02% for 1PM, 56.50% for 2PM, and 42.16%, 44.55%, and 38.09% for 1M MB, DB, and P, respectively, which were higher than our results. The discrepancy may be attributed to the older patient population of their study (14–81 years old). Ahn and Park [16]
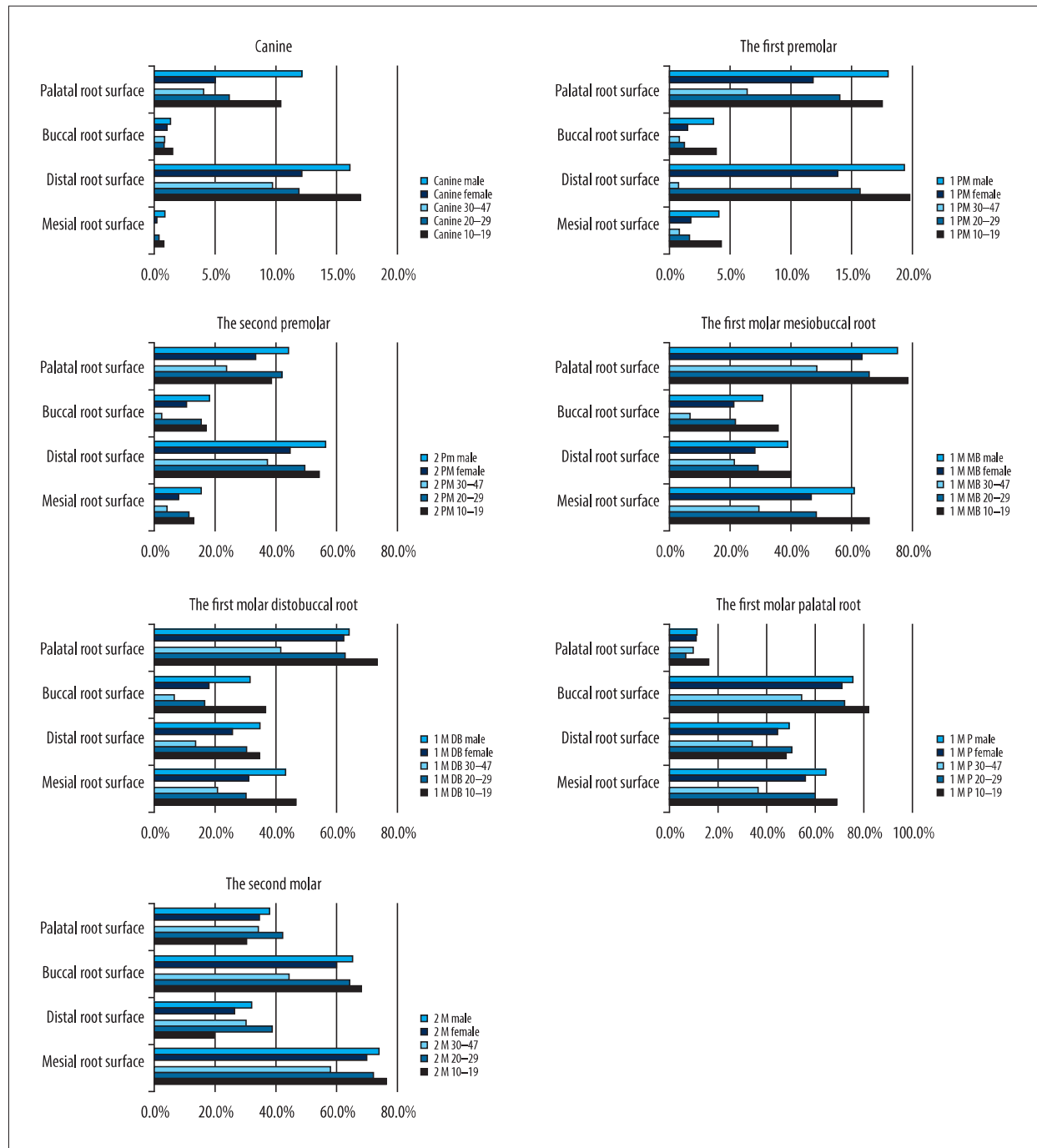
Figure 4. Contact ratios of the 4 root surfaces of the maxillary canines and posterior teeth grouped by age and sex.

reported noncontact ratios of 29.6% for 2PM and 15.65%, 19.45%, and 26.3% for 1M MB, DB, and P, respectively (10- to 28-year-old sample), which were similar to the results from the 10- to 29-year-old group in our study. In the present study, the frequencies of type NC significantly increased with age from canines to 2M (Figure 5). The trend agrees with that of Tian et al. [33] in posterior teeth but is contrary to the results of Ahn and Park [16] in 1M DB and P. Moreover, Ahn and Park [16]

found that age did not significantly influence the MSW-root relationship in 2PM and 1M MB. These results may be due to ethnic differences or different sample ages.

Herein, we suggested a method to quantitatively depict the relationship between the MSW and the maxillary teeth. However, the roots and the MSW have a surface contact rather than a line contact. The limitations of our study are that we replaced
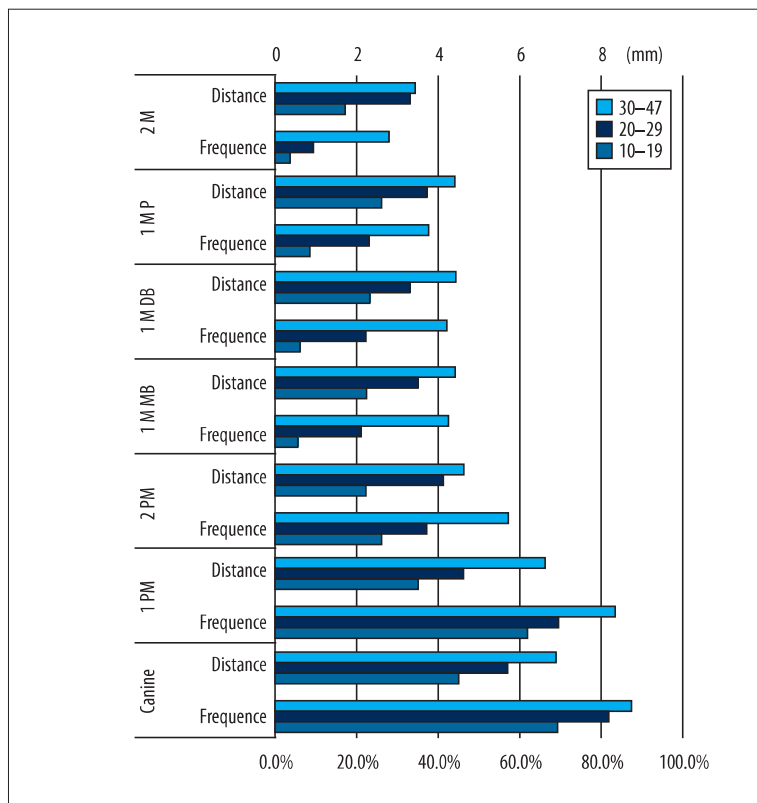
Figure 5. Frequencies and the mean distances of type NC in the maxillary canines and posterior teeth grouped by age.

the surface area measurement with a line segment and that the division of the 4 root surfaces could not be completely distinct. The present study is a preliminary report in the Chinese population. Further studies are needed worldwide to confirm the present preliminary results in other ethnic populations. With the development of technology, the amount of the MSW that needs to be remodeled may be identified more accurately in conjunction with the simulation of teeth position in each step of invisible orthodontic treatment. In addition, the balance of natural anchorage and the amount and direction of auxiliary anchorage may be estimated.

Conclusions

The present study presented preliminary results that the palatal root surfaces of the 1M MB and DB, the buccal root surface of the 1M P, and the mesial and buccal root surfaces of the 2M most frequently contacted the MSW, followed by the distal root surface of the 2PM and the mesial root surfaces of the 1M MB and P. Clinicians should observe the contact of root surfaces with the MSW, even in aged patients.

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