AJO-DO

A preliminary study of buccal and lingual alveolar bone thickness of posterior teeth in patients with skeletal Class III malocclusion and mandibular asymmetry

Xinnong Hu, Xiaoyi Huang, and Yan Gu
Beijing, China

Introduction: The purposes of this retrospective study were to investigate the buccal and lingual alveolar bone thickness values of the posterior teeth in patients with asymmetrical skeletal Class III malocclusion and compare them with patients with symmetrical skeletal Class III and Class I malocclusion. **Methods:** Seventy-eight cone-beam computed tomography scans were classified into 3 groups according to the sagittal pattern and menton deviation: asymmetrical Class III (n = 26), symmetrical Class III (n = 26), and symmetrical Class I (n = 26). The buccal and lingual alveolar bone thickness of the first molar and premolars in the maxilla and mandible were measured at 3, 6, and 8 mm apical to the cementoenamel junction and the apical and middle levels of the root. Measurements were compared among the 3 groups. **Results:** In the asymmetrical Class III group, the buccal alveolar bone along the distobuccal root of the maxillary first molar on the deviated side was thinner by 1.07 to 1.10 mm than that in the symmetrical Class I group at 6-mm, 8-mm, and middle-level planes (P <0.001, P <0.01, and P <0.001). The buccal alveolar bone thickness along the distal and mesial roots of the mandibular first molar on the deviated side was thinner by 1.28 to 1.85 mm, and by 0.72 to 1.21 mm, respectively (P <0.001 and P <0.01), than that in the symmetrical Class I group at 6-mm, 8-mm, apical and middle-level planes. **Conclusions:** In this preliminary study, patients with skeletal Class III malocclusion showed thinner buccal and lingual alveolar bone in the posterior teeth than subjects with Class I malocclusion. Particular attention should be paid to buccal alveolar bone thickness along the distobuccal root of the maxillary and distal root of the mandibular first molar to prevent periodontal complications in decompensation. Future studies should involve larger sample sizes, more repeatable and comprehensive measuring and statistical methods. (Am J Orthod Dentofacial Orthop 2022;162:66-79)

Patients with severe skeletal Class III malocclusion and facial asymmetry always present with remarkable dental compensation and need orthodontic treatment combined with orthognathic surgery to normalize skeletal and dental deformities and to improve facial esthetics.[1-4] Previous studies have indicated that subjects with skeletal Class III malocclusion often present with proclined maxillary incisors and retroclined mandibular incisors, accompanied by inadequate alveolar bone support.[1,5-8] For patients with skeletal Class III malocclusion and mandibular asymmetry, the compensatory inclination of posterior teeth varied between deviated and nondeviated sides. Maxillary posterior teeth showed buccal inclination on the deviated side compared with patients with Class I malocclusion, whereas no apparent buccolingual inclination of teeth was shown on the nondeviated side.[9,10] Mandibular posterior teeth in the patients were lingually inclined on the deviated side and buccally inclined on the nondeviated side compared with subjects with skeletal Class I malocclusion.[9,10]

To achieve ideal skeletal movement and stable occlusion by orthognathic surgery, adequate decompensation

From the Department of Orthodontics, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Peking University School and Hospital of Stomatology, Beijing 100081, China.

All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
This work was supported by the National Natural Science Foundation of China (NSFC81970979).

Address correspondence to: Yan Gu, Department of Orthodontics, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Peking University School and Hospital of Stomatology, No. 22 ZhongGuanCun Nandajie, HaiDian District, Beijing 100081, China; e-mail, guyan96@126.com.

Submitted, March 2020; revised and accepted, February 2021.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2021.02.024

of buccolingually inclined posterior teeth in patients with skeletal Class III malocclusion with and without mandibular asymmetry during presurgical orthodontic treatment must be performed, which is a substantial challenge to the alveolar boundary of the teeth. The periodontal limitation is an important consideration of the anatomic boundary for orthodontic tooth movement. Fenestration, dehiscence, and gingival recession occur with poor periodontal support and unpredictable tooth movement.[5,11-14]

To evaluate the extent of posterior teeth movement in patients with skeletal Class III malocclusion and mandibular asymmetry, the alveolar bone thickness of posterior teeth in the maxilla and mandible should be carefully considered before presurgical orthodontic treatment. Morphologic assessment of alveolar bone around teeth could be better assessed by cone-beam computed tomography (CBCT) imaging, which provides 3-dimensional information and overcomes the disadvantages inherent to 2-dimensional imaging such as superimposition, magnification, geometric distortion, and inconsistency of head position.[4,15,16]

The null hypotheses of this study included the following: (1) subjects with asymmetrical skeletal Class III malocclusion would show no significant differences between deviated and nondeviated sides in buccal and lingual alveolar bone thickness of posterior teeth, and (2) there would be no significant differences in the buccal and lingual alveolar bone thickness of posterior teeth when comparing asymmetrical and patients with symmetrical skeletal Class III malocclusion with patients with symmetrical skeletal Class I malocclusion.

MATERIAL AND METHODS

CBCT images of patients were collected from the Department of Oral Maxillofacial Surgery and the Department of Orthodontics, Peking University School and Hospital of Stomatology. This study was approved by the Biomedical Ethics Committee of Peking University School and Hospital of Stomatology (PKUSSIRB-201943020).

Subjects were included and excluded in this study according to their clinical examination records, medical and dental history, and imaging examination. Fifty-two subjects who satisfied the following inclusion and exclusion criteria were included in the Class III groups. The inclusion criteria were as follows: (1) aged ≥16 years, (2) Mongolian, (3) skeletal Class III (ANB angle, <0°, Wits appraisal values, ≤−3.6 mm), (4) crossbite or edge-to-edge position in anterior teeth, (5) Mp-SN ≥27°, and (6) complete permanent dentition. The exclusion criteria were as follows: (1) previous orthodontic or orthognathic treatment; (2) previous diagnosis of periodontitis or visible alveolar bone loss via clinical and imaging examination; (3) crowding by more than 3 mm in the posterior teeth area; (4) crown or large filling materials in the posterior teeth; (5) maxillary sinus bulging into the buccal or lingual region of the root in the maxillary posterior teeth; (6) furcation of the mesial or distal root of the mandibular first molar; and (7) cleft lip or palate, temporomandibular joint disease or other systemic diseases.

CBCT images of these subjects were reoriented in software, and the distance from the hard tissue menton point (Me) to the midsagittal plane was defined as the criterion for mandibular deviation. Two subgroups were classified: (1) asymmetrical Class III, 26 subjects (13 males, 13 females; average age, 21.1 ± 4.23 years) with mandibular deviation ≥4 mm; and (2) symmetrical Class III, 26 subjects (13 males, 13 females; average age, 20.7 ± 4.85 years) with mandibular deviation <2 mm (Table I).[9,10]

The symmetrical Class I group included 26 subjects with skeletal Class I malocclusion (13 males, 13 females; average age, 22.3 ± 2.92 years) who had ANB angles between 0.7° and 4.7°, Wits appraisal values between −3.6 mm and 2 mm, mandibular deviation <2 mm and other inclusion and exclusion criteria in accordance with those of the Class III groups (Table I).

CBCT images were obtained at intercuspal occlusion using the same device (NewTom AG, Marburg, Germany) used for the pretreatment examination. Scans were completed using the following settings: field of view, 15 × 15 cm; 110 kV; 2.81 mA; 3.6-second exposure; and voxel slice thickness, 0.3 mm.

Digital imaging and communications in medicine files from each scan were uploaded and evaluated with Dolphin 3D Imaging software (version 11.8; Dolphin Imaging and Management Solutions, Chatsworth, Calif). To ensure the consistent location of anatomic landmarks, the head position of each subject was reoriented according to the following reference planes: (1) the axial

Table I. Patient characteristics in different groups

Characteristics	*Asymmetrical Class III (n = 26)*	*Symmetrical Class III (n = 26)*	*Symmetrical Class I (n = 26)*
Age (y)	21.1 ± 4.23	20.7 ± 4.85	22.3 ± 2.92
ANB (°)	−3.3 ± 2.04	−4.6 ± 2.52	2.4 ± 1.13
Wits (mm)	−12.0 ± 4.31	−13.9 ± 4.28	−0.9 ± 2.00
Mandibular deviation (mm)	7.7 ± 2.81	1.0 ± 0.63	0.9 ± 0.60
Mp-SN (°)	39.1 ± 6.30	37.5 ± 6.48	35.5 ± 5.24

Note. Data presented as mean ± standard deviation.

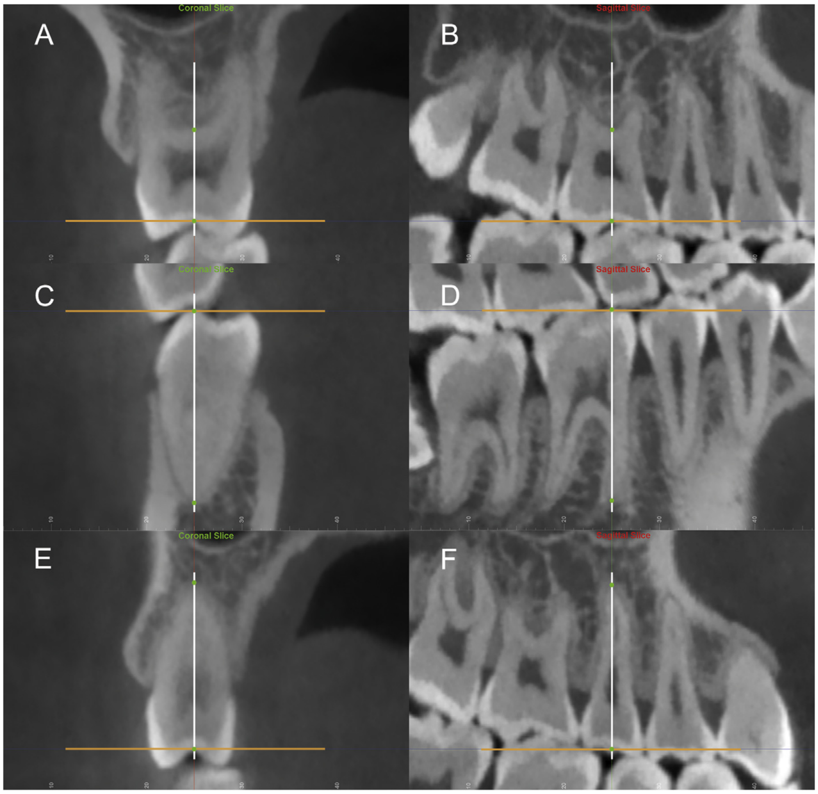

Fig 1. Reorientation of the measurement plane *(yellow)* perpendicular to the long axis *(white)* of teeth: **A** and **B**, Measurement plane perpendicular to the long axis of the maxillary first molar in the coronal and sagittal views; **C** and **D,** Measurement plane perpendicular to the long axis of the mandibular first molar in the coronal and sagittal views; **E** and **F,** Measurement plane perpendicular to the long axis of the single-rooted maxillary second premolar in the coronal and sagittal views.

plane was defined as the Frankfort horizontal plane, passing through bilateral orbitals and the right porion; (2) the midsagittal plane, perpendicular to the axial plane, passing through the nasion and basion; and (3) the coronal plane, perpendicular to the above 2 planes and passing through the basion. The Me point was defined as the most inferior point of the skeletal symphysis, the relative position of which the midsagittal plane was used to evaluate the direction of the mandibular deviation. The deviated side of each patient was defined as the side the Me point shifted toward the midsagittal plane, and the other side was defined as the nondeviated side.[17-19]

The long axis of the tooth was defined as follows: (1) maxillary first molar: the line passing through the central fossa and trifurcation; (2) mandibular first molar: the line passing through the mesiobuccal cusp and mesial root apex point; (3) single-rooted premolar: the line passing through the central fossa and apex; and (4) multirooted premolar: the line passing through the central fossa and furcation (shown in Fig 1).[9,20-22]

Buccal and lingual alveolar bone thicknesses of the maxillomandibular first molars and premolars were measured at the following 5 planes, perpendicular to the long axis of the tooth: (1) 3 mm apical to the cementoenamel junction (CEJ), (2) 6 mm apical to the CEJ, (3) 8 mm apical to the CEJ, (4) apical level of the root, and (5) middle level of the root.[5,23-28]

Measurement planes and buccal and lingual alveolar bone thicknesses are defined in Table II and shown in Figures 2-5. Measurement of bone thickness was evaluated on 3-dimensional sections, the axial view shown in Figures 3-5. If bone defects such as dehiscence and fenestration occurred at a certain measurement plane, the value of alveolar bone thickness at this level was recorded as zero.[28]

Statistical analysis

The buccal and lingual alveolar bone thicknesses of 20 patients chosen randomly were remeasured by 2 authors (X.N.H and X.Y.H) with an interval of 2 weeks.

Table II. Definitions of measurement planes and measurements

Variables	Description
Measurement planes	
CEJ plane	Perpendicular to the long axis of teeth, passing both buccal and lingual CEJ
3-mm, 6-mm, and 8-mm level plane	Parallel to the CEJ plane and at 3-mm, 6-mm, and 8-mm apical to the plane
Apical level plane	Parallel to the CEJ plane and passing the root apex of the tooth
Middle-level plane	Maxillary first molar: parallel to the CEJ plane, at the middle level between the CEJ plane and the palatal root apex Mandibular first molar: parallel to the CEJ plane, at the middle level between the CEJ plane and the mesial root apex Single-root premolars: parallel to the CEJ plane, at the middle level between the CEJ plane and the root apex Multiple-root premolars: parallel to the CEJ plane, at the middle level between the CEJ plane and the apex of the longer root
Measurements	
Buccal alveolar bone thickness at the 3-mm, 6-mm, and 8-mm and middle levels	Distance between the most prominent point on the buccal side of the root (mesiobuccal and distobuccal root of maxillary first molar, mesial and distal root of mandibular first molar, root of single-rooted premolar or buccal root of multirooted premolar) and the nearest outer buccal cortical bone edge point, measured at the 3-mm, 6-mm, and 8-mm and middle-level planes
Buccal alveolar bone thickness at the apical level	Distance between the apex of root (mesiobuccal and distobuccal root of maxillary first molar, mesial and distal root of mandibular first molar, root of single-rooted premolar or buccal root of multirooted premolar) and the nearest outer buccal cortical bone edge point, measured at the apical level plane
Lingual alveolar bone thickness at the 3-mm, 6-mm, and 8-mm and middle levels	Distance between the most prominent point on the lingual side of the root (palatal root of maxillary first molar, mesial and distal root of mandibular first molar, root of single-rooted premolar or lingual root of multirooted premolar) and the nearest outer lingual cortical bone edge point, measured at the 3-mm, 6-mm, and 8-mm and middle-level planes
Lingual alveolar bone thickness at the apical level	Distance between the apex of root (palatal root of maxillary first molar, mesial and distal root of mandibular first molar, root of single-rooted premolar or lingual root of multirooted premolar) and the nearest outer lingual cortical bone edge point, measured at the apical level plane

Interobserver and intraobserver reliabilities were calculated to evaluate the reproducibility of measurements (Supplementary Table I).

The normality of the data distribution was evaluated using the Shapiro-Wilk test and paired *t* tests or Wilcoxon signed-rank tests were used according to the normality of the data distribution to compare the parameters between deviated and nondeviated sides in each group with a significance level of 0.05 (Supplementary Tables II-V). To evaluate the differences among the groups, the values on the deviated and nondeviated sides in patients with asymmetrical Class III malocclusion were compared, respectively, with the average value on the 2 sides in symmetrical patients with Class III and symmetrical Class I malocclusion. One-way analysis of variance followed by the post-hoc Bonferroni test or Kruskal-Wallis test and further pairwise comparisons were used, according to the results of tests for normality of distribution and variance in homogeneity (Tables III-VI).

A minimum sample size of 16 subjects was required per group, calculated by PASS software (version 11; NCSS, Kaysville, Utah), with a significance level of 0.05, power of 80%, hypothesized means of 0, 0.35, 0.70, and standard deviation of 0.60 to detect differences in alveolar bone thickness among the 3 groups using 1-way analysis of variance.[5,29] In our previous study, we used a standard deviation of 0.60 mm because our previous study aimed to evaluate the alveolar bone thickness at the cervical third only, in which 3-mm level could represent the location of the measurement plane. In addition, we believe 0.35 mm is a suitable value for a significant mean difference between the groups.[29] Data are presented as the means and standard deviations.

RESULTS

The intraclass correlation values ranged from 0.751 to 0.991 for interobserver reliability and from 0.771 to 0.994 for intraobserver reliability. Bland-Altman means and 95% limits of agreement for interobserver and intraobserver reliabilities are shown in Supplementary Table I.

In symmetrical Class III and symmetrical Class I groups, alveolar bone thickness showed no significant

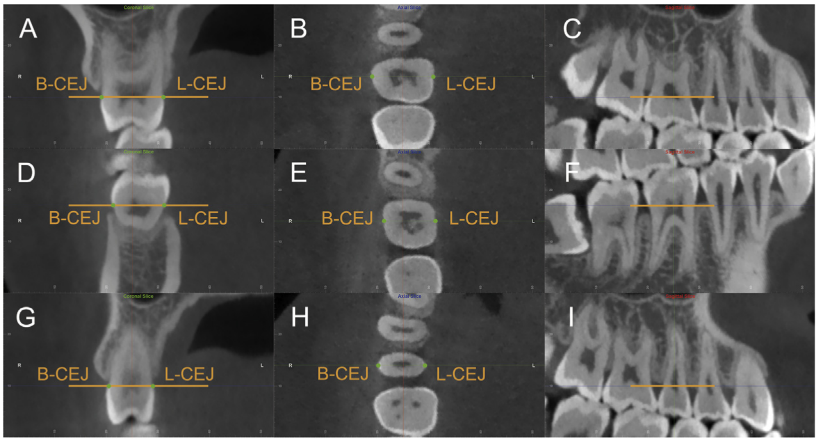

Fig 2. Location of the CEJ junction plane *(yellow)* of teeth parallel to the reoriented measurement plane: **A-C**, CEJ plane of the maxillary first molar in the coronal, axial, and sagittal views; **D-F,** CEJ plane of the mandibular first molar in the coronal, axial, and sagittal views; **G-I,** CEJ plane of the maxillary second premolar in the coronal, axial, and sagittal views. *B-CEJ*, CEJ point on the buccal side; *L-CEJ,* CEJ point on the lingual side.

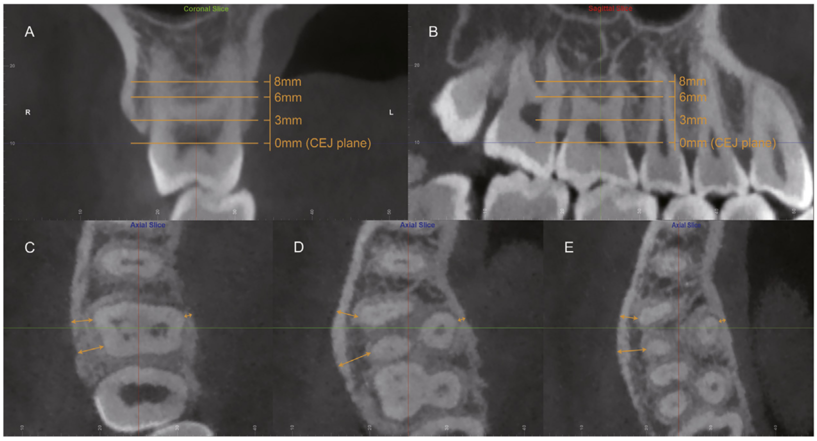

Fig 3. Measurement of buccal and lingual alveolar bone thicknesses of the maxillary first molar at the 3-mm, 6-mm, and 8-mm levels apical to the CEJ plane: **A** and **B,** Location of the 3-mm, 6-mm, and 8-mm levels parallel to the CEJ plane in the coronal and sagittal views; **C- E,** Measurement of the buccal and lingual alveolar bone thicknesses *(yellow)* of the maxillary first molar shown in the axial view at the 3-mm, 6-mm, and 8-mm levels apical to the CEJ plane.

difference between the deviated and nondeviated sides (Supplementary Tables II-V); hence, the mean values of the 2 sides were used for further comparison (Tables III-VI). In the asymmetrical Class III group, alveolar bone thicknesses were significantly different between the deviated and nondeviated sides at some sites.

On the deviated side in the asymmetrical Class III group, the maxillary posterior teeth showed significantly thinner buccal alveolar bone than that on the nondeviated side at these sites; the 3-mm and 6-mm levels along the mesiobuccal root of the maxillary first molar ($P < 0.05$ and $P < 0.01$; Supplementary Table II); the 6-mm and middle levels along the distobuccal root of the maxillary first molar ($P < 0.01$ and $P < 0.05$; Supplementary Table II); and the 3-mm, 6-mm, and middle levels of the maxillary second premolar ($P < 0.05$; Supplementary Table II).

In the asymmetrical Class III group, lingual alveolar bone on the nondeviated side was thinner by 0.23 to 0.32 mm than that on the deviated side at these sites: the 6-mm, 8-mm, and middle

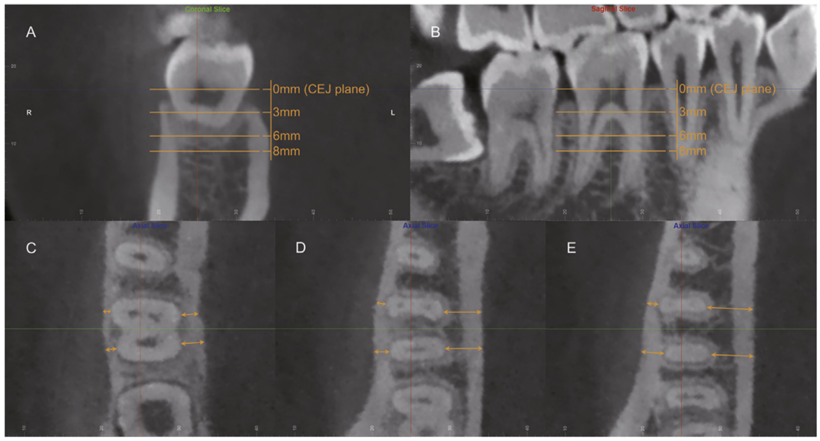

Fig 4. Measurement of buccal and lingual alveolar bone thicknesses of the mandibular first molar at the 3-mm, 6-mm, and 8-mm levels apical to the CEJ plane: **A** and **B,** Location of the 3-mm, 6-mm, and 8-mm levels parallel to the CEJ plane in the coronal and sagittal views; **C-E,** Measurement of buccal and lingual alveolar bone thicknesses *(yellow)* of the mandibular first molar shown in the axial view at the 3-mm, 6-mm, and 8-mm levels apical to the CEJ plane.

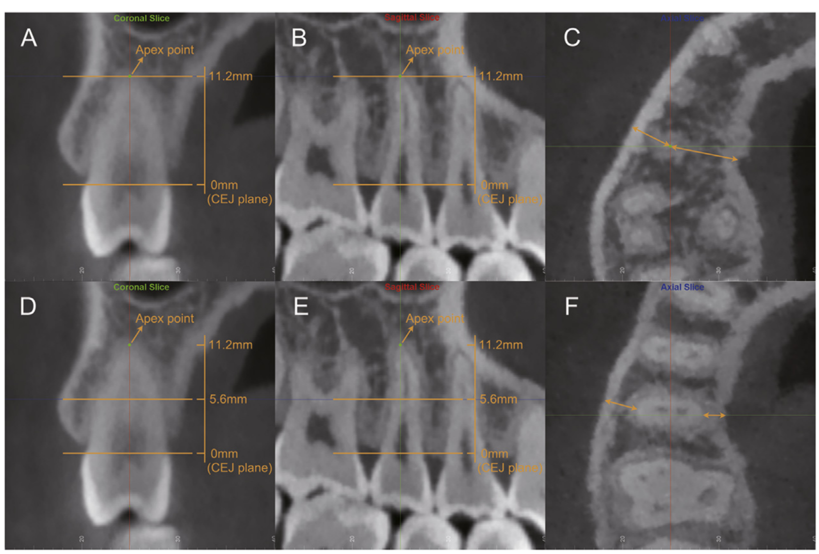

Fig 5. Measurement of buccal and lingual alveolar bone thicknesses of single-rooted maxillary premolars at the apical and middle levels of the root: **A** and **B,** Location of the apical level plane *(yellow)* parallel to the CEJ plane and passing through the apex of the tooth in the coronal and sagittal views; **C,** Measurement of buccal and lingual alveolar bone thicknesses *(yellow)* of single-rooted maxillary premolars at the apical level shown in the axial view; **D** and **E,** Location of the middle-level plane *(yellow)* parallel to the CEJ plane and at the middle level between the CEJ plane and root apex of the tooth in coronal and sagittal views; **F,** Measurement of buccal and lingual alveolar bone thicknesses *(yellow)* of a single-rooted maxillary premolar at the middle level shown in the axial view.

levels of the maxillary first molar and the 6-mm level of the second premolar (P <0.001, P <0.05, P <0.01, and P <0.05; Supplementary Table III).

In the asymmetrical Class III group, the distal root of the mandibular first molar and root of the second premolar showed 0.21-0.31 mm thinner buccal alveolar bone on the nondeviated side at the 3-mm level

Table III. Comparison of buccal alveolar bone thickness of the maxillary posterior teeth among the 3 groups

	Asymmetrical Class III					
Variable/tooth	*Deviated*	*Nondeviated*	*Symmetrical Class III*	*Symmetrical Class I*	P *value*	*Multiple comparisons*
3-mm						
6M	1.02 ± 0.58	1.26 ± 0.61	1.28 ± 0.56	1.57 ± 0.77	0.032‡,*	D = S; S = 1; D <1*
					0.496‡	ND = S = 1
6D	1.62 ± 0.66	1.64 ± 0.61	2.04 ± 0.73	2.26 ± 0.95	0.016†,*	D = S; S = 1; D <1*
					0.019†,*	ND = S; S = 1; ND <1*
5	0.95 ± 0.64	1.16 ± 0.73	1.09 ± 0.54	1.54 ± 0.63	0.002†,**	D = S; S <1*; D <1**
					0.030†,*	S = ND; ND = 1; S <1*
4	0.45 ± 0.41	0.46 ± 0.46	0.32 ± 0.32	0.64 ± 0.44	0.027‡,*	S = D; D = 1; S <1*
					0.036‡,*	S = ND; ND = 1; S <1*
6-mm						
6M	1.00 ± 0.84	1.35 ± 0.85	1.32 ± 0.83	1.67 ± 0.81	0.016†,*	D = S; S = 1; D <1*
					0.224†	S = ND = 1
6D	1.98 ± 0.89	2.45 ± 0.88	2.50 ± 0.92	3.06 ± 0.77	0.000†,***	D = S; S = 1; D <1***
					0.021†,*	ND = S; S = 1; ND <1*
5	1.68 ± 0.71	1.94 ± 0.61	1.98 ± 0.70	2.29 ± 0.95	0.053‡	D = S = 1
					0.496‡	ND = S = 1
4	0.95 ± 0.42	0.95 ± 0.52	0.93 ± 0.54	1.16 ± 0.47	0.161†	S = D = 1
					0.210†	S = ND = 1
8-mm						
6M	1.23 ± 1.13	1.26 ± 0.97	1.36 ± 0.87	1.74 ± 0.97	0.135‡	D = S = 1
					0.200‡	ND = S = 1
6D	1.85 ± 1.18	2.16 ± 1.04	2.38 ± 1.08	2.92 ± 0.90	0.002†,**	D = S; S = 1; D <1**
					0.025†,*	ND = S; S = 1; ND <1*
5	1.68 ± 0.90	1.88 ± 0.77	1.92 ± 0.78	2.22 ± 1.16	0.463‡	D = S = 1
					0.806‡	ND = S = 1
4	0.75 ± 0.54	0.82 ± 0.49	0.87 ± 0.52	0.97 ± 0.63	0.358†	D = S = 1
					0.595†	ND = S = 1
Apical						
6M	2.43 ± 1.16	2.73 ± 1.48	2.51 ± 1.00	3.17 ± 1.19	0.037†,*	D = S = 1
					0.149†	S = ND = 1
6D	2.86 ± 1.12	2.83 ± 1.02	3.02 ± 1.04	3.63 ± 0.97	0.024†,*	D = S; S = 1; D <1*
					0.016†,*	ND = S; S = 1; ND <1*
5	3.52 ± 1.10	3.42 ± 1.22	3.43 ± 1.07	3.58 ± 1.31	0.976‡	S = D = 1
					0.938‡	ND = S = 1
4	1.57 ± 0.95	1.64 ± 0.89	1.70 ± 1.12	1.73 ± 0.96	0.939†	D = S = 1
					0.950†	ND = S = 1
Middle						
6M	1.03 ± 0.91	1.28 ± 0.92	1.30 ± 0.84	1.64 ± 0.87	0.039‡,*	D = S; S = 1; D <1*
					0.269‡	ND = S = 1
6D	1.89 ± 1.03	2.29 ± 0.93	2.46 ± 1.00	2.99 ± 0.80	0.000†,***	D = S; S = 1; D <1***
					0.020†,*	ND = S; S = 1; ND <1*
5	1.62 ± 0.73	1.85 ± 0.65	1.95 ± 0.75	2.23 ± 0.97	0.053‡	D = S = 1
					0.438‡	ND = S = 1
4	0.88 ± 0.44	0.99 ± 0.48	0.95 ± 0.55	1.09 ± 0.58	0.342†	D = S = 1
					0.596†	S = ND = 1

Note. Data are presented as mean ± standard deviation. Results of *P* value and multiple comparisons in each measurement were divided into 2 rows. The first row showed the result of comparison among the deviated side in asymmetrical Class III group, symmetrical Class III group, and symmetrical Class I group, whereas the second one showed the result of comparison among the nondeviated side in asymmetrical Class III group, symmetrical Class III group and symmetrical Class I group.

D, deviated side of asymmetrical Class III group; *ND,* nondeviated side of asymmetrical Class III group; *S,* symmetrical Class III group; *1,* symmetrical Class I group; *6M,* mesiobuccal root of maxillary first molar; *6D,* distobuccal root of maxillary first molar; *5,* maxillary second premolar; *4,* maxillary first premolar.

†1-way ANOVA; ‡Kruskal-Wallis analysis was used to compare the values among the 3 groups; $^{*}P<0.05$; $^{**}P<0.001$; $^{***}P<0.001$.

Table IV. Comparison of lingual alveolar bone thickness of the maxillary posterior teeth among the 3 groups

	Asymmetrical Class III					
Variable/tooth	*Deviated*	*Nondeviated*	*Symmetrical Class III*	*Symmetrical Class I*	P *value*	*Multiple comparisons*
3-mm						
6	0.38 ± 0.40	0.39 ± 0.44	0.35 ± 0.41	0.78 ± 0.33	$0.000^{\ddagger,***}$	S = D; D <1**
					$0.000^{\ddagger,***}$	S = ND; ND <1**
5	0.84 ± 0.42	0.73 ± 0.36	0.98 ± 0.38	1.10 ± 0.40	$0.075^{\dagger}$	D = S = 1
					$0.003^{\dagger,**}$	ND = S; S = 1; ND <1**
4	0.59 ± 0.41	0.53 ± 0.40	0.67 ± 0.44	0.97 ± 0.32	$0.001^{\ddagger,**}$	D = S; S <1**
					$0.000^{\ddagger,***}$	ND = S; S <1**
6-mm						
6	1.31 ± 0.38	0.99 ± 0.34	1.07 ± 0.43	1.40 ± 0.44	$0.014^{\ddagger,*}$	S = D; D = 1; S <1*
					$0.002^{\ddagger,**}$	ND = S; S <1*; ND <1**
5	1.97 ± 0.47	1.74 ± 0.34	1.86 ± 0.38	2.30 ± 0.72	$0.041^{\ddagger,*}$	S = D; D = 1; S <1*
					$0.002^{\ddagger,**}$	ND = S; S = 1; ND <1**
4	1.49 ± 0.44	1.58 ± 0.70	1.57 ± 0.63	2.20 ± 0.64	$0.000^{\ddagger,***}$	D = S; S <1**; D <1***
					$0.000^{\ddagger,***}$	ND = S; S <1**
8-mm						
6	1.38 ± 0.43	1.13 ± 0.51	0.99 ± 0.51	1.84 ± 0.58	$0.000^{\ddagger,***}$	S <D*; D = 1; S <1***
					$0.000^{\ddagger,***}$	S = ND; ND <1***
5	2.65 ± 0.58	2.52 ± 0.75	2.55 ± 0.40	3.42 ± 1.04	$0.000^{\ddagger,***}$	S = D; D <1**; S <1***
					$0.000^{\ddagger,***}$	ND = S; S <1***
4	2.16 ± 0.68	2.52 ± 0.86	2.43 ± 0.91	3.41 ± 1.01	$0.000^{\dagger,***}$	D = S; S <1***
					$0.000^{\dagger,***}$	S = ND; ND <1**; S <1***
Apical						
6	2.86 ± 0.82	2.69 ± 1.10	2.56 ± 0.77	3.43 ± 1.24	$0.006^{\dagger,**}$	S = D; D = 1; S <1**
					$0.008^{\dagger,**}$	S = ND; ND <1*
5	7.18 ± 1.05	7.17 ± 1.55	6.85 ± 1.50	8.93 ± 1.56	$0.000^{\dagger,***}$	S = D; D <1***
					$0.000^{\dagger,***}$	S = ND; ND <1***
4	6.16 ± 1.34	6.62 ± 1.58	6.20 ± 2.00	8.08 ± 1.83	$0.000^{\dagger,***}$	D = S; S <1***
					$0.001^{\dagger,***}$	S = ND; ND <1*; S <1**
Middle						
6	1.27 ± 0.38	1.01 ± 0.43	1.04 ± 0.42	1.52 ± 0.48	$0.001^{\ddagger,***}$	S = D; D = 1; S <1***
					$0.000^{\ddagger,***}$	ND = S; S <1***
5	2.04 ± 0.45	1.83 ± 0.56	1.98 ± 0.48	2.57 ± 0.71	$0.000^{\dagger,***}$	S = D; D <1**; S <1***
					$0.000^{\dagger,***}$	ND = S; S <1**; ND <1***
4	1.59 ± 0.58	1.76 ± 0.72	1.72 ± 0.83	2.52 ± 0.77	$0.000^{\ddagger,***}$	D = S; S <1**; D <1***
					$0.000^{\ddagger,***}$	S = ND; ND <1**

Note. Data are presented as mean ± standard deviation. Results of *P* value and multiple comparisons in each measurement were divided into 2 rows. The first row showed the result of comparison among the deviated side in asymmetrical Class III group, symmetrical Class III group, and symmetrical Class I group, whereas the second one showed the result of comparison among the nondeviated side in asymmetrical Class III group, symmetrical Class III group and symmetrical Class I group.

D, deviated side of asymmetrical Class III group; *ND,* nondeviated side of asymmetrical Class III group; *S,* symmetrical Class III group; *1,* symmetrical Class I group; *6,* maxillary first molar; *5,* maxillary second premolar; *4,* maxillary first premolar.

†1-way ANOVA; ‡Kruskal-Wallis analysis was used to compare the values among the 3 groups; **P* <0.05; ***P* <0.001; ****P* <0.001.

(*P* <0.01; Supplementary Table IV) and 0.53-0.70 mm thinner buccal alveolar bone on the deviated side at the apical level (*P* <0.05 and *P* <0.01; Supplementary Table IV) compared with the findings on the other side.

On the deviated side in the asymmetrical Class III group, the lingual alveolar bone of the mandibular first molar was 0.33-0.45 mm thinner at 3- and 6-mm along the distal root (*P* <0.01, Supplementary Table V) and 0.22 mm thinner at the 3-mm level along the mesial root (*P* <0.05, Supplementary Table V) than that on the nondeviated side.

Generally, maxillomandibular posterior teeth in the asymmetrical Class III group and symmetrical Class III group showed thinner buccal and lingual alveolar bone thickness than those in the symmetrical Class I group, and some measurements showed significant differences (Tables III-VI; Fig 6).

Compared with the maxillary first molars in the symmetrical Class I group, the maxillary first molar on the deviated side in the asymmetrical Class III group showed 0.51-0.74 mm thinner buccal alveolar bone along the mesiobuccal root (*P* <0.05, *P* >0.05, *P* >0.05, and

Table V. Comparison of buccal alveolar bone thickness of the mandibular posterior teeth among the 3 groups

	Asymmetrical Class III					
	Deviated	*Nondeviated*	*Symmetrical Class III*	*Symmetrical Class I*	P *value*	*Multiple comparisons*
3-mm						
6M	0.55 ± 0.43	0.43 ± 0.43	0.58 ± 0.33	1.01 ± 0.52	0.002[‡,**]	D = S; S <1[**]
					0.000[‡,***]	ND = S; S <1[**]; ND <1[***]
6D	0.67 ± 0.49	0.36 ± 0.48	0.62 ± 0.42	1.22 ± 0.44	0.000[‡,***]	S = D; D <1[***]
					0.000[‡,***]	ND = S; S <1[***]
5	0.49 ± 0.48	0.28 ± 0.37	0.50 ± 0.38	0.81 ± 0.50	0.027[‡,*]	D = S; S = 1; D <1[*]
					0.000[‡,***]	ND = S; S = 1; ND <1[***]
4	0.05 ± 0.16	0.12 ± 0.24	0.03 ± 0.09	0.21 ± 0.26	0.001[‡,**]	D = S; S <1[**]
					0.009[‡,**]	S = ND; ND = 1; S <1[**]
6-mm						
6M	0.68 ± 0.59	0.70 ± 0.55	0.79 ± 0.52	1.44 ± 0.84	0.000[‡,***]	D = S; S <1[**]
					0.001[‡,**]	ND = S; S <1[**]
6D	1.05 ± 0.90	1.09 ± 0.86	1.29 ± 0.77	2.35 ± 0.97	0.000[‡,***]	D = S; S <1[***]
					0.000[‡,***]	ND = S; S <1[***]
5	0.64 ± 0.48	0.53 ± 0.48	0.72 ± 0.45	1.16 ± 0.57	0.003[‡,**]	D = S; S <1[*]; D <1[**]
					0.000[‡,***]	ND = S; S = 1; ND <1[***]
4	0.16 ± 0.28	0.14 ± 0.24	0.15 ± 0.19	0.38 ± 0.29	0.001[‡, **]	D = S; S <1[**]
					0.000[‡,***]	ND = S; S <1[**]
8-mm						
6M	1.12 ± 0.74	1.35 ± 0.70	1.31 ± 0.73	2.04 ± 1.07	0.001[†,***]	D = S; S <1[**]; D <1[***]
					0.004[†,**]	S = ND; ND <1[*]; S <1[**]
6D	1.83 ± 1.14	2.12 ± 1.17	2.17 ± 1.14	3.48 ± 1.23	0.000[‡,***]	D = S; S <1[**]; D <1[***]
					0.000[‡,***]	ND = S; S <1[**]; ND <1[***]
5	0.67 ± 0.54	0.87 ± 0.51	0.86 ± 0.60	1.64 ± 0.76	0.000[‡,***]	D = S; S <1[**]; D <1[***]
					0.000[‡,***]	S = ND; ND <1[**]
4	0.16 ± 0.37	0.20 ± 0.29	0.19 ± 0.25	0.55 ± 0.41	0.000[‡,***]	D = S; S <1[**]; D <1[***]
					0.000[‡,***]	S = ND; ND <1[**]
Apical						
6M	4.57 ± 1.18	5.03 ± 1.07	4.72 ± 1.06	5.78 ± 1.30	0.002[‡,**]	D = S; S <1[*]; D <1[**]
					0.017[‡,*]	S = ND; ND = 1; S <1[*]
6D	5.31 ± 1.19	6.01 ± 1.45	5.70 ± 1.47	7.16 ± 1.38	0.000[‡,***]	D = S; S <1[**]; D <1[***]
					0.001[‡,**]	S = ND; ND <1[*]; S <1[**]
5	3.48 ± 0.71	4.01 ± 0.99	3.64 ± 1.18	5.25 ± 1.22	0.000[‡,***]	D = S; S <1[***]
					0.000[‡,***]	S = ND; ND <1[**]; S <1[***]
4	3.08 ± 0.82	3.24 ± 1.15	3.06 ± 0.91	4.15 ± 0.96	0.000[‡,***]	S = D; D <1 [***]
					0.000[‡,***]	S = ND; ND <1[*]; S <1[***]
Middle						
6M	0.77 ± 0.61	0.81 ± 0.57	0.85 ± 0.54	1.49 ± 0.90	0.002[‡,**]	D = S; S <1[*]; D <1[**]
					0.009[‡,**]	ND = S; S <1[*]
6D	1.21 ± 0.89	1.23 ± 0.85	1.40 ± 0.87	2.49 ± 1.03	0.000[‡,***]	D = S; S <1[***]
					0.000[‡,***]	ND = S; S <1[***]
5	0.53 ± 0.44	0.61 ± 0.42	0.69 ± 0.53	1.34 ± 0.72	0.000[‡,***]	D = S; S <1[**]; D <1[***]
					0.000[‡,***]	ND = S; S <1[**]; ND <1[***]
4	0.14 ± 0.32	0.14 ± 0.27	0.16 ± 0.23	0.42 ± 0.30	0.000[‡,***]	D = S; S <1[**]; D <1[***]
					0.000[‡,***]	ND = S; S <1[**]; ND <1[***]

Note. Data are presented as mean ± standard deviation. Results of *P* value and multiple comparisons in each measurement were divided into 2 rows. The first row showed the result of comparison among the deviated side in asymmetrical Class III group, symmetrical Class III group, and symmetrical Class I group, whereas the second one showed the result of comparison among the nondeviated side in asymmetrical Class III group, symmetrical Class III group and symmetrical Class I group.

D, deviated side of asymmetrical Class III group; *ND,* nondeviated side of asymmetrical Class III group; *S,* symmetrical Class III group; *1,* symmetrical Class I group; *6M,* mesial root of mandibular first molar; *6D,* distal root of mandibular first molar; *5,* mandibular second premolar; *4,* mandibular first premolar.

[†]1-way ANOVA; [‡]Kruskal-Wallis analysis was used to compare the values among the 3 groups; **P* <0.05; ***P* <0.001; ****P* <0.001.

Table VI. Comparison of lingual alveolar bone thickness of the mandibular posterior teeth among the 3 groups

	Asymmetrical Class III					
Variable/tooth	*Deviated*	*Nondeviated*	*Symmetrical Class III*	*Symmetrical Class I*	P *value*	*Multiple comparisons*
3-mm						
6M	0.81 ± 0.64	1.03 ± 0.57	1.02 ± 0.60	1.65 ± 0.79	0.000†,***	D = S; S <1**; D <1***
					0.001†,***	S = ND; ND <1**
6D	1.10 ± 0.78	1.43 ± 0.85	1.26 ± 0.65	1.84 ± 0.74	0.001‡,**	D = S; S <1*; D <1**
					0.008‡,**	S = ND; ND = 1; S <1**
5	0.91 ± 0.48	1.04 ± 0.47	1.01 ± 0.49	1.60 ± 0.79	0.005‡,**	D = S; S <1*; D <1**
					0.013‡,*	S = ND; ND <1*
4	0.49 ± 0.41	0.58 ± 0.34	0.51 ± 0.37	1.34 ± 0.86	0.000‡,***	D = S; S <1***
					0.000‡,***	S = ND; ND <1***
6-mm						
6M	2.81 ± 0.84	2.74 ± 0.63	2.79 ± 0.82	3.79 ± 1.11	0.000†,***	S = D; D <1***
					0.000†,***	ND = S; S <1***
6D	3.02 ± 0.92	3.47 ± 0.74	3.25 ± 0.71	4.00 ± 0.96	0.000‡,***	D = S; S <1**; D <1***
					0.005‡,**	S = ND; ND = 1; S <1**
5	3.02 ± 0.73	3.02 ± 0.49	2.89 ± 0.75	3.79 ± 1.14	0.006‡,**	S = D; D <1*; S <1**
					0.003‡,**	S = ND; ND <1*; S <1**
4	2.14 ± 0.80	2.25 ± 0.59	2.06 ± 0.85	3.44 ± 1.02	0.000†,***	S = D; D <1***
					0.000†,***	S = ND; ND <1***
8-mm						
6M	3.82 ± 1.01	3.61 ± 0.80	3.79 ± 0.95	4.81 ± 1.23	0.001†,**	S = D; D <1**
					0.000†,***	ND = S; S <1**; ND <1***
6D	4.25 ± 0.81	4.43 ± 0.91	4.33 ± 0.84	4.92 ± 1.04	0.017†,*	D = S; S = 1; D <1*
					0.055†	S = ND = 1
5	4.04 ± 0.83	3.98 ± 0.61	3.87 ± 0.86	4.76 ± 1.12	0.007‡,**	S = D; D = 1; S <1**
					0.004‡,**	S = ND; ND <1*; S <1**
4	3.01 ± 0.98	3.17 ± 0.84	3.04 ± 1.14	4.37 ± 1.10	0.000‡,***	D = S; S <1***
					0.000‡,***	S = ND; ND <1***
Apical						
6M	7.55 ± 1.14	7.41 ± 1.10	7.37 ± 1.28	8.44 ± 1.23	0.005†,**	S = D; D <1*; S <1**
					0.002†,**	S = ND; ND <1**
6D	7.61 ± 1.21	7.53 ± 1.37	7.61 ± 1.17	8.28 ± 1.17	0.057‡	D = S = 1
					0.059‡	ND = S = 1
5	6.78 ± 1.27	6.48 ± 1.27	6.39 ± 1.36	6.89 ± 1.14	0.327‡	S = D = 1
					0.428‡	S = ND = 1
4	6.16 ± 1.19	6.04 ± 1.38	5.79 ± 1.69	7.05 ± 1.11	0.004†,**	S = D; D = 1; S <1**
					0.005†,**	S = ND; ND <1*; S <1**
Middle						
6M	3.03 ± 0.81	2.82 ± 0.66	2.83 ± 0.82	3.94 ± 1.17	0.000†,***	S = D; D <1**; S <1***
					0.000†,***	ND = S; S <1***
6D	3.46 ± 0.86	3.58 ± 0.74	3.31 ± 0.74	4.09 ± 1.00	0.006‡,**	S = D; D <1*; S <1**
					0.007‡,**	S = ND; ND = 1; S <1**
5	3.44 ± 0.79	3.40 ± 0.63	3.16 ± 0.96	4.38 ± 1.12	0.000‡,***	S = D; D <1**; S <1***
					0.000‡,***	S = ND; ND <1**; S <1***
4	2.60 ± 0.79	2.66 ± 0.68	2.48 ± 0.99	3.99 ± 1.05	0.000‡,***	S = D; D <1***
					0.000‡,***	S = ND; ND <1***

Note. Data are presented as mean ± standard deviation. Results of *P* value and multiple comparisons in each measurement were divided into 2 rows. The first row showed the result of comparison among the deviated side in asymmetrical Class III group, symmetrical Class III group, and symmetrical Class I group, whereas the second one showed the result of comparison among the nondeviated side in asymmetrical Class III group, symmetrical Class III group and symmetrical Class I group.

D, deviated side of asymmetrical Class III group; *ND*, nondeviated side of asymmetrical Class III group; *S*, symmetrical Class III group; *1*, symmetrical Class I group; *6M*, mesial root of mandibular first molar; *6D*, distal root of mandibular first molar; *5*, mandibular second premolar; *4*, mandibular first premolar.

†1-way ANOVA; ‡Kruskal-Wallis analysis was used to compare the values among the 3 groups; *P <0.05; **P <0.001; ***P <0.001.

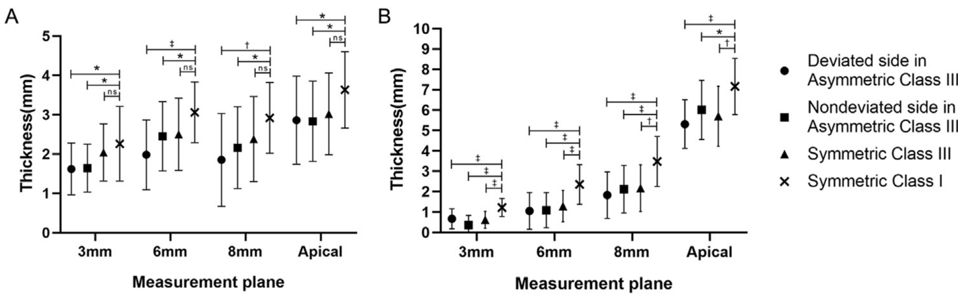

Fig 6. Mean (±standard deviation) distribution of buccal alveolar bone thickness along the **(A)** distobuccal root of the maxillary first molar and **(B)** distal root of the mandibular first molar among different groups at the 3-mm, 6-mm, 8-mm, and apical level planes. **P* <0.05; †*P* <0.01; ‡*P* <0.001; *ns*, no significant difference.

P <0.05; Table III) and 0.77-1.10 mm thinner buccal alveolar bone along the distobuccal root (*P* <0.001, *P* <0.01, *P* <0.05, *P* <0.001; Table III) at the 6-mm, 8-mm, apical, and middle-level planes, respectively.

In the asymmetrical Class III group, the maxillary premolars showed thinner lingual alveolar bone on the deviated side than those in the symmetrical Class I group, with differences of 1.75-1.92 mm and 0.77-1.25 mm at the apical and 8-mm levels, respectively (*P* <0.001 and *P* <0.01; Table IV). On the nondeviated side, it was found that the lingual alveolar bone thickness of premolars at the apical plane was thinner by 1.46-1.76 mm than that in the symmetrical Class I group (*P* <0.001 and *P* <0.05; Table IV).

At the 3-mm level on the deviated side in the asymmetrical Class III group, buccal alveolar bone thickness values along the mesial and distal root of the mandibular first molar and second and first premolars were 0.55 mm, 0.67 mm, 0.49 mm, and 0.05 mm, respectively; these values were significantly less than those in the symmetrical Class I group, as the average thickness values within this group, were 1.01, 1.22, 0.81, and 0.21 mm, respectively (*P* <0.01, *P* <0.001, *P* <0.05, and *P* <0.01; Table V).

In the asymmetrical Class III group, the buccal alveolar bone thickness of the mandibular first molar on the deviated side was thinner by 1.28-1.85 mm and 0.72-1.21 mm along with the distal and mesial roots than that in the symmetrical Class group I at the 6-mm, 8-mm, apical and middle-level planes, respectively (*P* <0.001 and *P* <0.01; Table V).

On the nondeviated side in the asymmetrical Class III group, the buccal alveolar bone thickness along the distal root of the mandibular first molar was 1.15-1.36 mm thinner at the 8-mm and apical levels and 1.26 mm thinner at the 6-mm and middle levels than the values observed in the symmetrical Class I group (*P* <0.05 and *P* <0.001; Table V).

On the deviated side in the asymmetrical Class III group, the lingual alveolar bone was 1.36, 0.99, and 0.89 mm thinner than the lingual alveolar bone in the symmetrical Class I group along the first premolar at the 8-mm level and along the mesial root of the first molar at the 8-mm and apical levels, respectively (*P* <0.001, *P* <0.01, and *P* <0.05; Table VI).

On the nondeviated side in the asymmetrical Class III group, the lingual alveolar bone thickness of the mandibular first molar and premolars was thinner by 0.41-0.76 mm at the 3-mm level (*P* <0.01, *P* >0.05, *P* <0.05, and *P* <0.001; Table VI) and by 0.51-1.33 mm at the 6-mm and middle levels than the lingual alveolar bone in the symmetrical Class I group (*P* <0.05 except the distal root of the first molar; Table VI).

DISCUSSION

Mandibular asymmetry occurs more frequently in patients with severe skeletal Class III malocclusion, which leads to different posterior teeth inclinations for dental compensation on deviated and nondeviated sides.[9,10] On the deviated side, the buccal inclination of maxillary posterior teeth and lingual inclination of mandibular posterior teeth are noted, whereas on the nondeviated side, opposite compensation of posterior teeth is found. Decompensation of posterior teeth inclination should be performed during presurgical orthodontic treatment for patients who need orthognathic surgery. The alveolar bone limitation is an important consideration for orthodontists and orthognathic surgeons when diagnosing and planning treatments. To decompensate the posterior teeth in patients with asymmetrical skeletal Class III malocclusion, especially on the deviated side, the lingual inclination of maxillary posterior teeth and buccal inclination of mandibular posterior teeth should be performed. In addition, adjusting the mandibular first molar on the nondeviated side so that it is upright in the lingual plane should also be considered.[9,10]

Some studies have indicated that skeletal Class III patients have thinner labial and lingual alveolar bone in the anterior teeth than skeletal Class I subjects.[5-8] Our study aimed to use CBCT images to investigate alveolar bone thickness along with the roots of the maxillary and mandibular posterior teeth at different levels in skeletal Class III patients with and without mandibular asymmetry.

On the deviated side, the lingual inclination of the maxillary posterior teeth was required during presurgical orthodontic treatment in orthognathic patients with asymmetrical skeletal Class III malocclusion to achieve the normal buccolingual inclination of teeth shown in subjects with Class I malocclusion.[9,10,29] According to our previous study, maxillary posterior teeth on the deviated side in patients with asymmetrical skeletal Class III malocclusion needed an average lingual inclination of 8.3°, 7.8°, and 7.3° for dental decompensation, whereas in Ahn's study, lingual inclinations of 8.5°, 8.6°, and 6.6° were required for the first molar, second premolar, and first premolar, respectively.[9,29] Therefore, special attention should be paid to the limitation of the buccal alveolar boundary along with the roots of maxillary posterior teeth when setting them upright. Pressure on the buccal alveolar bone was mainly concentrated at the apical third of the root when maxillary posterior teeth were upright to the lingual plane, which may result in a greater periodontal risk of fenestration.[7] According to the results of our study, maxillary posterior teeth on the deviated side in patients with asymmetrical Class III malocclusion showed thinner buccal alveolar bone than that in subjects with skeletal Class I malocclusion at all measured levels. On the deviated side in subjects with asymmetrical skeletal Class III malocclusion, it is worth noting that the buccal alveolar bone along the distobuccal root of the maxillary first molar was 0.77-1.07 mm thinner at the 8-mm and apical level planes ($P < 0.01$ and $P < 0.05$; Table III) and 1.08-1.10 mm thinner at the 6-mm and middle-level planes ($P < 0.001$; Table III) than that in subjects with skeletal Class I malocclusion. Previous studies defined the 6 mm and 8 mm apical regions to the CEJ plane as the middle and apical third of the root, respectively.[5,27] Therefore, we suggest that when uprighting the maxillary first molar on the deviated side, the buccal alveolar bone thickness should be carefully considered at the apical third and the middle third of the distobuccal root of the maxillary first molar.

According to Ahn et al,[9] mandibular first molars, second and first premolars on the deviated side in asymmetrical skeletal Class III patients should be buccally upright for dental decompensation at approximately 4.5°, 7.0°, and 9.1°, respectively. Buccal alveolar bone limitation of mandibular posterior teeth on the deviated side in patients with asymmetrical skeletal Class III malocclusion was a great challenge to orthodontists when uprighting the teeth in the buccal plane on the deviated side during presurgical orthodontic treatment planning.[26] In our study, at the 3-mm level on the deviated side in the asymmetrical Class III group, buccal alveolar bone thickness along with the mesial and distal roots of the mandibular first molar and second and first premolars was significantly thinner than that in the symmetrical Class I group ($P < 0.01$, $P < 0.001$, $P < 0.05$, and $P < 0.01$; Table V). On the deviated side in asymmetrical skeletal Class III patients, it is also worth noting that the buccal alveolar bone thickness along the distal root of the mandibular first molar was much thinner than that in skeletal Class I subjects, with a difference of 1.28-1.30 mm at the 6-mm and middle-level planes ($P < 0.001$; Table V). The above results indicated that fenestration, dehiscence, and gingival recession might occur at the sites mentioned above when uprighting lingually inclined mandibular posterior teeth on the deviated side for decompensation in patients with asymmetrical skeletal Class III malocclusion.

To make the findings more visible, comparisons of buccal alveolar bone thickness along the distobuccal root of the maxillary first molar and distal root of the mandibular first molar among the 3 groups are shown in Figure 6, in which the most significant differences were found. As is shown in Figure 6, buccal alveolar bone thickness along the distal root of mandibular first molar increased from the cervical to apical part of the root. Similarly, buccal alveolar bone thickness along the distobuccal root of the maxillary first molar was thinnest at the 3-mm level and was thickest at the apical level plane, whereas the values at the 8-mm level were less than that at the 6-mm level plane, in both subjects with skeletal Class III and Class I malocclusion. The differences could be explained from the morphologic aspect. From the cervical part to the apex of the root, the thickness of the alveolar bone around the root changed unevenly, which was influenced by the outer surface morphology of the root and cortical bone.

According to the studies by Ahn and Tyan, mandibular first molars on the nondeviated side were more buccally inclined in asymmetrical skeletal Class III patients than in skeletal Class I subjects.[9,10] In our study, on the nondeviated side in asymmetrical Class III patients, buccal alveolar bone along the distal root of the mandibular first molar at the 6-mm, 8-mm, middle, and apical level planes was on average 1.15-1.36 mm thinner than that in Class I subjects, which suggested a weak boundary of buccal alveolar bone to support concentrated pressure when lingually uprighting the mandibular first molar on the nondeviated side for dental decompensation (P <0.05; Table V).

The lingual alveolar bone is always abundant in maxillary and mandibular posterior teeth. However, it is worth noting that at the 3-mm level on the nondeviated side in patients with asymmetrical skeletal Class III malocclusion, lingual alveolar bone thickness along the roots of mandibular first molars and premolars was thinner by 0.41-0.76 mm than that in patients with symmetrical Class I malocclusion (Table VI), suggesting that caution should be taken, especially on the nondeviated side, when lingually uprighting mandibular posterior teeth.

The alveolar bone limitation is essential when making diagnoses and planning treatments. Transverse discrepancies and compensatory buccolingual inclinations of posterior teeth are frequently present in patients with severe skeletal Class III malocclusion. Therefore, traditional arch expansion or even surgically assisted rapid maxillary expansion may also lead to an unpredictable buccal inclination of posterior teeth.[30,31] Individualized multidisciplinary treatment, including alveolar bone distraction osteogenesis and corticotomy-assisted hard or soft tissue augmentation, is necessary to reduce or eliminate serious periodontal risk.

This study had some limitations. Systematic errors were present in some lingual measurements at the 3-mm level and some buccal measurements at the apical level according to the intraclass correlation values and Bland-Altman results because of anatomic characteristics and measurement divergences. Most lingual measurements at the 3-mm level in the maxilla were <1 mm, some of which could not be measured and were recorded as 0. Small changes in these scattered measurements could result in relatively significant differences. In addition, morphologic differences of root apexes could lead to variations at the same site. The above situations indicated the difficulty of measurements at specific sites and the necessity of defining repeatable measuring methods.

The menton deviation in this study was measured in CBCT images taken at the intercuspal occlusion. If the subjects with asymmetrical Class III malocclusion have a lateral functional shift from centric relation to a centric occlusion, the severity of mandibular asymmetry should be reassessed.

The sample size is inadequate for some measurements regarding the standard deviations (mm) of an alveolar bone thickness of the maxillomandibular first molar and premolars in skeletal Class I subjects in Sendyk's study.[5] We also did not discuss sex differences in this preliminary study. In addition, to avoid the chance of encountering type I error because of the repeated measurements, an adjusted P value might be recommended in this study. Therefore, we must emphasize that more comprehensive statistical methods and larger sample sizes are necessary for future studies to draw more accurate conclusions.

Morphologic tendencies were presented in this preliminary study to show alveolar bone thicknesses in skeletal Class III subjects with and without mandibular asymmetry and skeletal Class I subjects. Differences in alveolar bone thickness could be found in some measurements between the deviated and nondeviated sides in asymmetrical skeletal Class III subjects and among the 3 groups. To better generalize the result to the population, longitudinal studies should be involved with a larger sample size to improve the accuracy of evaluating alveolar bone morphology in subjects with asymmetrical skeletal Class III malocclusion.

CONCLUSIONS

1. The null hypotheses were rejected. Significant differences in buccal and lingual alveolar bone thicknesses of maxillomandibular posterior teeth were shown between the deviated and nondeviated sides in subjects with asymmetrical skeletal Class III malocclusion. The buccal and lingual alveolar bone thicknesses of maxillary and mandibular posterior teeth in patients with skeletal Class III malocclusion with and without mandibular asymmetry were significantly thinner than subjects with skeletal Class I malocclusion in some measured planes.
2. Particular attention should be paid to the buccal alveolar bone thickness along the distobuccal root of the maxillary and distal root of the mandibular first molar on the deviated side in subjects with asymmetrical skeletal Class III malocclusion to prevent periodontal complications in decompensation.
3. To improve the reliability of the conclusions, longitudinal studies should involve larger sample sizes, more repeatable and comprehensive measuring and statistical methods.

AUTHOR CREDIT STATEMENT

Xinnong Hu contributed to the data curation, data acquisition, data analysis, and original manuscript preparation; Xiaoyi Huang contributed to data acquisition; and Yan Gu contributed to the study design, data analysis, and manuscript review and editing.

SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ajodo.2021.02.024.

REFERENCES

1. Proffit WR, Fields HW Jr, Sarver DM. Contemporary Orthodontics. 4th ed. St Louis: Mosby; 2007.
2. Jacobs JD, Bell WH, Williams CE, Kennedy JW 3rd. Control of the transverse dimension with surgery and orthodontics. Am J Orthod 1980;77:284-306.
3. Takeshita N, Ishida M, Watanabe H, Hashimoto T, Daimaruya T, Hasegawa M, et al. Improvement of asymmetric stomatognathic functions, unilateral crossbite, and facial esthetics in a patient with skeletal Class III malocclusion and mandibular asymmetry, treated with orthognathic surgery. Am J Orthod Dentofacial Orthop 2013;144:441-54.
4. Ngan P, Moon W. Evolution of Class III treatment in orthodontics. Am J Orthod Dentofacial Orthop 2015;148:22-36.
5. Sendyk M, De Paiva JB, Abrão J, Rino Neto J. Correlation between buccolingual tooth inclination and alveolar bone thickness in subjects with Class III dentofacial deformities. Am J Orthod Dentofacial Orthop 2017;152:66-79.
6. Kook YA, Kim G, Kim Y. Comparison of alveolar bone loss around incisors in normal occlusion samples and surgical skeletal Class III patients. Angle Orthod 2012;82:645-52.
7. Kim Y, Park JU, Kook YA. Alveolar bone loss around incisors in surgical skeletal Class III patients. Angle Orthod 2009;79:676-82.
8. Yamada C, Kitai N, Kakimoto N, Murakami S, Furukawa S, Takada K. Spatial relationships between the mandibular central incisor and associated alveolar bone in adults with mandibular prognathism. Angle Orthod 2007;77:766-72.
9. Ahn J, Kim SJ, Lee JY, Chung CJ, Kim KH. Transverse dental compensation in relation to sagittal and transverse skeletal discrepancies in skeletal Class III patients. Am J Orthod Dentofacial Orthop 2017;151:148-56.
10. Tyan S, Park HS, Janchivdorj M, Han SH, Kim SJ, Ahn HW. Three-dimensional analysis of molar compensation in patients with facial asymmetry and mandibular prognathism. Angle Orthod 2016;86:421-30.
11. Farret MM, Farret MM, da Luz Vieira G, Assaf JH, de Lima EM. Orthodontic treatment of a mandibular incisor fenestration resulting from a broken retainer. Am J Orthod Dentofacial Orthop 2015;148:332-7.
12. Wehrbein H, Bauer W, Diedrich P. Mandibular incisors, alveolar bone, and symphysis after orthodontic treatment. A retrospective study. Am J Orthod Dentofacial Orthop 1996;110:239-46.
13. Enhos S, Uysal T, Yagci A, Veli İ, Ucar FI, Ozer T. Dehiscence and fenestration in patients with different vertical growth patterns assessed with cone-beam computed tomography. Angle Orthod 2012;82:868-74.
14. Handelman CS. The anterior alveolus: its importance in limiting orthodontic treatment and its influence on the occurrence of iatrogenic sequelae. Angle Orthod 1996;66:95-109: discussion 109-10.
15. Timock AM, Cook V, McDonald T, Leo MC, Crowe J, Benninger BL, et al. Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging. Am J Orthod Dentofacial Orthop 2011;140:734-44.
16. Kapila SD, Nervina JM. CBCT in orthodontics: assessment of treatment outcomes and indications for its use. Dentomaxillofac Radiol 2015;44:20140282.
17. Hwang S, Jeong S, Choi YJ, Chung CJ, Lee HS, Kim KH. Three-dimensional evaluation of dentofacial transverse widths of adults with various vertical facial patterns. Am J Orthod Dentofacial Orthop 2018;153:692-700.
18. Baek C, Paeng JY, Lee JS, Hong J. Morphologic evaluation and classification of facial asymmetry using 3-dimensional computed tomography. J Oral Maxillofac Surg 2012;70:1161-9.
19. Park JU, Kook YA, Kim Y. Assessment of asymmetry in a normal occlusion sample and asymmetric patients with three-dimensional cone beam computed tomography: a study for a transverse reference plane. Angle Orthod 2012;82:860-7.
20. Hwang S, Song J, Lee J, Choi YJ, Chung CJ, Kim KH. Three-dimensional evaluation of dentofacial transverse widths in adults with different sagittal facial patterns. Am J Orthod Dentofacial Orthop 2018;154:365-74.
21. Lee JY, Han SH, Ryu HS, Lee HM, Kim SC. Cone-beam computed tomography analysis of transverse dental compensation in patients with skeletal Class III malocclusion and facial asymmetry. Korean J Orthod 2018;48:357-66.
22. Miner RM, Al Qabandi S, Rigali PH, Will LA. Cone-beam computed tomography transverse analysis. Part I: normative data. Am J Orthod Dentofacial Orthop 2012;142:300-7.
23. Capps CJ, Campbell PM, Benson B, Buschang PH. Can posterior teeth of patients be translated buccally, and does bone form on the buccal surface in response? Angle Orthod 2016;86:527-34.
24. Morais JF, Melsen B, de Freitas KMS, Castello Branco N, Garib DG, Cattaneo PM. Evaluation of maxillary buccal alveolar bone before and after orthodontic alignment without extractions: a cone beam computed tomographic study. Angle Orthod 2018;88:748-56.
25. Nahás-Scocate AC, de Siqueira Brandão A, Patel MP, Lipiec-Ximenez ME, Chilvarquer I, do Valle-Corotti KM. Bone tissue amount related to upper incisors inclination. Angle Orthod 2014;84:279-85.
26. Ahn HW, Moon SC, Baek SH. Morphometric evaluation of changes in the alveolar bone and roots of the maxillary anterior teeth before and after en masse retraction using cone-beam computed tomography. Angle Orthod 2013;83:212-21.
27. Lee KJ, Joo E, Kim KD, Lee JS, Park YC, Yu HS. Computed tomographic analysis of tooth-bearing alveolar bone for orthodontic miniscrew placement. Am J Orthod Dentofacial Orthop 2009;135:486-94.
28. Evangelista K, Vasconcelos KdF, Bumann A, Hirsch E, Nitka M, Silva MAG. Dehiscence and fenestration in patients with Class I and Class II Division 1 malocclusion assessed with cone-beam computed tomography. Am J Orthod Dentofac Orthop 2010;138:133.e1-7.
29. Hu X, Huang X, Gu Y. Assessment of buccal and lingual alveolar bone thickness and buccolingual inclination of maxillary posterior teeth in patients with severe skeletal Class III malocclusion with mandibular asymmetry. Am J Orthod Dentofacial Orthop 2020;157:503-15.
30. Suri L, Taneja P. Surgically assisted rapid palatal expansion: a literature review. Am J Orthod Dentofacial Orthop 2008;133:290-302.
31. Sygouros A, Motro M, Ugurlu F, Acar A. Surgically assisted rapid maxillary expansion: cone-beam computed tomography evaluation of different surgical techniques and their effects on the maxillary dentoskeletal complex. Am J Orthod Dentofacial Orthop 2014;146:748-57.

Supplementary Table I. Bland-Altman means and 95% limits of agreement (LOA) for interobserver and intraobserver reliabilities

	Interobserver				*Intraobserver*			
	Deviated		*Nondeviated*		*Deviated*		*Nondeviated*	
Variable/tooth	*Mean*	*95% LOA*	*Mean*	*95% LOA*	*Mean*	*95% LOA*	*Mean*	*95% LOA*
Maxillary first molar								
MB3	−0.05	−0.71 to 0.61	−0.06	−0.60 to 0.47	0.13	−0.65 to 0.91	0.06	−0.27 to 0.39
DB3	0.08	−0.89 to 1.05	−0.16	−1.26 to 0.94	0.09	−0.55 to 0.74	0.04	−1.12 to 1.20
L3	0.03	−0.53 to 0.60	0.01	−0.60 to 0.62	−0.03	−0.51 to 0.46	−0.05	−0.58 to 0.48
MB6	0.02	−0.48 to 0.52	−0.06	−0.54 to 0.42	0.004	−0.41 to 0.42	−0.03	−0.28 to 0.22
DB6	−0.01	−0.36 to 0.34	−0.07	−1.07 to 0.93	0.01	−0.32 to 0.33	−0.08	−1.05 to 0.89
L6	−0.05	−0.65 to 0.56	−0.05	−0.48 to 0.37	−0.03	−0.41 to 0.36	0.01	−0.29 to 0.31
MB8	−0.002	−0.37 to 0.36	−0.05	−0.57 to 0.48	0.02	−0.31 to 0.34	−0.04	−0.41 to 0.34
DB8	0.05	−0.60 to 0.71	−0.10	−1.61 to 1.41	−0.01	−0.40 to 0.39	−0.21	−1.33 to 0.91
L8	0.01	−0.58 to 0.60	−0.09	−0.65 to 0.47	0.004	−0.31 to 0.31	0.01	−0.36 to 0.39
MBa	−0.40	−1.63 to 0.83	−0.27	−1.36 to 0.82	−0.14	−1.00 to 0.72	−0.05	−0.69 to 0.59
DBa	−0.26	−1.05 to 0.53	−0.43	−1.86 to 0.99	−0.02	−0.64 to 0.61	−0.17	−1.23 to 0.89
La	−0.18	−1.17 to 0.81	−0.11	−0.99 to 0.77	−0.10	−1.09 to 0.89	0.10	−0.58 to 0.77
MBm	−0.05	−0.44 to 0.34	−0.03	−0.63 to 0.56	−0.003	−0.37 to 0.36	−0.02	−0.43 to 0.39
DBm	−0.06	−0.72 to 0.61	−0.07	−1.26 to 1.11	−0.09	−0.53(0.36)	−0.10	−1.23 to 1.03
Lm	−0.07	−0.50 to 0.35	−0.03	−0.59 to 0.53	−0.02	−0.41 to 0.37	0.03	−0.32 to 0.38
Maxillary second premolar								
B3	−0.01	−0.45 to 0.42	0.08	−0.41 to 0.57	−0.04	−0.44 to 0.37	0.06	−0.33 to 0.46
L3	0.05	−0.40 to 0.49	0.12	−0.40 to 0.65	0.06	−0.59 to 0.71	0.08	−0.33 to 0.49
B6	−0.0005	−0.39 to 0.39	0.02	−0.47 to 0.52	−0.002	−0.23 to 0.23	−0.02	−0.31 to 0.26
L6	0.04	−0.43 to 0.50	0.04	−0.28 to 0.35	−0.08	−0.47 to 0.32	0.01	−0.28 to 0.31
B8	−0.02	−0.30 to 0.27	−0.06	−0.52 to 0.39	−0.03	−0.33 to 0.26	−0.01	−0.35 to 0.33
L8	0.004	−0.52 to 0.53	−0.06	−0.82 to 0.71	−0.09	−0.52 to 0.33	0.03	−0.32 to 0.38
Ba	−0.05	−0.61 to 0.51	−0.24	−1.61 to 1.12	−0.04	−0.47 to 0.40	−0.27	−1.20 to 0.66
La	−0.04	−1.00 to 0.92	−0.30	−2.55 to 1.94	0.11	−0.65 to 0.87	−0.10	−1.86 to 1.67
Bm	−0.07	−0.37 to 0.23	0.01	−0.59 to 0.61	−0.07	−0.30 to 0.17	−0.05	−0.28 to 0.18
Lm	0.01	−0.44 to 0.45	0.01	−0.55 to 0.57	0.004	−0.29 to 0.30	0.06	−0.30 to 0.43
Maxillary first premolar								
B3	0.04	−0.58 to 0.66	0.01	−0.52 to 0.53	0.04	−0.49 to 0.57	0.003	−0.71 to 0.71
L3	0.01	−0.65 to 0.67	0.12	−0.60 to 0.85	−0.005	−0.31 to 0.30	−0.04	−0.53 to 0.45
B6	0.002	−0.27 to 0.28	0.02	−0.49 to 0.54	0.04	−0.29 to 0.37	0.03	−0.29 to 0.36
L6	0.09	−0.50 to 0.69	0.06	−0.47 to 0.58	0.05	−0.58 to 0.68	−0.02	−0.33 to 0.29
B8	−0.05	−0.54 to 0.45	−0.08	−0.52 to 0.36	0.01	−0.38 to 0.40	0.02	−0.31 to 0.35
L8	0.08	−0.25 to 0.40	0.02	−0.52 to 0.55	0.03	−0.45 to 0.50	−0.01	−0.59 to 0.56
Ba	−0.20	−1.59 to 1.19	−0.35	−1.67 to 0.96	−0.06	−0.88 to 0.77	−0.33	−1.27 to 0.62
La	−0.24	−1.70 to 1.22	−0.001	−1.47 to 1.47	−0.26	−1.61 to 1.09	−0.04	−1.01 to 0.93
Bm	−0.07	−0.42 to 0.28	−0.03	−0.38 to 0.32	−0.02	−0.34 to 0.30	0.02	−0.29 to 0.34
Lm	0.04	−0.51 to 0.59	0.01	−0.36 to 0.37	0.03	−0.50 to 0.56	0.02	−0.22 to 0.27
Mandibular first molar								
MB3	−0.03	−0.44 to 0.38	−0.04	−0.48 to 0.40	−0.03	−0.37 to 0.30	0.03	−0.25 to 0.30
ML3	−0.31	−1.00 to 0.38	−0.17	−1.26 to 0.92	−0.08	−0.51 to 0.36	−0.06	−0.93 to 0.80
DB3	−0.04	−0.54 to 0.45	−0.11	−0.77 to 0.56	−0.07	−0.39 to 0.26	−0.05	−0.47 to 0.36
DL3	−0.36	−1.11 to 0.38	−0.24	−1.33 to 0.86	−0.08	−0.62 to 0.46	−0.10	−0.82 to 0.62
MB6	−0.05	−0.55 to 0.44	−0.02	−0.24 to 0.20	−0.01	−0.37 to 0.34	0.04	−0.29 to 0.37
ML6	−0.20	−0.89 to 0.50	−0.16	−1.10 to 0.78	0.02	−0.35 to 0.39	−0.003	−0.50 to 0.50
DB6	−0.06	−0.48 to 0.36	−0.07	−0.49 to 0.35	−0.06	−0.42 to 0.29	−0.07	−0.49 to 0.35
DL6	−0.18	−0.90 to 0.53	−0.16	−0.97 to 0.66	−0.002	−0.38 to 0.38	−0.08	−0.52 to 0.37
MB8	0.04	−0.35 to 0.43	−0.08	−0.43 to 0.27	0.03	−0.30 to 0.35	−0.02	−0.37 to 0.33
ML8	0.002	−0.61 to 0.61	−0.10	−1.01 to 0.82	0.10	−0.28 to 0.49	−0.07	−0.62 to 0.48
DB8	−0.04	−0.62 to 0.53	−0.05	−0.88 to 0.78	−0.02	−0.38 to 0.35	−0.07	−0.57 to 0.43

Supplementary Table I. Continued

	Interobserver				Intraobserver			
	Deviated		Nondeviated		Deviated		Nondeviated	
Variable/tooth	*Mean*	*95% LOA*	*Mean*	*95% LOA*	*Mean*	*95% LOA*	*Mean*	*95% LOA*
DL8	−0.03	−0.65 to 0.60	−0.04	−0.80 to 0.71	−0.01	−0.45 to 0.43	0.01	−0.53 to 0.54
MBa	0.20	−1.35 to 1.74	0.11	−1.45 to 1.67	0.09	−0.41 to 0.58	−0.02	−0.56 to 0.53
MLa	−0.23	−1.85 to 1.39	−0.12	−1.52 to 1.27	−0.03	−0.65 to 0.59	−0.03	−0.53 to 0.47
DBa	0.04	−0.52 to 0.59	−0.07	−0.83 to 0.70	0.06	−0.23 to 0.35	−0.15	−0.77 to 0.48
DLa	−0.05	−0.54 to 0.43	0.18	−0.78 to 1.14	−0.09	−0.44 to 0.27	−0.13	−2.94 to 2.67
MBm	−0.05	−0.54 to 0.43	−0.05	−0.56 to 0.46	0.01	−0.27 to 0.29	0.04	−0.37 to 0.44
MLm	0.06	−0.67 to 0.78	−0.07	−0.76 to 0.62	0.06	−0.36 to 0.48	−0.01	−0.39 to 0.37
DBm	0.02	−0.52 to 0.55	−0.004	−0.63 to 0.63	0.02	−0.48 to 0.52	0.01	−0.47 to 0.49
DLm	−0.08	−0.68 to 0.52	−0.06	−0.79 to 0.67	0.01	−0.39 to 0.42	−0.01	−0.69 to 0.68
Mandibular second premolar								
B3	−0.001	−0.72 to 0.72	−0.002	−0.45 to 0.45	−0.05	−0.46 to 0.36	0.01	−0.43 to 0.45
L3	0.06	−0.65 to 0.76	−0.04	−0.59 to 0.51	−0.03	−0.73 to 0.68	−0.04	−0.48 to 0.41
B6	−0.04	−0.37 to 0.30	0.06	−0.38 to 0.49	−0.02	−0.45 to 0.41	0.03	−0.42 to 0.49
L6	−0.01	−0.57 to 0.56	−0.02	−0.59 to 0.55	−0.08	−0.45 to 0.29	0.01	−0.57 to 0.59
B8	0.05	−0.35 to 0.45	−0.04	−0.50 to 0.41	0.07	−0.34 to 0.47	−0.03	−0.37 to 0.32
L8	0.004	−0.38 to 0.38	−0.11	−0.54 to 0.33	−0.08	−0.51 to 0.36	−0.06	−0.52 to 0.40
Ba	0.12	−0.57 to 0.81	−0.25	−0.95 to 0.46	0.04	−0.48 to 0.57	−0.20	−0.85 to 0.46
La	−0.16	−0.56 to 0.23	−0.04	−0.92 to 0.84	−0.06	−0.35 to 0.23	0.12	−0.59 to 0.83
Bm	−0.05	−0.41 to 0.31	0.01	−0.45 to 0.47	−0.05	−0.34 to 0.24	0.01	−0.39 to 0.41
Lm	0.01	−0.53 to 0.55	−0.01	−0.64 to 0.62	0.01	−0.39 to 0.42	−0.02	−0.46 to 0.42
Mandibular first premolar								
B3	−0.05	−0.30 to 0.20	−0.03	−0.33 to 0.28	−0.07	−0.47 to 0.33	−0.06	−0.42 to 0.29
L3	−0.16	−0.87 to 0.54	−0.15	−0.48 to 0.18	−0.19	−1.08 to 0.70	−0.11	−0.57 to 0.35
B6	−0.05	−0.28 to 0.19	−0.01	−0.28 to 0.26	−0.04	−0.24 to 0.17	−0.04	−0.22 to 0.15
L6	−0.04	−0.41 to 0.33	−0.24	−1.00 to 0.53	−0.04	−0.49 to 0.41	−0.08	−0.63 to 0.48
B8	−0.07	−0.41 to 0.26	−0.11	−0.38 to 0.17	−0.06	−0.38 to 0.27	−0.06	−0.30 to 0.19
L8	−0.03	−0.57 to 0.52	−0.06	−0.61 to 0.48	−0.05	−0.49 to 0.40	−0.07	−0.59 to 0.45
Ba	0.04	−0.67 to 0.76	0.04	−0.58 to 0.66	0.05	−0.52 to 0.63	0.04	−0.39 to 0.47
La	−0.05	−0.57 to 0.46	−0.18	−0.71 to 0.36	−0.08	−0.88 to 0.71	−0.12	−0.88 to 0.63
Bm	0.06	−1.25 to 1.37	−0.02	−0.38 to 0.34	0.13	−1.14 to 1.39	−0.05	−0.24 to 0.14
Lm	−0.19	−1.48 to 1.10	−0.11	−1.08 to 0.86	−0.18	−1.46 to 1.10	−0.07	−0.62 to 0.48

MB, mesiobuccal root of maxillary first molar/buccal side of the mesial root of mandibular first molar; *DB*, distobuccal root of maxillary first molar/buccal side of distal root of mandibular first molar; *L*, lingual side of the tooth; *B*, buccal side of the tooth; *ML*, lingual side of mesial root of mandibular first molar; *DL*, lingual side of distal root of mandibular first molar.
3, 3-mm level apical to CEJ; *6*, 6-mm level apical to CEJ; *8*, 8-mm level apical to CEJ; *a*, apical level of tooth; *m*, middle level of tooth.

Supplementary Table II. Comparison of the buccal alveolar bone thickness of the maxillary posterior teeth between the deviated and nondeviated sides in each group

	Asymmetrical Class III			*Symmetrical Class III*			*Symmetrical Class I*		
Variable/tooth	*Deviated*	*Nondeviated*	P *value*	*Deviated*	*Nondeviated*	P *value*	*Deviated*	*Nondeviated*	P *value*
3-mm									
6M	1.02 ± 0.58	1.26 ± 0.61	0.020[†,*]	1.22 ± 0.60	1.35 ± 0.68	0.527[‡]	1.61 ± 0.77	1.52 ± 0.86	0.365[†]
6D	1.62 ± 0.66	1.64 ± 0.61	0.881[†]	1.89 ± 0.82	2.18 ± 0.84	0.086[‡]	2.35 ± 1.01	2.17 ± 1.04	0.235[†]
5	0.95 ± 0.64	1.16 ± 0.73	0.041[†,*]	1.15 ± 0.52	1.04 ± 0.66	0.310[†]	1.59 ± 0.60	1.49 ± 0.79	0.411[†]
4	0.45 ± 0.41	0.46 ± 0.46	0.924[†]	0.31 ± 0.41	0.33 ± 0.35	0.770[†]	0.65 ± 0.52	0.63 ± 0.47	0.794[†]
6-mm									
6M	1.00 ± 0.84	1.35 ± 0.85	0.005[†,**]	1.38 ± 0.87	1.26 ± 0.84	0.142[†]	1.64 ± 0.81	1.70 ± 0.91	0.929[‡]
6D	1.98 ± 0.89	2.45 ± 0.88	0.006[†,**]	2.41 ± 0.86	2.59 ± 1.06	0.143[†]	3.03 ± 0.79	3.10 ± 0.86	0.600[†]
5	1.68 ± 0.71	1.94 ± 0.61	0.016[†,*]	1.99 ± 0.65	1.98 ± 0.84	0.909[†]	2.31 ± 0.96	2.28 ± 1.07	0.802[†]
4	0.95 ± 0.42	0.95 ± 0.52	0.953[†]	0.93 ± 0.56	0.94 ± 0.58	0.915[†]	1.10 ± 0.51	1.22 ± 0.55	0.219[†]
8-mm									
6M	1.23 ± 1.13	1.26 ± 0.97	0.871[†]	1.41 ± 0.89	1.32 ± 0.90	0.304[†]	1.72 ± 0.98	1.77 ± 1.12	0.765[†]
6D	1.85 ± 1.18	2.16 ± 1.04	0.159[†]	2.28 ± 1.06	2.48 ± 1.15	0.051[†]	2.91 ± 0.94	2.93 ± 0.98	0.829[†]
5	1.68 ± 0.90	1.88 ± 0.77	0.158[†]	1.92 ± 0.81	1.92 ± 0.86	0.989[†]	2.29 ± 1.15	2.14 ± 1.31	0.354[†]
4	0.75 ± 0.54	0.82 ± 0.49	0.507[†]	0.93 ± 0.55	0.82 ± 0.60	0.291[†]	0.97 ± 0.67	0.98 ± 0.67	0.897[†]
Apical									
6M	2.43 ± 1.16	2.73 ± 1.48	0.213[†]	2.47 ± 1.19	2.55 ± 0.99	0.633[†]	3.24 ± 1.27	3.11 ± 1.29	0.909[‡]
6D	2.86 ± 1.12	2.83 ± 1.02	0.916[†]	2.93 ± 1.05	3.11 ± 1.20	0.286[†]	3.69 ± 1.14	3.57 ± 0.98	0.496[†]
5	3.52 ± 1.10	3.42 ± 1.22	0.725[†]	3.54 ± 1.12	3.33 ± 1.16	0.179[†]	3.73 ± 1.50	3.42 ± 1.45	0.247[†]
4	1.57 ± 0.95	1.64 ± 0.89	0.685[†]	1.79 ± 1.09	1.61 ± 1.24	0.171[†]	1.80 ± 1.09	1.66 ± 0.96	0.361[†]
Middle									
6M	1.03 ± 0.91	1.28 ± 0.92	0.082[†]	1.32 ± 0.88	1.27 ± 0.88	0.633[†]	1.60 ± 0.87	1.68 ± 0.97	0.620[‡]
6D	1.89 ± 1.03	2.29 ± 0.93	0.020[†,*]	2.39 ± 0.99	2.54 ± 1.07	0.121[†]	2.98 ± 0.79	3.00 ± 0.90	0.830[†]
5	1.62 ± 0.73	1.85 ± 0.65	0.037[†,*]	1.92 ± 0.68	1.97 ± 0.88	0.654[†]	2.23 ± 0.92	2.23 ± 1.13	0.997[†]
4	0.88 ± 0.44	0.99 ± 0.48	0.285[†]	0.97 ± 0.58	0.93 ± 0.58	0.592[†]	1.06 ± 0.61	1.13 ± 0.63	0.416[†]

Note. Data are presented as mean ± standard deviation.
D, deviated side; *ND*, nondeviated side; *6M*, mesiobuccal root of maxillary first molar; *6D*, distobuccal root of maxillary first molar; *5*, maxillary second premolar; *4*, maxillary first premolar.
[†]Paired *t* test or [‡]Wilcoxon signed-rank test was used to compare the values on the deviated and nondeviated sides in each group; $^{*}P < 0.05$; $^{**}P < 0.01$.

Supplementary Table III. Comparison of the lingual alveolar bone thickness of the maxillary posterior teeth between the deviated and nondeviated sides in each group

	Asymmetrical Class III			*Symmetrical Class III*			*Symmetrical Class I*		
Variable/tooth	*Deviated*	*Nondeviated*	P *value*	*Deviated*	*Nondeviated*	P *value*	*Deviated*	*Nondeviated*	P *value*
3-mm									
6	0.38 ± 0.40	0.39 ± 0.44	0.934†	0.39 ± 0.46	0.31 ± 0.45	0.246‡	0.79 ± 0.39	0.76 ± 0.41	0.620‡
5	0.84 ± 0.42	0.73 ± 0.36	0.263†	0.97 ± 0.47	0.98 ± 0.37	0.960†	1.15 ± 0.56	1.05 ± 0.40	0.355†
4	0.59 ± 0.41	0.53 ± 0.40	0.537†	0.68 ± 0.52	0.65 ± 0.45	0.774†	0.94 ± 0.38	0.99 ± 0.33	0.364†
6-mm									
6	1.31 ± 0.38	0.99 ± 0.34	0.000†,***	1.11 ± 0.48	1.03 ± 0.48	0.316†	1.44 ± 0.47	1.37 ± 0.50	0.354‡
5	1.97 ± 0.47	1.74 ± 0.34	0.033†,*	1.89 ± 0.46	1.83 ± 0.40	0.481†	2.42 ± 0.93	2.18 ± 0.68	0.073‡
4	1.49 ± 0.44	1.58 ± 0.70	0.480†	1.63 ± 0.76	1.51 ± 0.62	0.675‡	2.13 ± 0.66	2.27 ± 0.75	0.200‡
8-mm									
6	1.38 ± 0.43	1.13 ± 0.51	0.039†,*	1.07 ± 0.55	0.90 ± 0.61	0.161†	1.86 ± 0.63	1.83 ± 0.61	0.742†
5	2.65 ± 0.58	2.52 ± 0.74	0.395†	2.60 ± 0.43	2.49 ± 0.52	0.291†	3.45 ± 1.29	3.40 ± 1.02	0.732‡
4	2.16 ± 0.68	2.52 ± 0.86	0.057†	2.49 ± 1.11	2.38 ± 0.89	0.751‡	3.35 ± 0.98	3.48 ± 1.15	0.790‡
Apical									
6	2.86 ± 0.82	2.69 ± 1.10	0.411†	2.69 ± 0.98	2.44 ± 0.77	0.144†	3.30 ± 1.38	3.55 ± 1.27	0.194†
5	7.18 ± 1.05	7.17 ± 1.55	0.969†	6.61 ± 1.51	7.09 ± 1.77	0.087†	9.13 ± 1.44	8.73 ± 2.12	0.283†
4	6.16 ± 1.34	6.62 ± 1.58	0.136†	6.25 ± 2.06	6.14 ± 2.15	0.929‡	8.07 ± 2.00	8.09 ± 2.35	0.960†
Middle									
6	1.27 ± 0.38	1.01 ± 0.43	0.005†,**	1.09 ± 0.43	1.00 ± 0.48	0.164†	1.57 ± 0.50	1.46 ± 0.53	0.129†
5	2.04 ± 0.45	1.83 ± 0.56	0.080†	1.98 ± 0.53	1.97 ± 0.51	0.897†	2.67 ± 0.96	2.47 ± 0.67	0.245†
4	1.59 ± 0.58	1.76 ± 0.72	0.231†	1.76 ± 0.89	1.67 ± 0.87	0.620‡	2.43 ± 0.89	2.60 ± 0.80	0.112‡

Note. Data are presented as mean ± standard deviation.
D, deviated side; *ND,* nondeviated side; *6,* maxillary first molar; *5,* maxillary second premolar; *4,* maxillary first premolar.
†Paired t test or ‡Wilcoxon signed-rank test was used to compare the values on the deviated and nondeviated sides in each group; *P <0.05 **P <0.01; ***P <0.001.

Supplementary Table IV. Comparison of the buccal alveolar bone thickness of the mandibular posterior teeth between the deviated and nondeviated sides in each group

	Asymmetrical Class III			*Symmetrical Class III*			*Symmetrical Class I*		
Variable/tooth	*Deviated*	*Nondeviated*	P *value*	*Deviated*	*Nondeviated*	P *value*	*Deviated*	*Nondeviated*	P *value*
3-mm									
6M	0.55 ± 0.43	0.43 ± 0.43	0.220†	0.55 ± 0.31	0.61 ± 0.40	0.317†	1.00 ± 0.54	1.01 ± 0.52	0.784†
6D	0.67 ± 0.49	0.36 ± 0.48	0.009†,**	0.58 ± 0.43	0.67 ± 0.52	0.326†	1.21 ± 0.44	1.23 ± 0.55	0.787†
5	0.49 ± 0.48	0.28 ± 0.37	0.009†,**	0.48 ± 0.42	0.52 ± 0.39	0.483†	0.85 ± 0.51	0.77 ± 0.52	0.052‡
4	0.05 ± 0.16	0.12 ± 0.24	0.326‡	0.05 ± 0.15	0.02 ± 0.07	0.273‡	0.17 ± 0.25	0.24 ± 0.32	0.177‡
6-mm									
6M	0.68 ± 0.59	0.70 ± 0.55	0.914†	0.77 ± 0.52	0.81 ± 0.61	0.705†	1.40 ± 0.81	1.49 ± 0.92	0.293†
6D	1.05 ± 0.90	1.09 ± 0.86	0.877†	1.29 ± 0.75	1.30 ± 0.90	0.920†	2.33 ± 0.88	2.37 ± 1.16	0.820†
5	0.64 ± 0.48	0.53 ± 0.48	0.198†	0.76 ± 0.55	0.69 ± 0.47	0.480†	1.11 ± 0.64	1.22 ± 0.57	0.243†
4	0.16 ± 0.28	0.14 ± 0.24	0.683‡	0.19 ± 0.23	0.11 ± 0.20	0.055‡	0.35 ± 0.33	0.41 ± 0.31	0.238†
8-mm									
6M	1.12 ± 0.74	1.35 ± 0.70	0.174†	1.28 ± 0.72	1.34 ± 0.82	0.551†	1.99 ± 0.96	2.09 ± 1.25	0.413†
6D	1.83 ± 1.14	2.12 ± 1.17	0.252†	2.26 ± 1.20	2.07 ± 1.25	0.283†	3.47 ± 1.08	3.50 ± 1.50	0.857†
5	0.67 ± 0.54	0.87 ± 0.51	0.066†	0.89 ± 0.71	0.83 ± 0.63	0.575†	1.54 ± 0.77	1.75 ± 0.83	0.057†
4	0.16 ± 0.37	0.20 ± 0.29	0.279‡	0.20 ± 0.33	0.17 ± 0.26	0.638‡	0.51 ± 0.45	0.60 ± 0.44	0.171†
Apical									
6M	4.57 ± 1.18	5.03 ± 1.07	0.097†	4.76 ± 1.07	4.69 ± 1.23	0.702†	5.83 ± 1.20	5.73 ± 1.48	0.443†
6D	5.31 ± 1.19	6.01 ± 1.45	0.011†,*	5.78 ± 1.48	5.62 ± 1.64	0.461†	7.21 ± 1.38	7.11 ± 1.57	0.615†
5	3.48 ± 0.71	4.01 ± 0.99	0.007†,**	3.60 ± 1.23	3.68 ± 1.29	0.626†	5.12 ± 1.29	5.38 ± 1.24	0.067†
4	3.08 ± 0.82	3.24 ± 1.15	0.409†	3.07 ± 1.06	3.06 ± 0.86	0.920†	4.10 ± 1.02	4.20 ± 0.96	0.330†
Middle									
6M	0.77 ± 0.61	0.81 ± 0.57	0.759†	0.84 ± 0.51	0.87 ± 0.64	0.725†	1.46 ± 0.81	1.51 ± 1.03	0.511†
6D	1.21 ± 0.89	1.23 ± 0.85	0.517†	1.42 ± 0.88	1.38 ± 0.99	0.774†	2.46 ± 0.93	2.52 ± 1.22	0.676†
5	0.53 ± 0.44	0.61 ± 0.42	0.409†	0.69 ± 0.54	0.70 ± 0.58	0.808‡	1.25 ± 0.78	1.44 ± 0.75	0.062†
4	0.14 ± 0.32	0.14 ± 0.27	0.767‡	0.19 ± 0.27	0.13 ± 0.25	0.272‡	0.37 ± 0.35	0.48 ± 0.32	0.074†

Note. Data are presented as mean ± standard deviation.
D, deviated side; *ND*, nondeviated side; *6M*, mesial root of mandibular first molar; *6D*, distal root of mandibular first molar; *5*, mandibular second premolar; *4*, mandibular first premolar.
†Paired *t* test or ‡Wilcoxon signed-rank test was used to compare the values on the deviated and nondeviated sides in each group;; **P* <0.05; ***P* <0.01.

Supplementary Table V. Comparison of the lingual alveolar bone thickness of the mandibular posterior teeth between the deviated and nondeviated sides in each group

	Asymmetrical Class III			*Symmetrical Class III*			*Symmetrical Class I*		
Variable/tooth	*Deviated*	*Nondeviated*	P *value*	*Deviated*	*Nondeviated*	P *value*	*Deviated*	*Nondeviated*	P *value*
3-mm									
6M	0.81 ± 0.64	1.03 ± 0.57	0.046†,*	0.92 ± 0.61	1.13 ± 0.76	0.278‡	1.57 ± 0.87	1.73 ± 0.79	0.128†
6D	1.10 ± 0.78	1.43 ± 0.85	0.005†,**	1.16 ± 0.74	1.37 ± 0.72	0.367‡	1.78 ± 0.84	1.89 ± 0.77	0.424†
5	0.91 ± 0.48	1.04 ± 0.47	0.205†	0.97 ± 0.56	1.04 ± 0.54	0.479†	1.54 ± 0.81	1.66 ± 0.86	0.286†
4	0.49 ± 0.41	0.58 ± 0.34	0.245†	0.51 ± 0.43	0.52 ± 0.42	0.859†	1.40 ± 0.83	1.27 ± 1.00	0.312†
6-mm									
6M	2.81 ± 0.84	2.74 ± 0.63	0.563†	2.79 ± 0.88	2.79 ± 0.86	0.981†	3.73 ± 1.12	3.85 ± 1.17	0.320†
6D	3.02 ± 0.92	3.47 ± 0.74	0.005†,**	3.16 ± 0.76	3.34 ± 0.78	0.155†	3.93 ± 1.02	4.08 ± 0.97	0.125†
5	3.02 ± 0.73	3.02 ± 0.49	0.993†	2.90 ± 0.78	2.88 ± 0.85	0.901†	3.78 ± 1.13	3.80 ± 1.28	0.928†
4	2.14 ± 0.80	2.25 ± 0.59	0.377†	2.01 ± 0.91	2.11 ± 0.92	0.437†	3.48 ± 0.93	3.39 ± 1.18	0.454†
8-mm									
6M	3.82 ± 1.01	3.61 ± 0.80	0.156†	3.73 ± 1.01	3.86 ± 0.99	0.308†	4.77 ± 1.30	4.85 ± 1.24	0.557†
6D	4.25 ± 0.81	4.43 ± 0.91	0.198†	4.25 ± 0.94	4.41 ± 0.91	0.319†	4.81 ± 1.11	5.04 ± 1.07	0.083†
5	4.04 ± 0.83	3.98 ± 0.61	0.707†	3.87 ± 1.03	3.87 ± 0.92	0.999†	4.84 ± 1.14	4.68 ± 1.25	0.338†
4	3.01 ± 0.98	3.17 ± 0.84	0.375†	2.97 ± 1.18	3.12 ± 1.24	0.345†	4.33 ± 1.06	4.40 ± 1.23	0.588†
Apical									
6M	7.55 ± 1.14	7.41 ± 1.10	0.498†	7.28 ± 1.25	7.46 ± 1.45	0.331†	8.33 ± 1.28	8.54 ± 1.29	0.160†
6D	7.61 ± 1.21	7.53 ± 1.37	0.730†	7.48 ± 1.37	7.75 ± 1.15	0.167†	8.17 ± 1.23	8.39 ± 1.22	0.145†
5	6.78 ± 1.27	6.48 ± 1.27	0.060†	6.38 ± 1.56	6.40 ± 1.37	0.915†	6.99 ± 1.15	6.78 ± 1.33	0.300†
4	6.16 ± 1.19	6.04 ± 1.38	0.500†	5.73 ± 1.70	5.85 ± 1.78	0.485†	7.06 ± 1.08	7.03 ± 1.32	0.881†
Middle									
6M	3.03 ± 0.81	2.82 ± 0.66	0.112†	2.88 ± 0.85	2.78 ± 0.85	0.274†	3.85 ± 1.20	4.03 ± 1.23	0.171†
6D	3.46 ± 0.86	3.58 ± 0.74	0.413†	3.20 ± 0.81	3.42 ± 0.79	0.066†	3.99 ± 1.04	4.19 ± 1.03	0.076†
5	3.44 ± 0.79	3.40 ± 0.63	0.750†	3.11 ± 1.04	3.21 ± 0.98	0.466†	4.43 ± 1.14	4.33 ± 1.26	0.560†
4	2.60 ± 0.79	2.66 ± 0.68	0.701†	2.41 ± 1.08	2.56 ± 1.03	0.241†	3.96 ± 0.97	4.02 ± 1.24	0.702†

Note. Data are presented as mean ± standard deviation.
D, deviated side; *ND*, nondeviated side; *6M*, mesial root of mandibular first molar; *6D*, distal root of mandibular first molar; *5*, mandibular second premolar; *4*, mandibular first premolar.
†Paired *t* test or ‡Wilcoxon signed-rank test was used to compare the values on the deviated and nondeviated sides in each group; *$P < 0.05$; **$P < 0.01$.