Original Article

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

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ABSTRACT

Objective: To evaluate the morphometric changes in the alveolar bone and roots of the maxillary anterior teeth (MXAT) after en masse retraction with maximum anchorage (EMR-MA).

Materials and Methods: The samples consisted of 37 female adult patients who had Class I dentoalveolar protrusion (CI-DAP) and were treated by extraction of the first premolars and EMR-MA. Using three-dimensional cone-beam computed tomography taken before treatment and after space closure, the maxillary central incisors (MXCI, N = 66), lateral incisors (MXLI, N = 69), and canines (MXC, N = 69) were superimposed using individual reference planes. After alveolar bone area (ABA), vertical bone level (VBL), root length (RL), root area (RA), and prevalence of dehiscence (PD) were measured at the cervical, middle, and apical levels, statistical analyses were performed.

Results: On the palatal side, ABA significantly decreased in all levels of MXAT ($P < .001$; middle of MXC, $P < .01$). MXCI and MXLI exhibited a greater decrease in the ratio of change in palatal ABA than did MXC (cervical, $P < .01$; middle and apical, $P < .05$; total, $P < .001$). Palatal/labial ABA ratios decreased in MXCI (cervical, middle, total, $P < .001$; apical, $P < .05$) and MXLI (cervical, $P < .001$; apical, $P < .05$). They showed greater amounts and ratios of change in VBL on the palatal side compared to the labial side (all $P < .001$). The palatal side showed more PD in the cervical area than did the labial side (MXCI and MXLI, $P < .001$; MXC, $P < .01$). Significant root resorption occurred in MXAT (RL and RA, all $P < .001$).

Conclusions: During EMR-MA in cases with CI-DAP, ABA and VBL on the palatal side and RL and RA of MXCI and MXLI were significantly decreased. (*Angle Orthod.* 2013;83:212–221.)

KEY WORDS: Alveolar bone; Root; Maxillary anterior teeth; En masse retraction; Extraction space closure; 3D-CBCT

INTRODUCTION

There are two concepts in orthodontic tooth movement in terms of alveolar bone remodeling. If the alveolar bone is remodeled with coordination of resorption and apposition, tooth movement and bone remodeling occur at a 1:1 ratio, and the tooth remains in the alveolar housing. This kind of tooth movement is known as "with-the-bone."[1] However, if balance between resorption and apposition of the alveolar bone is not established during tooth movement, the tooth will move out of the alveolar housing, which is referred to as "through-the-bone."[2]

Bialveolar protrusion is one of the most common chief complaints in Asian orthodontic patients. The conventional treatment modality is extraction of the first premolars and retraction of the anterior teeth with maximum anchorage.[3,4] However, excessive retraction

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of the anterior teeth may result in iatrogenic sequelae such as root resorption, alveolar bone loss, dehiscence, fenestration, and gingival recession.[5–8] Therefore, morphometric evaluation of the alveolar bone and roots of the anterior teeth after en masse retraction may be a good model with which to explain the therapeutic limitation of orthodontic tooth movement and to define the "with-the-bone" and "through-the-bone" concepts.

Conventional two-dimensional (2D) lateral cephalograms have several limitations in terms of investigating the changes in the alveolar bone and roots, especially in the anterior region, as a result of the midsagittal projection.[5,9–11] The advent of cone-beam computed tomography (CBCT) has made it possible to qualitatively and quantitatively evaluate the height and thickness of the alveolar bone and the length and thickness of the root.[8,12–15]

To the authors' knowledge, few studies have investigated the alveolar bone and root of the individual teeth according to a customized reference plane using CBCT images. Therefore, the purpose of this study was to evaluate the morphometric changes in the alveolar bone and roots of the maxillary anterior teeth (MXAT) after en masse retraction with maximum anchorage (EMR-MA) using superimposition of individual teeth with CBCT images.

MATERIALS AND METHODS

This retrospective study was performed under the approval of the Institutional Review Board (IRB) of KyungHee University Dental Hospital (IRB No.: KHD IRB-1108-04). The samples comprised 37 female adult patients with Class I dentoalveolar protrusion (mean age = 26.6 ± 8.5 years; treatment duration = 1.8 ± 0.4 years; SNA, 81.4°; SNB, 77.8°; maxillary central incisor [MXCI] to SN, 127.7°; IMPA, 98.9°; Table 1). These patients were treated by a single orthodontist with extraction of the four first premolars and sliding mechanics using EMR-MA. Working wire was 0.019 × 0.025–inch stainless-steel wire without extra torque, and a 0.022-inch straight-wire appliance with Roth setup (Clippy-C, Tomy, Futaba, Fukushima, Japan) was used. Conventional anchorage such as TPA and/or headgear and elastic chains with a force of 200 g was used. The amount of retraction of MXCI according to every 1 mm of anchorage loss of the maxillary first molar (MX1 to MX6 ratio) was 3.67 ± 0.58 mm (Table 1).

The inclusion criteria for sampling were as follows: skeletal and dental Class I relationships, mild anterior crowding (arch length discrepancy of ≤3mm), labioversion of MXCI (MXCI-SN > 120°), and controlled tipping movement of the MXCI from superimposition of the lateral cephalograms before treatment (T1) and after space closure (T2) (Table 1; Figure 1). The exclusion criteria included tooth size anomaly, periodontal problems, spacing or moderate to severe crowding, and root resorption of the MXAT before orthodontic treatment.

Table 1. Cephalometric Characteristics of the Samples (N = 37, Females)[a]

Variables	Ethnic Norm	Mean	SD
Age at T1 stage (year)	NS	26.62	8.46
Duration of orthodontic treatment, (T2-T1, year)	NS	1.81	0.42
Skeletal horizontal			
SNA, °	81.62	81.40	3.81
SNB, °	79.17	77.83	3.91
ANB, °	2.46	3.57	2.48
Skeletal vertical			
Posterior/anterior facial height ratio, %	66.82	63.62	4.57
SN to mandibular plane angle, °	33.39	37.87	5.54
Dental			
MXCI-SN, °	106.90	127.74	3.49
IMPA, °	95.91	98.93	6.43
Interincisal angle, °	123.82	112.35	6.75
Changes of MXCI			
ΔEdge-AP, mm	NA	−5.66	1.53
ΔEdge-V, mm	NA	−0.69	0.89
ΔRoot-AP, mm	NA	0.63	1.44
ΔRoot-V, mm	NA	−0.30	1.05
Δaxis change, °	NA	10.42	5.94
Anchorage value			
ΔMX6M-AP, mm	NA	1.70	0.53
MX1 to MX6 ratio	NA	3.67	0.58

[a] Ethnic norm is the mean values of Korean female adults. SD indicates standard deviation; MXCI, maxillary central incisor; Δ, difference between pretreatment (T1) and postretraction (T2); Edge-AP, sagittal distance from the vertical reference plane (VRP) to the incisal edge of the MXCI (MXCIE); Edge-V, vertical distance from the horizontal reference plane (HRP) to the MXCIE; Root-AP, sagittal distance from the VRP to the root apex of the MXCI (MXCIA); Root-V, vertical distance from the HRP to the MXCIA; axis change, angular change of the incisor long axis of the MXCI to the SN plane; MX6M-AP, sagittal distance from the VRP to the most mesial point of the mesial surface of the maxillary first molar crown; and MX1 to MX6 ratio [(ΔEdge-AP)/(ΔMX6M-AP) × (−1)], the amount of retraction of MXCIE according to every 1 mm of anchorage loss of the maxillary first molar crown. NA means not applicable.

To evaluate the alveolar bone accurately, CBCT images were taken at the T1 and T2 stages (Implagraphy, Vatech, Seoul, Korea; 12 × 9–cm field of view, 90-kVp tube voltage, 4.0-mA tube current, 0.2-mm isotropic voxel size, and 24-second scan time). The obtained data were analyzed by InVivoDental (Anatomage, San Jose, Calif). To set an identical reference plane in the T1 and T2 stages, three-dimensional (3D) superimposition of the maxillary central incisors (MXCI, N = 66), maxillary lateral incisors (MXLI, N = 69), and maxillary canines (MXC, N = 69) was

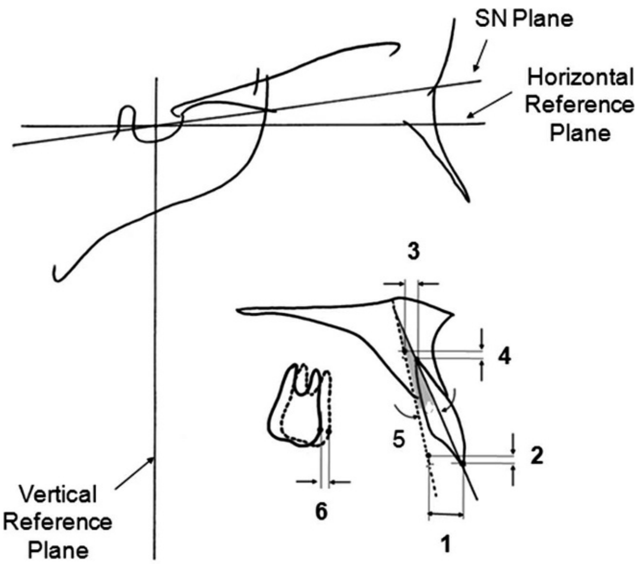

Figure 1. Reference planes and variables on the lateral cephalogram. Reference planes: Horizontal reference plane (HRP), a horizontal plane angulated 7° clockwise to the Sella-Nasion plane passing through Sella; Vertical reference plane (VRP), a perpendicular plane to the HRP passing through Sella. Variables: (1) Δedge-AP, the amount of change in the sagittal distance (Δsagittal distance) from VRP to the incisal edge of the maxillary central incisor (MXCIE); (2) Δedge-V, the amount of change in the vertical distance (Δvertical distance) from HRP to MXCIE; (3) Δroot-AP, Δsagittal distance from VRP to the root apex of the MXCI (MXCIA); (4) Δroot-V, Δvertical distance from HRP to MXCIA; (5) Δaxis, the angular change of the long axis (LA) of MXCI; and (6) ΔMX6M-AP, Δsagittal distance from the VRP to the most mesial point of the mesial surface of the maxillary first molar.

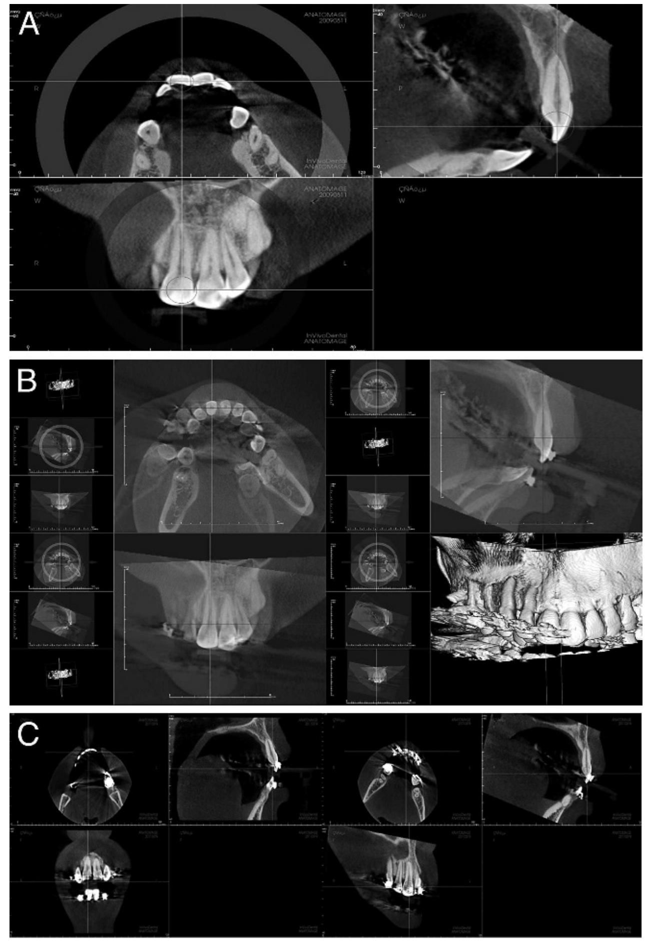

Figure 2. Three-dimensional (3D) superimposition of cone-beam computed tomography (CBCT) images of the right maxillary central incisor (MXCI) based on its long axis (LA) and clinical crown between the pretreatment (T1) and postretraction (T2) stages. (A) Setting of a LA of the MXCI on the sagittal image at the T1 stage. (B) After 3D superimposition by the best-fit method between the two sets of homologous landmarks in the T1 and T2 images, a manual refinement process was performed. (C) Reorientation of the T2 image with the same LA of the T1 image through 3D superimposition (left: raw image; right: reoriented image at the T2 stage).

performed as follows (Figure 2). First, the long axis of each anterior tooth was set on the sagittal image at the T1 stage. Next, 3D superimposition was performed by the best-fit method using two sets of homologous landmarks in each CBCT image and a manual refinement process. Then the T2 image was reoriented on the same coordinate axis as the T1 image.

Definitions of landmarks, reference planes, and variables are given in Figure 3. The alveolar bone area (ABA) was measured at the cervical, middle, and apical levels, respectively. Trisection of the root length into the cervical, middle, and apex levels was duplicated in the T2 stage to guarantee the same slice levels as those in the T1 stage. Vertical bone level (VBL), root length (RL), root area (RA), and prevalence of dehiscence (PD) were measured both on the palatal and labial sides. The percentage of VBL to RL, the ratio of ABA change, and the ratio of palatal to labial ABA were calculated.

All of the measurements were repeated by the same operator after 2 weeks. The difference ranged from 0.27 mm to 0.35 mm for linear measurements, from 0.25° to 0.47° for angular measurements, and from 0.31 mm^2 to 0.48 mm^2 for area measurements, according to Dahlberg's formula.[16] The mean of the two measurements was used for this study. Independent *t*-test, paired *t*-test, one-way analysis of variance (ANOVA) with Duncan's multiple comparison test, and cross-tab analysis were performed for statistical analyses.

RESULTS

Amount and Ratio of Changes in the Labial and Palatal ABA (Table 2)

On the labial side, ABA increased in the middle level of MXCI ($P < .001$) and in the middle and total levels of MXLI ($P < .001$ and $P < .05$, respectively). However, on the palatal side, ABA decreased in all levels of MXCI (all $P < .001$), MXLI (all $P < .001$), and MXC (cervical, apical, total, $P < .001$; middle, $P < .01$).

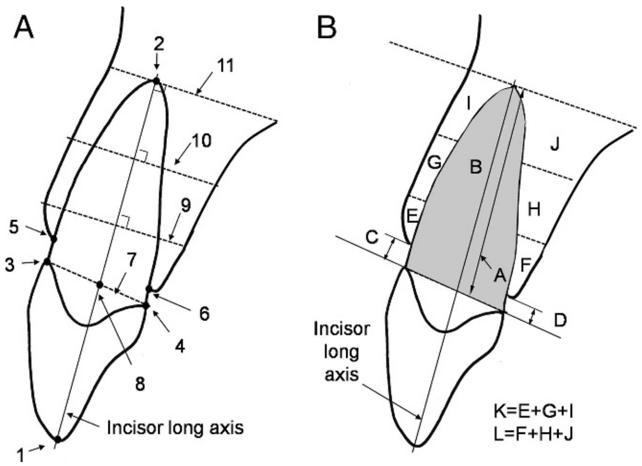

Figure 3. (A) Landmarks and reference planes: (1) Incisor edge or canine tip point; (2) root apex (RA) point; (3, 4) cementoenamel junction (CEJ) points; (5, 6) alveolar crest (AC) points; (7) CEJ line (a line that connects points 3 and 4); (8) intersection point between long axis (LA; a line from points 1 to 2) and CEJ line; (9) intersecting line perpendicular to LA at the cervical third of root length (LCTRL); (10) intersecting line perpendicular to LA at the middle third of root length (LLTRL); (11) intersecting line perpendicular to LA at RA (LARL); (B) Variables: A, root length (distance from points 2 and 8); B, root area (root area below CEJ line); C and D, vertical alveolar bone level (distance from CEJ to AC parallel to LA); E and F, cervical alveolar bone area (ABA); G and H, middle ABA; I and J, apical ABA; and K and L, total ABA on the labial (E + G + I) and palatal sides (F + H + J). Paired variables are the labial and palatal sides.

Although MXCI and MXLI showed a significant decrease in the ratio of change in ABA (ΔABA ratio) compared to MXC on the palatal side (cervical, 78% and 80% vs 48%, $P < .01$; middle, 60% and 55% vs 18%, $P < .05$; apical, 42% and 47% vs 26%, $P < .05$; total, 50% and 52% vs 25%, $P < .001$), MXCI exhibited a greater amount of change in ABA (ΔABA amount) than did MXC only in the middle level (-4.3 mm^2 vs -2.3 mm^2, $P < .05$).

Palatal to Labial ABA Ratio (Table 3)

Although palatal to labial ABA ratios (P/L-ABA ratios) decreased in all areas of MXCI (cervical, middle, total, $P < .001$; apical, $P < .05$) and in some areas of MXLI (cervical, $P < .001$; apical, $P < .05$), MXC did not show differences in any of the areas between the T1 and T2 stages. Differences in ΔP/L-ABA ratio among MXCI, MXLI, and MXC were not significant in any of the areas.

VBL of the Alveolar Bone (Table 4)

At the T1 stage, the amounts and ratios of VBL (VBL amount and VBL ratio, respectively) were greater on the labial side than on the palatal side in MXAT (MXCI and MXLI, $P < .001$; MXC, $P < .01$). At T2 stage, the VBL amount and VBL ratio of MXAT increased both on the palatal and labial sides. Although MXCI and MXLI exhibited a greater ΔVBL amount and ΔVBL ratio on the palatal side than on the labial side, MXC did not exhibit differences in ΔVBL amount between the labial and palatal sides (ΔVBL amount; MXCI and MXLI, $P < .001$; ΔVBL ratio; 1.6% vs 29.3%, 4.9% vs 36.1%, 8.3% vs 15.3%, MXCI and MXLI, $P < .001$; MXC, $P < .05$).

In comparison of ΔVBL on the palatal side, MXCI and MXLI showed higher values than MXC in terms of

Table 2. Comparison of the Amounts of the Alveolar Bone Area Between the Pretreatment (T1) and Postretraction (T2) Stages in Each Tooth and the Amounts of Change during the T1 and T2 Stages and Ratio Among the Maxillary Anterior Teeth

Alveolar Bone Area	Maxillary Central Incisors (N = 66, Group 1)						Maxillary Lateral Incisors (N = 69, Group 2)					
	T1		TΔ		ΔT/T1		T1		TΔ		ΔT/T1	
	Mean	SD	Mean	SD	Ratio	P-Value[a]	Mean	SD	Mean	SD	Ratio	P-Value[a]
Labial side												
Cervical	1.56	1.98	−0.16	1.89	−0.10	.5005	1.05	0.80	0.05	0.98	0.04	.6922
Middle	2.41	1.13	0.65	1.47	0.27	.0007***	1.29	0.96	0.84	1.49	0.65	.0000***
Apical	3.30	2.29	−0.19	2.42	−0.06	.5247	1.69	1.74	0.09	1.62	0.05	.6409
Total	7.27	4.17	0.30	3.78	0.04	.5243	4.03	2.74	0.98	3.31	0.24	.0168*
Palatal side												
Cervical	2.32	1.35	−1.82	1.18	−0.78	.0000***	1.75	1.14	−1.40	0.94	−0.80	.0000***
Middle	7.18	3.58	−4.32	3.09	−0.60	.0000***	6.17	4.00	−3.38	3.30	−0.55	.0000***
Apical	15.92	7.17	−6.66	6.62	−0.42	.0000***	13.14	6.95	−6.17	6.27	−0.47	.0000***
Total	25.42	11.43	−12.79	9.75	−0.50	.0000***	21.06	11.76	−10.95	9.62	−0.52	.0000***

[a] Paired *t*-test was performed to compare the values in the T1 and T2 stages.

[b] One-way analysis of variance (ANOVA) with Duncan's multiple comparison test was performed to assess the differences in the amount (T2-T1, ΔT) and ratio (ΔT/T1) of change in the cervical, middle, apical, and total levels. SD indicates standard deviation. In multiple comparison, the maxillary anterior teeth were allocated into group 1 (maxillary central incisors), group 2 (maxillary lateral incisors), and group 3 (maxillary canines). The ratio of the changes in the alveolar bone area was computed as follows: [amount of the changes in the alveolar bone area (T2-T1, ΔT)/amount of the alveolar bone area at T1 stage].

* $P < .05$; ** $P < .01$; *** $P < .001$.

the amount and ratio (all $P < .001$). However, on the labial side, MXC had a greater ΔVBL amount than did MXCI ($P < .05$).

Root Resorption (Table 5)

Although significant root resorption occurred in MXCI, MXLI, and MXC (RL, all $P < .001$; RA, all $P < .001$), the amounts of decreases in RL and RA did not differ among MXCI, MXLI, and MXC.

PD in the Cervical Area (Table 6)

Root exposure (dehiscence) in the cervical area occurred more frequently on the palatal side than on the labial side (MXCI and MXLI, $P < .001$; MXC, $P < .01$). In addition, there was a higher percentage of dehiscence in MXLI and MXC than in MXCI on the labial side (14% and 12% vs 2%, $P < .05$) and in MXCI and MXLI than in MXC on the palatal side (67% and 68% vs 32%, $P < .001$).

DISCUSSION

The findings that ABA increased in the middle level of MXCI ($P < .001$) and in the middle and total levels of MXLI ($P < .001$ and $P < .05$, respectively) on the labial side and decreased in all the levels of MXAT ($P < .001$; middle of MXC, $P < .01$) on the palatal side (Table 2) imply that en masse retraction of the MXAT might result in tooth movement "through-the-bone." This implication was confirmed by the fact that P/L-ABA ratios decreased in all areas of MXCI (cervical, middle, total, $P < .001$; apical, $P < .05$) and in some areas of MXLI (cervical, $P < .001$; apical, $P < .05$) after retraction (Table 3).

The increase in ΔABA amount on the labial side was much lower than the decrease in ΔABA amount on the palatal side (4% vs −50% in MXCI, 24% vs −52% in MXLI; Table 2), which means that bone apposition in the tension area of the inner side of the labial alveolar bone was not sufficient and/or bone resorption occurred on the outer side of the labial alveolar bone. Sarikaya et al.[8] reported that the apposition process in the inner cortical plate of the labial alveolar bone is somewhat slower than the resorption process in the outer cortical plate of the labial alveolar bone.

The decrease in ABA of MXCI and MXLI was more significant in the cervical region of the palatal side (−78% and −80%, respectively; Table 2) because the MXAT of the samples showed a controlled tipping movement pattern, leading to a greater accumulation of pressure in the alveolar crest region on the palatal side. However, on the labial side, the middle area of MXCI and MXLI showed a greater increase in ABA than did the cervical area, where more tension existed (27% vs −10%, 65% vs 4%, respectively; Table 2). The reason that the cervical area did not show an increase in ABA on the labial side seems to be an inflammatory periodontal response concentrated in the cervical area, resulting in loss of VBL in spite of the greater tensional force. Therefore, the entire alveolar housing, not merely the bone in the apical zone, should be considered when a clinician tries to define the therapeutic limits for orthodontic tooth movement.[8]

At the T1 stage, VBL on the labial side was greater than that on the palatal side in all of the MXAT (MXCI

Table 2. Extended

Maxillary Canines (N = 69, Group 3)						Comparison of the Amount of Change During T1 and T2 and Ratio Among the Maxillary Anterior Teeth in the Levels of Each Side			
T1		TΔ		ΔT/T1		Amount		Ratio	
Mean	SD	Mean	SD	Ratio	P-Value[a]	P-Value[b]	Multiple Comparison	P-Value[b]	Multiple Comparison
1.16	0.89	0.64	2.67	0.54	.0517	.0532	–	.4769	–
1.29	1.10	0.40	1.82	0.31	.0694	.2844	–	.2765	–
2.09	3.29	−0.10	3.73	−0.05	.8162	.8276	–	.1731	–
4.54	4.21	0.94	6.21	0.20	.2144	.6358	–	.7221	–
3.27	2.43	−1.57	2.11	−0.48	.0000***	.2629	–	.0054**	(2,1) < 3
13.01	6.09	−2.29	6.44	−0.18	.0043**	.0373*	(1,2) < (2,3)	.0190*	(1,2) < 3
31.54	11.70	−8.25	13.51	−0.26	.0000***	.4048	–	.0244*	(2,1) < 3
47.82	18.16	−12.10	18.66	−0.25	.0000***	.3900	–	.0005***	(2,1) < 3

Table 3. Comparison of the Palatal to Labial Alveolar Bone Area Ratio Between the Pretreatment (T1) and Postretraction (T2) Stages in Each Tooth and the Amounts of Change During the T1 and T2 Stages Among the Maxillary Anterior Teeth

Palatal/Labial Alveolar Bone Area Ratio	Maxillary Central Incisors (N = 66)					Maxillary Lateral Incisors (N = 69)		
	T1		T2			T1		T2
	Mean	SD	Mean	SD	*P*-Value[a]	Mean	SD	Mean
Cervical	2.75	4.41	0.56	1.23	.0003***	2.18	2.26	0.29
Middle	3.66	3.20	1.51	2.13	.0000***	6.71	10.86	4.83
Apical	9.38	15.03	4.63	6.17	.0170*	23.19	43.91	10.47
Total	4.37	3.15	2.42	2.42	.0001***	11.55	34.02	5.21

[a] Paired *t*-test was performed.

[b] One-way analysis of variance (ANOVA) with Duncan's multiple comparison test was performed. SD indicates standard deviation. The palatal to labial alveolar bone area ratio in the cervical, middle, apical, and total levels was calculated as follows: palatal alveolar bone area/labial alveolar bone area.

* $P < .05$; *** $P < .001$.

Table 4. Comparison of the Amount and Ratio of the Vertical Bone Level of the Alveolar Bone Between the Pretreatment (T1) and Postretraction (T2) Stages in Each Tooth and the Amounts of Change During the T1 and T2 Stages Among the Maxillary Anterior Teeth

Vertical Bone Level			Maxillary Central Incisors (N = 66, Group 1)					Maxillary Lateral Incisors (N = 69, Group 2)	
			T1		TΔ			T1	
			Mean	SD	Mean	SD	*P*-Value[a]	Mean	SD
Labial side		Amount, mm	1.67	0.75	0.20	0.65	.0136*	2.52	2.30
		Ratio, %	13.88	6.52	1.64	5.78	.0015**	24.58	24.34
Palatal side		Amount, mm	1.30	0.51	3.65	2.65	.0000***	1.52	1.06
		Ratio, %	10.91	4.97	29.32	20.63	.0000***	12.92	9.92
Comparison of the values between	*P*-Value[c]	Amount, mm	.0001***		.0000***			.0001***	
labial and palatal sides		Ratio, %	.0001***		.0000***			.0001***	

[a] Paired *t*-test was performed to compare the values in the T1 and T2 stages.

[b] One-way analysis of variance (ANOVA) with Duncan's multiple comparison test was performed.

[c] Independent *t*-test was performed. SD indicates standard deviation. In multiple comparison, the maxillary anterior teeth were allocated into group 1 (maxillary central incisors), group 2 (maxillary lateral incisors), and group 3 (maxillary canines). The ratio of the vertical alveolar bone loss was computed as follows: [(amount of the vertical loss of the alveolar bone/root length) $\times$ 100].

* $P < .05$; ** $P < .01$; *** $P < .001$.

Table 5. Comparison of Root Resorption in Terms of Root Length and Root Area Between the Pretreatment (T1) and Postretraction (T2) Stages in Each Tooth and the Amounts of Change During the T1 and T2 Stages Among the Maxillary Anterior Teeth

	Maxillary Central Incisors (N = 66)					Maxillary Lateral Incisors (N = 69)			
	T1		T2			T1		T2	
	Mean	SD	Mean	SD	*P*-Value[a]	Mean	SD	Mean	SD
Root length	12.33	1.44	11.26	1.52	.0000***	12.28	1.93	11.14	1.83
Root area	55.87	11.07	52.32	10.74	.0000***	55.06	9.19	51.64	9.26

[a] Paired *t*-test was performed.

[b] One-way analysis of variance (ANOVA) test was performed. SD indicates standard deviation.

*** $P < .001$.

and MXLI, $P < .001$; MXC, $P < .01$; Table 4). These findings are consistent with those of Nahm et al.,[13] who reported VBL ratios of 19.3% and 15.0% for the labial and palatal aspects of the MXAT, respectively. The finding that at the T2 stage, MXCI and MXLI showed a greater VBL and a higher PD on the palatal side than on the labial side compared to MXC (Table 4) might result from the discrepancy in the direction of tooth movement in relation to the labiolingual long axis of the roots among MXCI, MXLI, and MXC (Figure 4).

Dehiscence is a major bony defect that is difficult to discern on conventional 2D radiographs.[17] A previous CBCT study[18] defined dehiscence as the absence of cortical bone around the root in at least three sequential views. In our study, dehiscence was determined when the ABA covering the cervical root

Table 3. Extended

Maxillary Lateral Incisors (N = 69)		Maxillary Canines (N = 69)					Comparison of the Amount of Change During T1 and T2 Among the Maxillary Anterior Teeth
T2		T1		T2			
SD	*P*-Value[a]	Mean	SD	Mean	SD	*P*-Value[a]	*P*-Value[b]
0.75	.0000***	3.30	4.43	3.49	17.11	.9224	.2649
21.95	.4468	15.43	16.15	13.83	27.48	.7221	.9899
31.01	.0290*	38.29	55.39	30.09	48.94	.4575	.6778
12.04	.1699	14.87	10.92	15.01	24.21	.9663	.3535

Table 4. Extended

Maxillary Lateral Incisors (N = 69, Group 2)			Maxillary Canines (N = 69, Group 3)					Comparison of the Amount of Change During T1 and T2 Among the Maxillary Anterior Teeth	
T			T1		TΔ				
Mean	SD	*P*-Value[a]	Mean	SD	Mean	SD	*P*-Value[a]	*P*-Value[b]	Multiple Comparison
0.62	1.92	.0095**	3.31	3.14	1.35	3.80	.0042**	.0271*	(1,2) < (2,3)
4.94	15.79	.0341*	21.1	21.91	8.33	23.1	.0005***	.0671	–
4.42	3.09	.0000***	1.75	1.22	2.42	2.05	.0000***	.0001***	3 < (1,2)
36.05	25.04	.0000***	11.29	8.25	15.32	12.99	.0000***	.0000***	3 < (1,2)
.0000***			.0012**		.0528				
.0000***			.0012**		.0410*				

Table 5. Extended

Maxillary Lateral Incisors (N = 69)	Maxillary Canines (N = 69)					Comparison of the Amount of Change During T1 and T2 Among the Maxillary Anterior Teeth
	T1		T2			
P-Value[a]	Mean	SD	Mean	SD	*P*-Value[a]	*P*-Value[b]
.0000***	15.79	1.49	14.91	1.60	.0000***	.2198
.0000***	85.24	11.94	82.48	11.89	.0000***	.3445

was zero. In spite of this strict definition of PD, a strikingly higher PD in the cervical area on the palatal side was shown after space closure (67% of MXCI, 68% of MXLI, and 32% of MXC, respectively; Table 6). Because the upper parts of the roots of MXAT are supported by thin alveolar bone[13] they are vulnerable to dehiscence during retraction. However, a potential limitation of this result can exist in the risk of overestimating dehiscence. A previous study[19] reported that the positive predictive value of dehiscence was only 0.51 and that alveolar bone height could be measured with an accuracy of 0.6 mm using CBCT with a voxel size of 0.38 mm at 2 mA. Moreover, since additional bone remodeling continues slowly after active tooth movement, the results from this study should be interpreted conservatively when one is applying them to the clinical situation.

Since patients with dentoalveolar protrusion usually have thin and elongated anterior alveoli and/or a bony defect before treatment,[8,11,13] pushing the tooth against

Table 6. Comparison of the Prevalence of Dehiscence in the Cervical Area Between the Labial and Palatal Sides in Each Tooth and Among the Maxillary Anterior Teeth on Each Side at the postretraction (T2) Stage[a]

	Maxillary Central Incisors (N = 66)		Maxillary Lateral Incisors (N = 69)		Maxillary Canines (N = 69)		
	Incidence, No.	%	Incidence, No.	%	Incidence, No.	%	*P*-Value
Labial side							
Cervical	1	2	10	14	8	12	.0251*
Middle	1	2	11	16	9	14	–
Apical	2	3	13	19	12	18	–
Palatal side							
Cervical	44	67	47	68	21	32	.0000***
Middle	8	12	22	32	0	0	–
Apical	1	2	2	3	0	0	–
Comparison of the prevalence of dehiscence in the cervical area between the labial and palatal sides							
P-value	.0000***	–	.0000***	–	.0066**	–	–

[a] Cross-tab analysis was performed. If the alveolar bone area covering the root decreased to zero at the T2 stage, it was considered to represent dehiscence.

* $P < .05$; ** $P < .01$; *** $P < .001$.

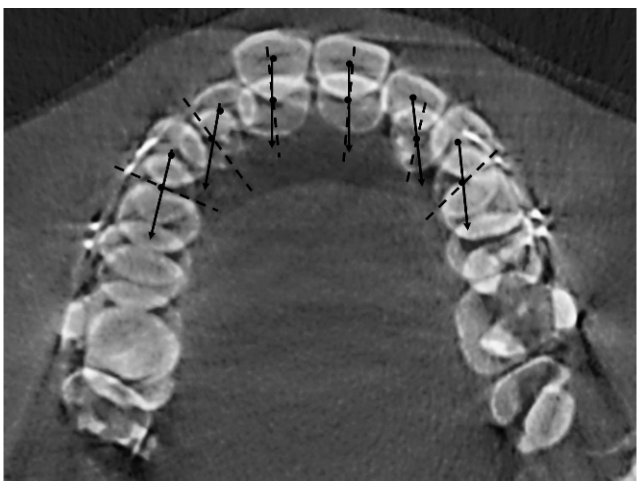

Figure 4. Direction of tooth movement from the pretreatment (T1) to the postretraction (T2) stages (solid arrow). The labiolingual long axis (LA) of the maxillary anterior teeth at the T2 stage was used as a reference for the sagittal image (dashed line).

the thin cortical bone may cause root resorption and/or an alveolar bone defect (Figure 5). If the bracket prescription with excessive root torque is used in the MXAT, excessive root movement can cause a greater risk of root resorption and PD of the labial or palatal cortical plate.[7] For these patients, retraction of the anterior teeth using absolute anchorage with orthodontic mini-implants may not always be the right answer. If labioversion of the incisors is excessive and the alveolus is thin, retraction of the anterior teeth combined with corticotomy of the alveolar bone can offer an effective alternative with which to minimize the risk of uncontrolled movements of the anterior teeth.[3,4,11]

Another important issue is whether or not the repair of alveolar bone loss is possible after space closure and during the retention period. In this study, some patients who were able to undergo CBCT at the debonding stage did not show spontaneous bone apposition on the labial and palatal sides (Figure 6).

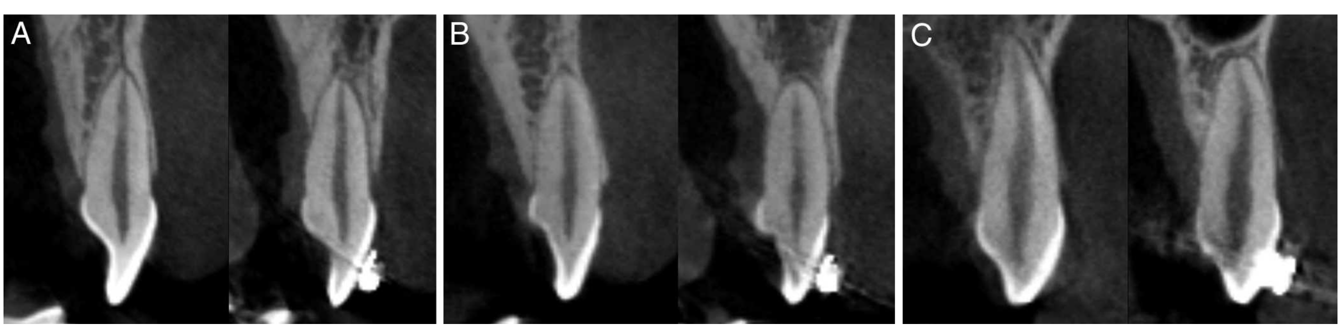

Figure 5. Examples of the sagittal images of the maxillary central incisor (MXCI) (A), maxillary lateral incisor (MXLI) (B), and maxillary canine (MXC) (C) at the pretreatment (T1) (left image) and postretraction (T2) stages (right image).

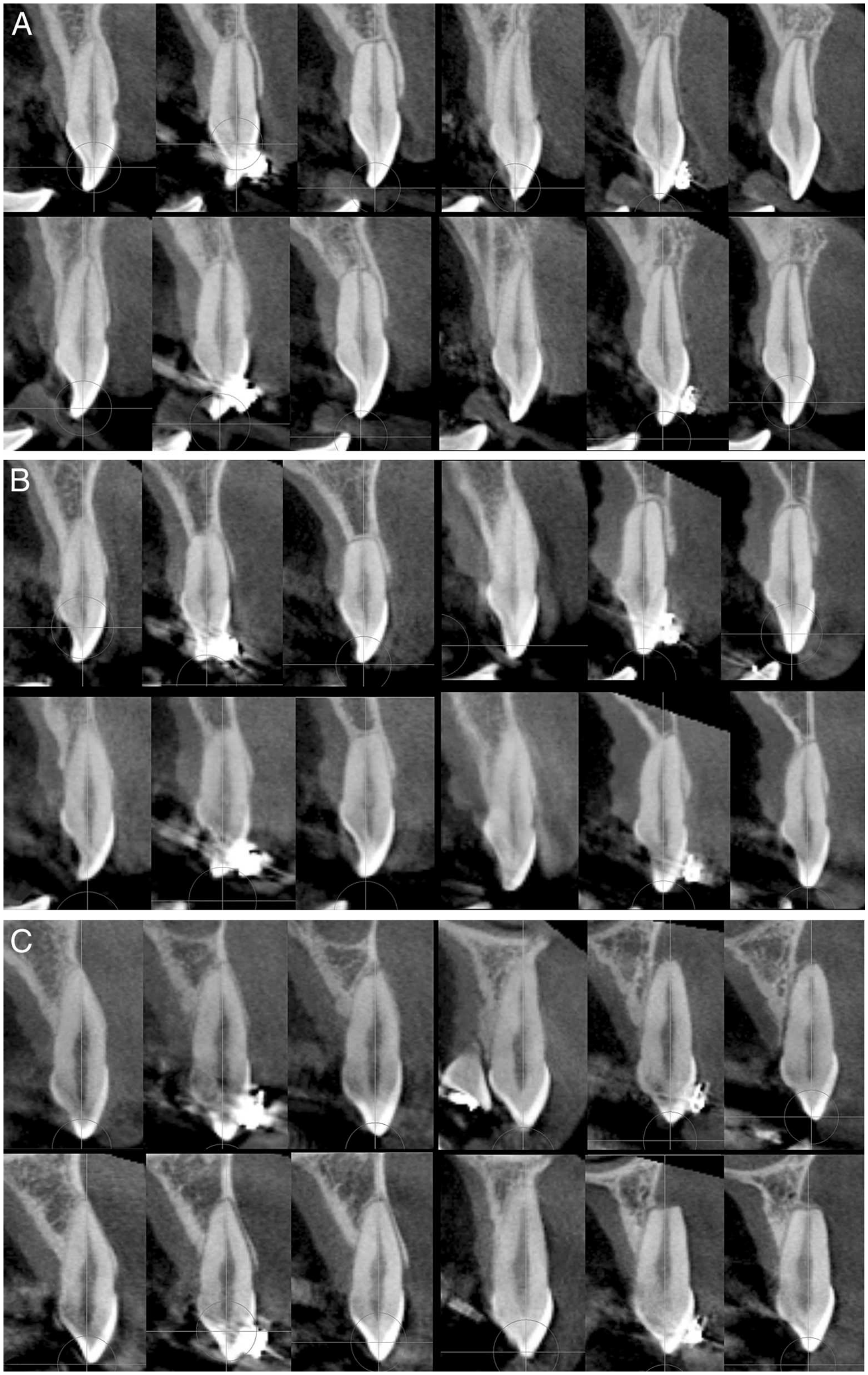

Figure 6. Examples of the maxillary central incisor (MXCI) (A), maxillary lateral incisor (MXLI) (B), and maxillary canine (MXC) (C) at the pretreatment (T1), postretraction (T2), and debonding stages.

Previous studies[6,8,20,21] reported that once the cortical plate had been penetrated by the root, recovery of the well-defined dense cortical plate would not occur. Therefore, longitudinal studies are needed to investigate whether repair of the alveolar bone defect takes place after space closure and during the retention period and to identify discriminative factors for good and poor capacity for alveolar bone remodeling.

CONCLUSION

- During EMR-MA in patients with Class I dentoalveolar protrusion, the ABA and VBL on the palatal side and the RL and RA of the MXCI and MXLI were significantly decreased.

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