Original Article

Recovery bone formation on radiographic palatal bone dehiscences after incisor retraction with microimplants

Ho-Jin Kim[a]; Hyung-Kyu Noh[a]; Hyo-Sang Park[b]

ABSTRACT

Objectives: To investigate the difference in labial and palatal alveolar bone thickness and height during the retention period after incisor retraction treatment with microimplant.

Materials and Methods: A sample of 21 patients (mean age: 17.80 ± 4.38 years) who underwent incisor retraction treatment using microimplants after premolar extraction was investigated. The cone-beam computed tomography images at pretreatment, posttreatment, and retention were used to measure anterior alveolar bone thickness (labial, palatal, and total; at three vertical levels) and height (labial and palatal) and differences in the incisor position during treatment or retention. Repeated-measures analysis of variance with Bonferroni correction was performed to compare the variables at T0, T1, and T2.

Results: The maxillary central incisor moved posteriorly by approximately 8.0 mm along with intrusive movement of 1.8 mm after treatment. The alveolar bone thickness significantly decreased on the palatal side and increased on the labial side after treatment. Thereafter, the palatal bone thickness significantly increased and labial bone thickness decreased during the retention period. The palatal interdental bone depressed by incisor retraction showed substantial bone deposition after retention.

Conclusions: Radiographic palatal bone dehiscences on the incisor root and palatal bone depression between the incisor roots were apparent after treatment. This palatal bone loss around the incisor roots noticeably recovered with newly formed bone during retention. (*Angle Orthod*. 2024;94:168–179.)

KEY WORDS: Incisor retraction; Microimplant; Radiographic palatal bone dehiscence; Alveolar bone remodeling

INTRODUCTION

The envelope of discrepancy regarding orthodontic treatment was broadened by the increased amount of tooth movement possible with absolute anchorage,[1] as skeletal anchorage provides more absolute anchorage. As the tooth movement limits increase in distance with skeletal anchorage, concern was raised about the palatal alveolar bone as a limit of tooth movement and the alveolar bone changes occurring with proximity of roots to the palatal bone.[2–4] Cone-beam computed tomography (CBCT) has made it feasible to measure three-dimensional distance or volumetric values of the alveolar bone accurately. Previous CBCT studies demonstrated a decrease in palatal bone thickness and an increase in labial bone thickness after incisor retraction.[5–7] Thus, a large extent of incisor retraction with bodily movement using skeletal anchorage can move incisor roots sufficiently to contact the palatal bone and may result in palatal bone dehiscence, raising concerns for clinicians. Interestingly, an earlier case report presented critical bone apposition at 10-year retention at the site of palatal bone loss caused by extensive incisor retraction during treatment.[2] This suggested the possibility of spontaneous bone healing under favorable conditions including healthy periodontium and thick biotype gingiva. However, thus far, no CBCT study has examined whether bone dehiscences recovered with newly formed bone during the retention period.

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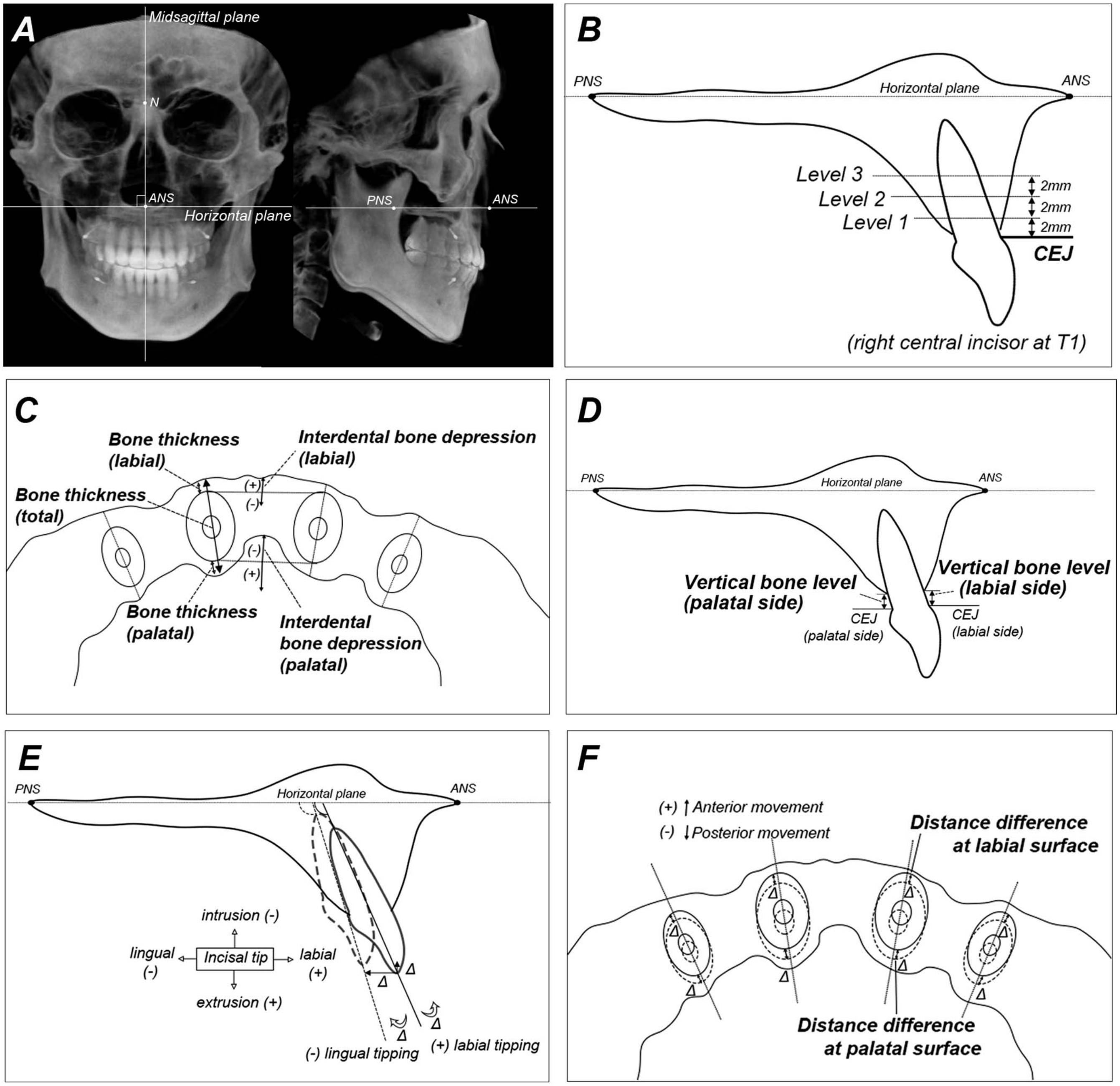

Figure 1. Reference planes and measurements in cone-beam computed tomography image. (A) Midsagittal and horizontal reference planes of the maxilla. (B) Sagittal section. Vertical levels of the axial section based on the cementoenamel junction (CEJ) of the right maxillary central incisor at posttreatment. (C) Axial section. Alveolar bone thickness (along the anteroposterior line of the tooth) and interdental bone depression (distance between the labial/palatal interdental line and the most depressed point of the interdental bone). (D) Vertical bone level (distance from the alveolar bone crest to the CEJ). (E) Difference in the incisal tip position and tooth inclination on the sagittal sections between time points. (F) Difference in the tooth position on the axial sections between time points (at the labial or palatal root surface). ANS indicates anterior nasal spine; N, nasion; PNS, posterior nasal spine; T1, posttreatment.

Therefore, this study investigated long-term changes in the maxillary alveolar bone thickness and height in patients who underwent large amounts of incisor retraction using microimplants after premolar extraction. The tooth and alveolar bone parameters were measured and compared using CBCT images at pretreatment (T0), posttreatment (T1), and retention (T2). In addition, the assessment of the palatal alveolar bone by the cephalometric image was compared with that of the CBCT image. The null hypothesis was that there would be no significant differences in the alveolar bone thickness and height at T1 and T2.

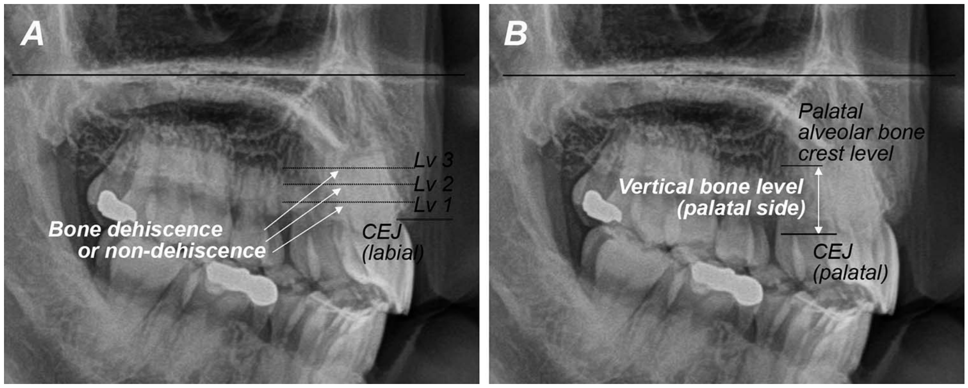

Figure 2. Alveolar bone assessment by cephalometric images. (A) Determination of palatal bone dehiscence of the central incisor at each vertical level (Lv). (B) Palatal vertical bone level of the incisor. CEJ indicates cementoenamel junction. Lv indicates level.

MATERIALS AND METHODS

The institutional review board of Kyungpook National University Dental Hospital (No. KNUDH-2023-06-02-00) approved this retrospective study.

The inclusion criteria were: (1) skeletal Class I or II relationship (point A–nasion–point B angle [ANB] $>$ 0°); (2) $>$5 mm posterior movement of the maxillary central incisor based on the incisal tip position during treatment; (3) four premolar extraction for orthodontic treatment; (4) maxillary microimplants to maximize incisor retraction; and (5) patients who had CBCT and cephalograms at three time points (T0, T1, and T2). Patients with previous orthodontic treatment, trauma history, periodontal problems, or cleft lip and palate were excluded.

The sample size was calculated using G*power version 3.1.9.7 (Heinrich Heine University, Düsseldorf, Düsseldorf, Germany) based on a previous CBCT study evaluating alveolar bone changes after treatment.[6] Considering a test power of 0.80, a two-tailed significance level of 0.05, and an effect size of 0.80, a minimum sample of 17 patients was required. To increase the power of this study, 21 patients (six men, 15 women; mean age: 17.80 $\pm$ 4.38 years; age range, 12.0–31.6 years) were included. All patients were treated by one clinician (HS Park) and subsequently underwent follow-up checkups for $>$24 months.

0.022-inch preadjusted brackets were bonded and the microimplants (AbsoAnchor, Dentos Co. Ltd., Daegu, Korea) were placed in the maxilla for incisor retraction. During space closure by sliding mechanics, elastomeric thread was applied with a force of 150–200 g from the microimplants to the anterior hooks crimped on 0.016 $\times$ 0.022-inch or 0.017 $\times$ 0.025-inch stainless steel archwires.[8,9] After treatment completion, lingual fixed retainers bonded on the incisors and wraparound retainers in both arches were used during the retention period.

Table 1. Cephalometric Measurements[a,*]

	T0	T1	T2	*P* Value**
Skeletal				
SNA (°)	81.42 $\pm$ 3.25^A	79.59 $\pm$ 3.98^B	79.58 $\pm$ 3.53^B	.000
SNB (°)	75.02 $\pm$ 4.00	75.10 $\pm$ 4.86	74.57 $\pm$ 4.50	.238
ANB (°)	6.39 $\pm$ 2.35^A	4.49 $\pm$ 2.07^B	5.01 $\pm$ 1.86^B	.000
FMA (°)	33.28 $\pm$ 6.47	31.82 $\pm$ 5.70	32.13 $\pm$ 6.16	.043
Dental				
FH/UI (°)	115.56 $\pm$ 9.82^A	105.75 $\pm$ 6.41^B	105.93 $\pm$ 5.19^B	.000
IMPA (°)	99.45 $\pm$ 7.48^A	92.23 $\pm$ 8.82^B	93.72 $\pm$ 7.79^B	.005
Interincisal angle (°)	111.65 $\pm$ 10.45^A	130.23 $\pm$ 10.36^B	128.21 $\pm$ 9.07^B	.000
Soft tissue				
E-line to upper lip (mm)	4.13 $\pm$ 1.95^A	$-$0.16 $\pm$ 1.78^B	$-$0.34 $\pm$ 1.36^B	.000
E-line to lower lip (mm)	6.85 $\pm$ 2.77^A	2.26 $\pm$ 2.66^B	1.41 $\pm$ 2.45^B	.000

[a] ANB indicates point A-nasion-point B angle; FH/UI, the maxillary incisor angulation relative to the Frankfort horizontal plane; FMA, Frankfort-mandibular plane angle; IMPA, mandibular incisor angulation relative to the mandibular plane; SNA, sella-nasion-point A angle; SNB, sella-nasion-point B angle; T0, pre-treatment; T1, posttreatment; T2, retention.

* Values are mean $\pm$ standard deviation.

** Values in the same row with no superscript letters indicate statistically nonsignificant differences, and values with different superscript letters indicate significant differences at $P < .05$ based on the repeated-measures analysis of variance with Bonferroni correction.

Table 2. Differences in the Incisal Tip Position and Tooth Inclination of the Maxillary Incisors Between T0 and T1 and Between T1 and T2 Using Cone-Beam Computed Tomography Images*,**

	12		11		21		22	
	ΔT1-T0	ΔT2-T1	ΔT1-T0	ΔT2-T1	ΔT1-T0	ΔT2-T1	ΔT1-T0	ΔT2-T1
Incisal tip position (mm)								
Horizontal	−5.47 ± 2.00	0.95 ± 0.80	−8.03 ± 1.80	0.99 ± 0.68	−8.39 ± 2.11	0.94 ± 0.82	−5.25 ± 2.21	0.95 ± 1.18
Vertical	−1.77 ± 1.41	1.20 ± 0.82	−1.74 ± 1.52	1.22 ± 0.77	−1.80 ± 1.63	1.33 ± 0.70	−1.98 ± 1.24	1.18 ± 0.62
Tooth inclination (°)	−4.53 ± 8.04	0.21 ± 5.43	−8.92 ± 8.82	−1.61 ± 4.08	−9.27 ± 10.86	−2.69 ± 4.03	−2.99 ± 9.00	−1.42 ± 3.85

* Values are mean ± standard deviation.
** ΔT1-T0, difference between pretreatment (T0) and posttreatment (T1); ΔT2-T1, difference between posttreatment (T1) and retention (T2).

CBCT (CB MercuRay; Hitachi, Osaka, Japan; 120 kVp, 15 mA, voxel size of 0.377 mm, and scan time of 9.6 s) data were acquired at T0, T1, and T2 (>24 months after treatment completion). The variables of the tooth and alveolar bone were measured using CBCT imaging software (Invivo 5; Anatomage Inc., San Jose, CA, USA).

The midsagittal and horizontal reference planes of the maxilla were established based on the CBCT image at T1 (Figure 1A). Once the T1 CBCT image was oriented based on the reference planes, the T0 or T2 CBCT image was superimposed on the T1 image using voxel-based registration of the maxilla.[10] The axial sections parallel to the horizontal reference plane were set at the levels of 2, 4, and 6 mm apical to the cementoenamel junction (CEJ) of the right maxillary central incisor at T1 (Figure 1B). On each level of axial sections, alveolar bone thicknesses (labial, palatal, and total) and interdental bone depressions (labial and palatal) were measured (Figure 1C). In addition, on each sagittal section of the incisors, the vertical bone level (labial and palatal) was measured relative to the CEJ (Figure 1D). To assess tooth movement during the treatment or retention period, differences in incisal tip position and tooth inclination were measured between T0 and T1 or between T1 and T2 on each sagittal section of the incisor (Figure 1E). On the axial sections, differences in the tooth position were measured at the labial and palatal root surfaces (Figure 1F).

To evaluate the overall treatment result and stability, cephalometric measurements at T0, T1, and T2 were obtained. In addition, the validity of cephalometric images regarding palatal bone assessment was investigated. The existence of palatal bone dehiscence of the central incisor on cephalometric images was determined at each vertical level (Figure 2A), and the sites were divided into dehiscence and nondehiscence groups. Then, CT measurements of bone thickness and interdental bone depression on the palatal side were compared between the groups. The vertical palatal bone level of the central incisor on the cephalometric images was compared with that of the CBCT images (Figure 2B).

Statistical Analysis

All measurements were acquired by a single investigator (HJ Kim) and randomly re-measured for 10 patients after 2 weeks. The intraclass correlation coefficients were >0.90, meaning high reliability of the measurements. Method error was evaluated using Dahlberg's formula and the differences in linear and angular CBCT measurements were 0.17–0.31 mm and 0.55°–0.71°, respectively.

The Kolmogorov–Smirnov test was performed to assess the normality of the data distribution. To compare variables at T0, T1, and T2, repeated-measures

Table 3. Difference in Tooth Position on Each Axial Section View of Computed Tomography Images*

(mm)	12		11		21		22	
	ΔT0-T1	ΔT1-T2	ΔT0-T1	ΔT1-T2	ΔT0-T1	ΔT1-T2	ΔT0-T1	ΔT1-T2
Level 1 (n = 21)								
At labial root surface	−4.24 ± 1.09	0.40 ± 0.57	−4.50 ± 1.44	0.71 ± 0.60	−4.78 ± 1.36	0.98 ± 0.56	−4.51 ± 1.20	0.64 ± 0.90
At palatal root surface	−4.91 ± 1.47	0.72 ± 0.65	−5.15 ± 1.75	1.28 ± 0.65	−5.35 ± 1.82	1.30 ± 0.63	−5.00 ± 1.55	0.41 ± 0.62
Level 2 (n = 21)								
At labial root surface	−3.86 ± 1.22	0.43 ± 0.61	−3.98 ± 1.57	0.86 ± 0.58	−4.18 ± 1.65	1.01 ± 0.50	−4.11 ± 1.30	0.61 ± 0.46
At palatal root surface	−4.44 ± 1.33	0.80 ± 0.75	−4.82 ± 1.69	1.24 ± 0.60	−4.79 ± 1.83	1.38 ± 0.66	−4.59 ± 1.62	0.81 ± 0.58
Level 3 (n = 17)								
At labial root surface	−3.33 ± 1.54	0.50 ± 0.79	−3.56 ± 1.85	0.92 ± 0.60	−3.44 ± 1.87	1.22 ± 0.55	−3.75 ± 1.49	0.88 ± 0.42
At palatal root surface	−4.19 ± 1.44	0.82 ± 1.10	−4.72 ± 1.95	1.35 ± 0.78	−4.44 ± 2.05	1.54 ± 0.71	−4.54 ± 1.74	1.26 ± 0.71

* Values are mean ± standard deviation. ΔT0-T1, difference between pretreatment (T0) and posttreatment (T1); ΔT0-T1, difference between posttreatment (T1) and retention (T2).

Table 4. Alveolar Bone Thickness and Vertical Bone Level of the Maxillary Incisors*,**

	12					
	T0	T1	T2	*P* Value	ΔT1−T0	ΔT2−T1
Bone Thickness (mm)						
Level 1 (n = 21)						
Labial	0.71 ± 0.96	0.96 ± 0.63	0.84 ± 0.53	.192	0.24 ± 0.74	−0.12 ± 0.38
Palatal	2.47 ± 1.09^{A}	0.31 ± 0.59^{B}	1.08 ± 0.65^{C}	.000	−2.16 ± 1.01	0.78 ± 0.51
Total	9.00 ± 0.92^{A}	7.65 ± 0.79^{B}	7.88 ± 0.76^{B}	.000	−1.35 ± 0.95	0.23 ± 0.53
Level 2 (n = 21)						
Labial	0.61 ± 0.27^{A}	1.29 ± 0.63^{B}	0.92 ± 0.49^{C}	.000	0.68 ± 0.69	−0.38 ± 0.49
Palatal	3.21 ± 1.34^{A}	0.61 ± 0.92^{B}	1.41 ± 0.84^{C}	.000	−2.60 ± 1.27	0.81 ± 0.72
Total	9.06 ± 1.28^{A}	7.82 ± 0.65^{B}	7.67 ± 0.88^{B}	.000	−1.24 ± 1.17	−0.16 ± 0.64
Level 3 (n = 17)						
Labial	0.76 ± 0.44^{A}	1.47 ± 0.64^{B}	1.02 ± 0.45^{C}	.000	0.71 ± 0.71	−0.45 ± 0.50
Palatal	3.80 ± 1.19^{A}	1.43 ± 1.21^{B}	2.44 ± 1.31^{C}	.000	−2.37 ± 1.07	1.01 ± 0.75
Total	8.68 ± 1.30^{A}	7.40 ± 1.19^{B}	7.28 ± 1.27^{B}	.000	−1.28 ± 1.20	−0.12 ± 0.47
Vertical bone level (mm)						
Labial	0.48 ± 0.17^{A}	1.38 ± 0.77^{B}	1.54 ± 0.72^{B}	.000	0.90 ± 0.78	0.16 ± 0.93
Palatal	0.55 ± 0.17^{A}	4.30 ± 2.82^{B}	1.46 ±1.08^{C}	.000	3.76 ± 2.86	−2.84 ± 2.75
	21					
	T0	T1	T2	*P* Value	ΔT1–T0	ΔT2–T1
Bone thickness (mm)						
Level 1 (n = 21)						
Labial	0.81 ± 0.45	1.00 ± 0.61	0.88 ± 0.50	.311	0.20 ± 0.73	−0.13 ± 0.55
Palatal	3.48 ± 1.59^{A}	0.46 ± 0.84^{B}	1.73 ± 1.08^{C}	.000	−3.02 ± 1.31	1.27 ± 0.56
Total	10.10 ± 1.52^{A}	7.88 ± 1.21^{B}	8.42 ± 1.19^{C}	.000	−2.22 ± 1.17	0.54 ± 0.80
Level 2 (n = 21)						
Labial	0.88 ± 0.45^{A}	1.53 ± 0.75^{B}	0.92 ± 0.44^{A}	.000	0.65 ± 0.90	−0.60 ± 0.61
Palatal	4.62 ± 1.98^{A}	1.27 ± 1.48^{B}	2.86 ± 1.56^{C}	.000	−3.35 ± 1.70	1.59 ± 0.75
Total	10.50 ± 1.78^{A}	8.45 ± 1.32^{B}	9.01 ± 1.36^{C}	.000	−2.05 ± 1.17	0.57 ± 0.58
Level 3 (n = 17)						
Labial	1.05 ± 0.49^{AB}	1.64 ± 0.88^{A}	1.02 ± 0.49^{B}	.003	0.59 ± 1.01	−0.62 ± 0.63
Palatal	5.65 ± 1.74^{A}	2.49 ± 1.81^{B}	4.03 ± 1.70^{C}	.000	−3.16 ± 1.77	1.54 ± 0.98
Total	10.56 ± 1.66^{A}	8.87 ± 1.31^{B}	9.44 ± 1.60^{C}	.000	−1.69 ± 1.29	0.57 ± 0.63
Bone height (mm)						
Labial	0.43 ± 0.15^{A}	1.08 ± 0.44^{B}	1.13 ± 0.57^{B}	.000	0.65 ± 0.48	0.04 ± 0.43
Palatal	0.39 ± 0.12^{A}	4.62 ± 3.07^{B}	1.03 ± 0.77^{C}	.000	4.23 ± 3.12	−3.60 ± 2.84

* Values are mean ± standard deviation. T0, pre-treatment; T1, post-treatment; T2, retention; ΔT1-T0, difference between values at T0 and T1; ΔT2-T1, difference between values at T1 and T2.

** Values in the same row with no superscript letters indicate statistically nonsignificant differences, and values with different superscript letters indicate significant differences at $P < .05$ based on the repeated-measures analysis of variance with Bonferroni correction.

analysis of variance with Bonferroni correction was performed. If the sphericity assumption was violated, the Greenhouse–Geisser correction was used. To compare measurements of the palatal alveolar bone between cephalometric and CBCT images, an independent *t*-test was used. If there was not a normal distribution, the Mann–Whitney *U*-test was performed. The statistical analyses were performed using IBM SPSS version 22 (IBM Corp., Armonk, NY, USA) at $P < .05$ as the significance level.

RESULTS

The mean treatment duration and retention periods were 33.36 ± 8.03 and 51.28 ± 21.64 months, respectively.

Regarding cephalometric measurements (Table 1), all variables showed significant differences between T0 and T1, except for the sella-nasion-point B angle (SNB) and Frankfort-mandibular plane angle (FMA). However, no significant differences were found between T1 and T2.

When assessing the amount of maxillary incisor movement after treatment using CBCT images, the incisal tip of the central and lateral incisors moved posteriorly by approximately 8.0 and 5.3 mm, respectively, along with intrusion of 1.8 mm (Table 2). During the retention period, the incisors underwent anterior and extrusive movements by approximately 1.0 mm. In addition, for the difference in tooth position on each axial section, the incisors were moved posteriorly by 3.5–5.0 mm during treatment and relapsed anteriorly by 0.5–1.5 mm during the retention period (Table 3).

Table 4. Extended

11					
T0	T1	T2	*P* Value	ΔT1−T0	ΔT2−T1
0.91 ± 0.43	1.10 ± 0.58	0.95 ± 0.54	.249	0.19 ± 0.06	−0.15 ± 0.52
3.44 ± 1.61A	0.77 ± 1.06B	1.98 ± 1.26C	.000	−2.67 ± 1.06	1.21 ± 0.68
10.03 ± 1.58A	8.25 ± 1.26B	8.72 ± 1.25C	.000	−1.78 ± 1.05	0.46 ± 0.48
0.98 ± 0.54A	1.66 ± 0.76B	1.09 ± 0.69A	.001	0.68 ± 0.83	−0.57 ± 0.53
4.75 ± 1.95A	1.72 ± 1.60B	2.93 ± 1.76C	.000	−3.03 ± 1.36	1.21 ± 0.79
10.53 ± 1.88A	8.91 ± 1.59B	9.12 ± 1.34B	.000	−1.62 ± 1.55	0.21 ± 0.72
1.18 ± 0.46AB	1.93 ± 1.03A	1.22 ± 0.71B	.004	0.75 ± 1.17	−0.71 ± 0.75
5.61 ± 2.52A	2.42 ± 1.83B	3.74 ± 1.57C	.000	−3.19 ± 1.52	1.32 ± 0.82
10.47 ± 2.24A	9.20 ± 1.73B	9.25 ± 1.62B	.001	−1.28 ± 1.79	0.06 ± 0.62
0.57 ± 0.21A	1.00 ± 0.50B	1.05 ± 0.58B	.000	0.43 ± 0.45	0.05 ± 0.48
0.50 ± 0.24A	4.35 ± 2.64B	0.94 ± 0.89A	.000	3.85 ± 2.69	−3.40 ± 2.31
22					
T0	T1	T2	*P* value	ΔT1-T0	ΔT2-T1
0.58 ± 0.34	0.87 ± 0.58	0.84 ± 0.58	.025	0.29 ± 0.56	−0.03 ± 0.44
2.41 ± 1.15A	0.19 ± 0.50B	0.90 ± 0.65C	.000	−2.21 ± 1.04	0.70 ± 0.52
8.99 ± 1.00A	7.66 ± 0.78B	7.80 ± 0.76B	.000	−1.33 ± 1.02	0.15 ± 0.65
0.52 ± 0.28A	1.28 ± 0.60B	0.83 ± 0.56C	.000	0.76 ± 0.52	−0.46 ± 0.44
3.33 ± 1.38A	0.61 ± 0.77B	1.21 ± 0.91C	.000	−2.72 ± 1.16	0.60 ± 0.63
9.26 ± 1.14A	7.93 ± 0.86B	7.78 ± 0.73B	.000	−1.33 ± 0.98	−0.15 ± 0.42
0.46 ± 0.24A	1.28 ± 0.83B	0.90 ± 0.49C	.000	0.82 ± 0.89	− 0.39 ± 0.53
4.01 ± 1.44A	1.24 ± 1.33B	2.23 ± 1.41C	.000	−2.77 ± 1.17	0.99 ± 0.99
8.91 ± 1.47A	7.79 ± 1.06B	7.61 ± 1.24B	.000	−1.42 ± 1.12	0.12 ± 0.50
0.43 ± 0.19A	1.41 ± 0.61B	1.20 ± 0.61B	.000	0.98 ± 0.62	−0.21 ± 0.62
0.46 ± 0.16A	4.35 ± 3.22B	1.51 ± 1.54C	.000	3.89 ± 3.17	−2.85 ± 3.42

Regarding alveolar bone measurement on CBCT images, the palatal bone thickness at T1 was significantly less than that at T0, and the value at T2 was significantly greater than that at T1 (Table 4 and Figure 3). Conversely, the labial bone mostly showed a significant increase after treatment and a significant decrease after the retention period, but not at level 1. Concerning the vertical bone level, the alveolar bone height showed a significant decrease on the labial and palatal sides after treatment. Specifically, the decrease on the palatal side was approximately 4.0 mm, which was a clinically significant amount. During the retention period, the palatal bone height significantly increased; however, no significant difference was found on the labial side. The number of palatal bone dehiscence sites defined in the CBCT images at T1 was 57, 31, and 11 sites at levels 1, 2, and 3, and those were reduced to 3, 1, and 0 sites, respectively.

The degree of interdental bone depression significantly increased on the palatal side at T1, particularly between the central incisors (Table 5 and Figure 4). The bone depression was significantly alleviated at T2 by bone apposition.

Comparing the palatal bone dehiscence and nondehiscence groups based on cephalometric images, CBCT measurements of palatal bone thickness and interdental bone depression were significantly less in the bone dehiscence group than in the nondehiscence group (Table 6). When comparing vertical palatal bone levels evaluated by cephalometric and CBCT images, the alveolar bone height measured by cephalometric images was significantly lower than those measured by CBCT images (Table 7), meaning that evaluation using cephalometric images may result in reduced alveolar bone detection.

DISCUSSION

After treatment, a number of palatal bone dehiscence sites were detected in the CBCT images. However, no

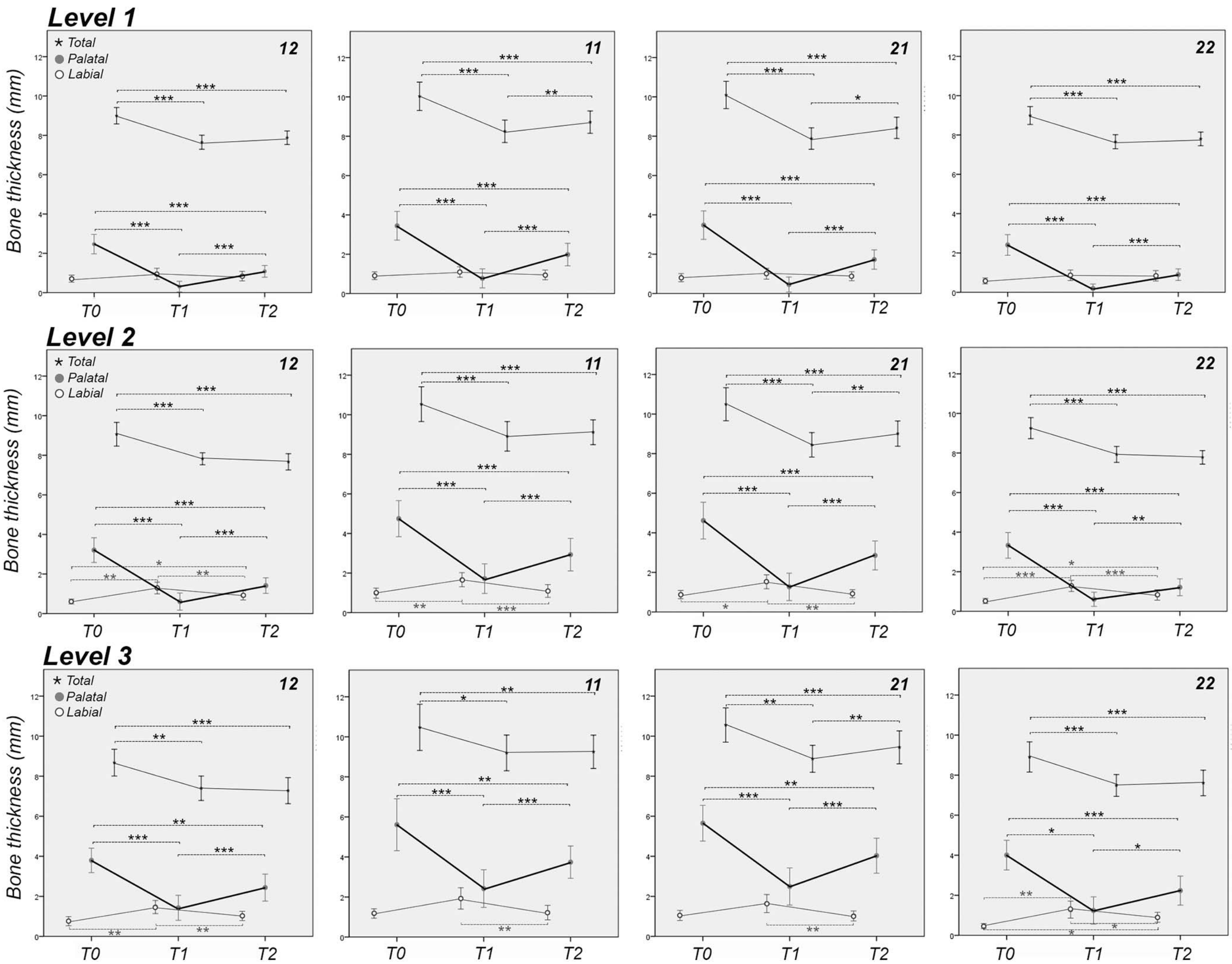

Figure 3. Alveolar bone thickness (significant difference between time points; * $P < .05$, *** $P < .01$, *** $P < .001$). T0 indicates pretreatment; T1, posttreatment; T2, retention.

clinical complications, such as gingival recession, inflammation, or root exposure, occurred after treatment, even during the retention period. Additionally, the dehiscence and palatal vertical bone loss recovered during retention. Likewise, the number of palatal bone dehiscence sites defined in the CBCT images decreased substantially, from 99 at T1 (41.9%, 99/236) to only 4 at T2 (1.7%, 4/236) in total. The mean retention duration was 51.28 ±

Table 5. Interdental Bone Depression of the Maxillary Incisors*,**

(mm)	12-11			
	T0	T1	T2	*P* Value
Level 1 (n = 21)				
Labial	0.51 ± 0.53^{AB}	0.88 ± 0.37^{A}	0.43 ± 0.60^{B}	.008
Palatal	2.92 ± 1.31^{A}	-0.33 ± 0.88^{B}	0.57 ± 0.90^{C}	.000
Level 2 (n = 21)				
Labial	0.23 ± 0.59^{A}	1.01 ± 0.55^{B}	0.37 ± 0.60^{A}	.000
Palatal	3.98 ± 1.76^{A}	0.53 ± 1.32^{B}	1.42 ± 1.43^{C}	.000
Level 3 (n = 17)				
Labial	0.30 ± 0.72^{A}	1.21 ± 0.59^{B}	0.49 ± 0.67^{A}	.000
Palatal	4.61 ± 1.61^{A}	1.33 ± 1.36^{B}	2.32 ± 1.29^{C}	.000

* Values are mean ± standard deviation. T0, pre-treatment; T1, post-treatment; T2, retention.

** Values in the same row with different superscript letters indicate significant differences at $P < .05$ based on the repeated-measures analysis of variance with Bonferroni correction.

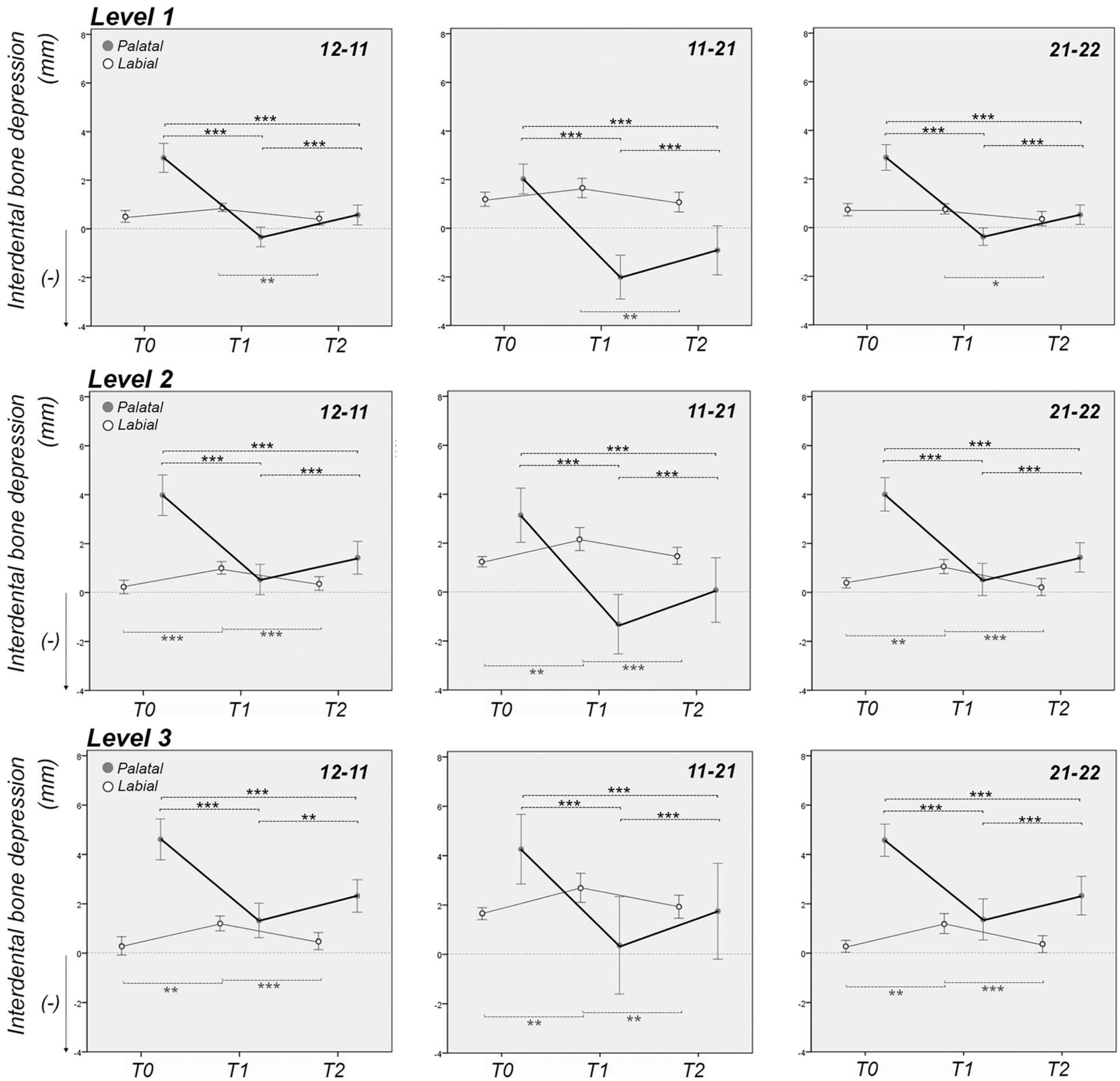

Figure 4. Interdental bone depression (significant difference between time points; * $P < .05$, ** $P < .01$, *** $P < .001$). T0 indicates pretreatment; T1, posttreatment; T2, retention.

Table 5. Extended

11-21				21-22			
T0	T1	T2	*P* Value	T0	T1	T2	*P* Value
1.20 ± 0.64^{AB}	1.66 ± 0.87^{A}	1.08 ± 0.89^{B}	.016	0.74 ± 0.56^{AB}	0.77 ± 0.46^{A}	0.37 ± 0.65^{B}	.028
2.03 ± 1.35^{A}	−2.01 ± 1.98^{B}	−0.91 ± 2.21^{C}	.000	2.89 ± 1.16^{A}	−0.37 ± 0.79^{B}	0.53 ± 0.88^{C}	.000
1.24 ± 0.45^{A}	2.17 ± 1.01^{B}	1.48 ± 0.74^{A}	.000	0.39 ± 0.45^{A}	1.06 ± 0.62^{B}	0.22 ± 0.74^{A}	.000
3.14 ± 2.37^{A}	−1.31 ± 2.60^{B}	0.08 ± 2.82^{C}	.000	4.00 ± 1.46^{A}	0.53 ± 1.41^{B}	1.43 ± 1.28^{C}	.000
1.65 ± 0.47^{A}	2.70 ± 1.14^{B}	1.93 ± 0.91^{A}	.000	0.28 ± 0.47^{A}	1.20 ± 0.79^{B}	0.36 ± 0.67^{A}	.000
4.26 ± 2.74^{A}	0.37 ± 3.84^{B}	1.75 ± 3.78^{C}	.000	4.58 ± 1.27^{A}	1.37 ± 1.63^{B}	2.33 ± 1.52^{C}	.000

Table 6. Comparison of CT Bone Measurements Between the Palatal Bone Dehiscence and Nondehiscence Groups by Cephalometric Images*,**

	T1			T2		
	By Cephalometric Image			By Cephalometric Image		
	Dehiscence Group (n = 30)	Nondehiscence Group (n = 29)	*P* Value	Dehiscence Group (n = 14)	Nondehiscence Group (n = 45)	*P* Value
CT measurement (mm)						
Palatal bone thickness (including all vertical levels)						
11	0.38 ± 0.51	2.78 ± 1.47	.000	1.23 ± 0.56	3.29 ± 1.60	.000
21	0.23 ± 0.43	2.43 ± 1.60	.000	1.49 ± 0.83	3.17 ± 1.72	.000
Palatal interdental bone depression (including all vertical levels)						
12-11	−0.45 ± 0.68	1.36 ± 1.26	.000	0.04 ± 0.81	1.76 ± 1.28	.000
11-21	−2.89 ± 1.63	0.75 ± 2.87	.000	−2.35 ± 1.24	0.95 ± 3.07	.000
21-22	−0.55 ± 0.79	1.45 ± 1.27	.000	0.28 ± 0.80	1.68 ± 1.40	.000

* Values are mean ± standard deviation. CT indicates computed tomography; T1, post-treatment; T2, retention.

** The Mann–Whitney *U*-test was performed to compare the dehiscence and non-dehiscence groups.

21.64 months, quite sufficient to adequately evaluate alveolar bone changes over time.

Regarding changes in alveolar bone thickness, after treatment, a decrease and an increase were observed on the palatal and labial sides, respectively. However, reversal of the changes occurred during the retention period, although the thickness at T2 was not fully recovered up to that at T0, particularly on the palatal side. One interesting finding was that the difference in bone thickness on the labial or palatal sides between T0 and T1 was less than the posterior movement of the incisor on each axial section. At level 3, the ratios of palatal bone apposition and labial bone resorption to the amount of tooth movement were 25.6% and 86.1%, respectively (Figure 5A). This can be interpreted as delayed remodeling on the bone surfaces. Also, the total alveolar bone thickness significantly decreased during treatment and, subsequently, a remarkable increase was seen during the retention period, particularly at the central incisors. In other words, catabolic bone metabolism might occur first, followed by an anabolic response during the retention period.[11]

Table 7. Comparison of Vertical Palatal Bone Level Between Cephalometric and Cone-Beam Computed Tomography Images*,**

	Cephalogram	CBCT	*P* Value
Vertical palatal bone level (mm)			
T1	6.19 ± 2.99	4.49 ± 2.71	.000
T2	3.22 ± 2.54	0.99 ± 0.69	.001

* Values are mean ± standard deviation. CBCT indicates cone beam computed tomography; T1, post-treatment; T2, retention.

** An independent *t*-test was performed to compare vertical palatal bone levels by cephalometric and CBCT images.

Anterior movement of the incisor was observed in each axial section during the retention period, while the palatal bone thickness was increased and the labial bone thickness was decreased. At approximately half of all palatal sites, the extent of those bone changes was greater than that of the anterior tooth movement (Figure 6). Thus, alveolar bone recovery on the palatal side of the incisor roots could be explained not only by the relapsed anterior movement of the incisors, but also by bone apposition over the incisor roots along the periodontal ligament and periosteum.

Additionally, depressions were observed in the interdental palatal bone after incisor retraction at T1. This could be explained by significant posterior movement of the incisors at a higher rate than bone remodeling could occur (Figure 5B). These depressions were filled with new bone during the retention period. The palatal bone overlying incisor roots was moved posteriorly by bone apposition simultaneously with root posterior movement, although the amount of bone adaptation was less than that of the root movement. The bone at the interdental area did not have sufficient bone apposition to follow root movement during treatment, and the depressions were filled with new bone during the retention period. This palatal bone recovery might result from the intact periodontal ligament and periosteal tissues protected by the thick palatal mucosa[12,13] that are closely associated with bone regeneration.[14–17]

At sites with palatal bone dehiscence determined by cephalometric images, the CBCT measurement of palatal bone depression between the central incisors was mostly negative. Therefore, it could be assumed that the cortical line of interdental palatal bone depression between the incisors might have an influence on the appearance of palatal bone position on the cephalometric images (Figure 7). The interdental bone with

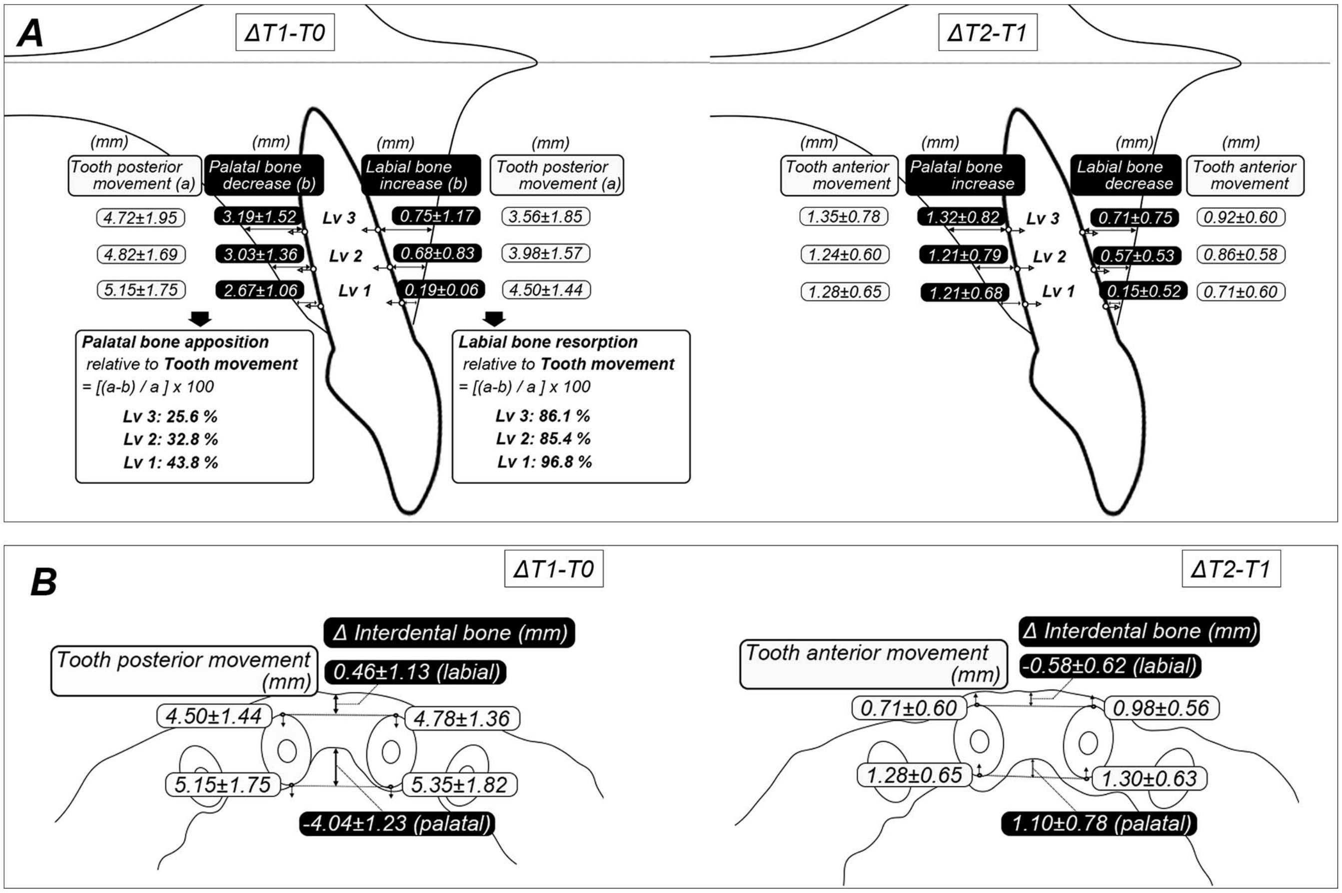

Figure 5. Summary illustration of the difference in alveolar bone thickness, interdental bone depression, and tooth position. (A) Sagittal section. Alveolar bone thickness of the right maxillary central incisor. (B) Axial section. Interdental bone depression at level 1. Lv indicates level; T0, pretreatment; T1, posttreatment; T2, retention.

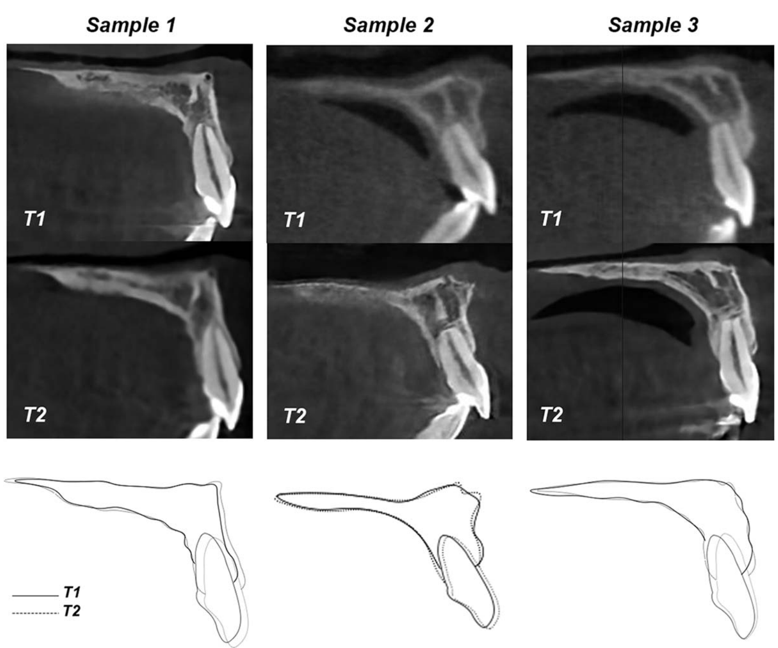

Figure 6. Sagittal section views of three samples showing significant palatal bone apposition at retention. T1 indicates posttreatment; T2, retention.

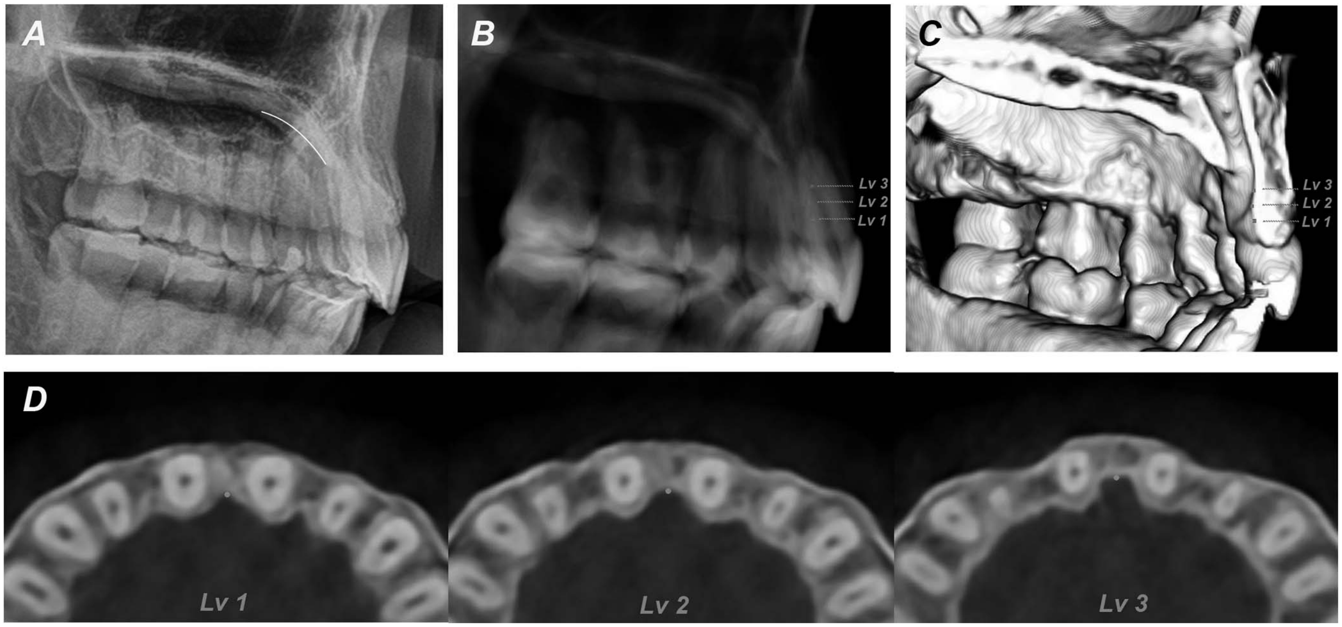

Figure 7. Palatal alveolar bone images of a sample (at retention). (A) Cephalometric image. (B) Cone-beam computed tomography (CBCT) image (grayscale mode). Landmarks of the interdental palatal bone depression. (C) CBCT image (bone mode). Landmarks of the interdental palatal bone depression. (D) Axial sections of CBCT image. Landmarks of the interdental palatal bone depression. Lv indicates level.

higher density seems to be the outermost palatal cortical bone relative to the newly formed thin bone, likely due to the low resolution of the cephalometric images and overlapping of the midline structures. Owing to this, observers may have difficulty in detecting the actual position of the alveolar bone, particularly on the palatal side of the maxilla.[5,18] Thus, the alveolar bone thickness and height can be underestimated in cephalometric images. These cephalometric images may be concerning to clinicians; however, CBCT images may confirm that there are no serious complications in the palatal bone (Figure 7D). Despite this palatal bone recovery, incisor retraction into the palatal cortical bone may increase root resorption;[19] thus, caution should be observed during treatment.

This study provided valuable findings regarding the long-term morphometric changes in the alveolar bone after incisor retraction including the retention period. However, there were some limitations to this study. The sample included some young adolescent patients; thus, this may have influenced the observed alveolar bone changes over time irrespective of the maxilla-based CBCT superimpositions done to minimize the effect of skeletal growth. In addition, although the amount of palatal bone changes was mostly greater than the voxel size, some of the results should be interpreted cautiously due to the limited resolution. It would be interesting to assess the effect of skeletal growth on alveolar bone changes after tooth movement compared to the alveolar bone changes in adult patients in further studies.

CONCLUSIONS

- The null hypothesis of this study was rejected.
- There were significant decreases in palatal alveolar bone thickness and height and an apparent depression of the palatal interdental bone after incisor retraction treatment using microimplants, and these recovered significantly with new bone apposition during retention.
- Bone parameters derived from cephalometric images may be underestimated compared to those using CBCT images.

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