Original Article

Three-dimensional morphologic analysis of the maxillary alveolar bone after anterior tooth retraction with temporary anchorage devices

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ABSTRACT

Objectives: To investigate three-dimensional (3D) morphologic changes in the alveolar bone around the maxillary central incisors of patients who underwent premolar extraction and subsequent anterior tooth retraction using temporary anchorage devices (TADs).

Materials and Methods: The subjects consisted of 16 patients with bimaxillary protrusion. The maxillary anterior teeth were retracted using sliding or loop mechanics and TADs for anchorage reinforcement. Cephalograms and computed tomography scans taken pretreatment and posttreatment were registered with respect to the palatal structures. The movement of the maxillary central incisors and morphologic changes in the anterior alveolar bone were evaluated quantitatively.

Results: Displacement in the palatal direction was observed in the alveolar bone around the incisors and the interdental septum. The displacement and bone remodeling/tooth movement ratio were larger on the labial side than the palatal side, and decreased progressively from the crest to apex level. The bone thickness was significantly increased on the labial side and decreased on the palatal side.

Conclusions: Regional differences exist in morphologic changes of the alveolar bone during anterior tooth retraction using TADs. Attention should be paid to the crest region of the palatal alveolar bone because of its small original thickness and low remodeling activity. (*Angle Orthod*. 2023;93:667–674.)

KEY WORDS: 3D analysis; Alveolar bone; Temporary anchorage devices; Incisor retraction

INTRODUCTION

The anatomical limits of the alveolar bone, where tooth movement is allowed, and the adaptive response to orthodontic force are thought to vary among patients.[1–3] If a tooth moves beyond the anatomical limits and remodeling capacity of the alveolar bone, undesirable complications are more likely, such as decreases in the thickness and height of the alveolar bone,[2–8] fenestration, dehiscence,[5–7] and severe root resorption.[2,3,5] However, some patients exhibit minimal undesirable complications despite large amounts of tooth movement.[2]

Various studies have examined changes in the alveolar bone after maxillary incisor retraction using cephalometric radiography[2,9] and computed tomography (CT).[4–8,10–12] CT studies that estimated changes in alveolar bone thickness have produced controversial results. Concerning the labial side, some studies have reported a significant increase in bone thickness at the crest level,[8,10] midroot level,[4] or almost all levels,[12] while others have reported no significant changes[7] or a decrease in bone thickness at all levels.[11] The

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Accepted: May 2023. Submitted: December 2022.
Published Online: July 17, 2023

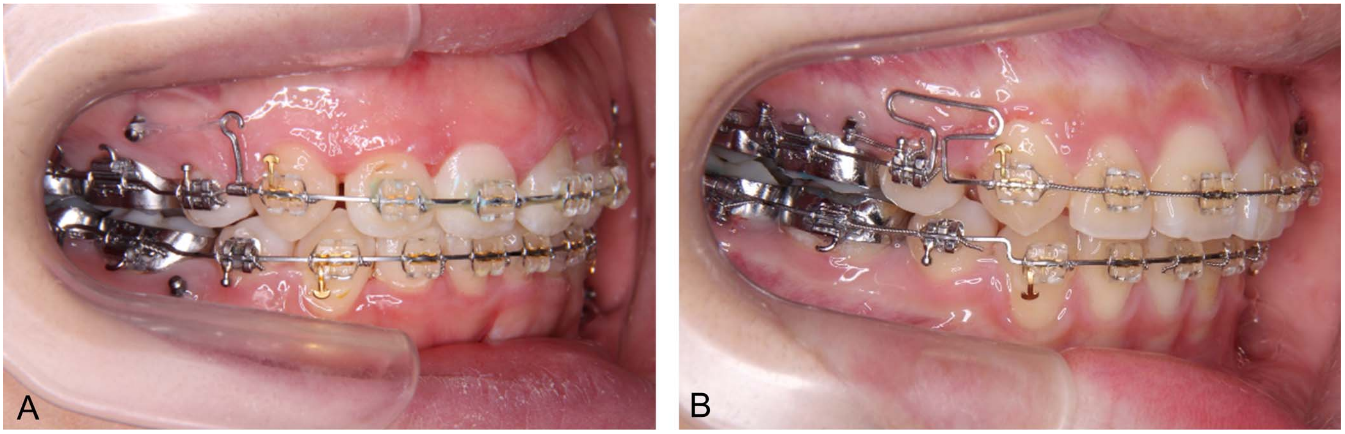

Figure 1. Mechanics of retraction of the maxillary anterior teeth. (A) Sliding mechanics. (B) Loop mechanics.

changes on the palatal side also varied according to each study, and no consensus has been reached.

Patients with bimaxillary protrusion generally require maximum anchorage.[6,13] Although various adjunct appliances have been used to reinforce anchorage, temporary anchorage devices (TADs) are commonly used for adult patients. TADs can provide powerful anchorage without patient cooperation, and can make it possible to perform tooth movement, which is difficult using traditional approaches. However, anchorage reinforcement via TADs may increase the amount of incisor movement, and impose excessive strain on the alveolar bone.[6] Only two studies[4,6] have evaluated changes in the alveolar bone after incisor retraction via TADs. Although these studies evaluated alveolar bone height[4,6] and thickness at the midroot level,[4] the extent to which incisor retraction with TADs influences the overall morphology of the alveolar bone has not been sufficiently determined.

Changes in the alveolar bone can be explained by the "differential apposition-resorption" phenomenon at the outer periosteal side and inner periodontal ligament (PDL) side.[1] This phenomenon can be approximately quantified according to changes in bone thickness,[4,7–10] bone area,[5] crest height,[4,6] and the bone remodeling/tooth movement (B/T) ratio.[9,11] The B/T ratio is the displacement of the alveolar bone surface divided by the amount of tooth movement.[9,11] A B/T ratio of 1 during anterior tooth retraction indicates that the morphology of the alveolar bone has been maintained. This is referred to as "tooth movement with bone."[14] If the B/T ratio is less than 1 on the palatal side or more than 1 on the labial side during anterior tooth retraction, then the alveolar bone thickness decreases, which is referred to as "tooth movement through bone."[14] Although the B/T ratio is an effective indicator of bone remodeling during tooth movement, data concerning the B/T ratio during anterior tooth retraction are limited.

3D morphologic changes were evaluated in the alveolar bone around the maxillary central incisors in patients with bimaxillary protrusion who underwent premolar extraction and subsequent anterior tooth retraction via TADs. Alveolar bone displacement, thickness, and the B/T ratio at various bone levels were evaluated using CT images.

MATERIALS AND METHODS

This study was approved by the ethics committee of Tohoku University Hospital (no. 2020–3–3). The inclusion criteria were: patients treated via retraction of the maxillary anterior teeth using TADs; movement of the incisal edge of the maxillary central incisors $\geq$5 mm; CT data with adequate image quality obtained at pre- and post-treatment assessments; no congenital or systemic disorders; and no missing teeth except the third molars.

The sample size was determined based on previous studies[7,11] in which the difference between the means at two different time points and the mean of the standard deviation were set at 0.35 and 0.49, respectively. With the significant difference threshold and power set at 0.05% and 80%, respectively, the required sample size was calculated as 16. The study population consisted of 16 patients (one male and 15 females).

The average age at the pretreatment assessment was 19.1 $\pm$ 6.3 years. All patients were treated via a pre-adjusted edgewise appliance after extraction of the four first premolars. The brackets had a nominal slot size of 0.018 inches (Crystabrace 7; Dentsply, Tokyo, Japan). TADs were placed in the interdental regions between the first molar and second premolar. The maxillary anterior teeth were retracted using sliding or loop mechanics (Figure 1). For the sliding mechanics, an elastic was engaged between the TAD and a hook was placed on the distal canine region of 0.016 $\times$ 0.022-inch stainless steel wires. For the loop mechanics, 0.016 $\times$ 0.022-inch beta titanium wires with T-loops were placed between the canine and

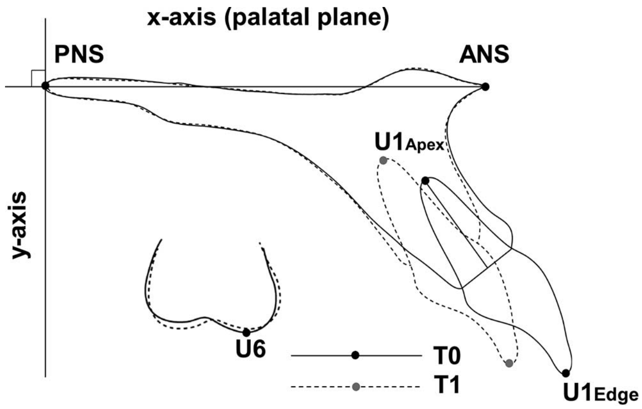

Figure 2. Cephalometric measurement of tooth movement. $U1_{Edge}$: incisal edge; $U1_{Apex}$: root apex of the central incisor; U6: mesiobuccal cusp of the first molar.

second premolar. The TADs were used as anchorage for retraction in loop mechanics, not for application of direct force to the anterior teeth. An initial force of 200 g per side was applied. The duration of active treatment was 3.14 $\pm$ 0.62 years.

Lateral cephalograms and CT scan images were collected at the pretreatment (T0) and posttreatment (T1) assessments. In addition to the conventional cephalometric measurements, the movement of the incisal edge ($U1_{Edge}$) and root apex ($U1_{Apex}$) of the maxillary central incisors and first molar (U6) were measured using the Cartesian coordinate system (Figure 2).

CT data regarding skull characteristics were acquired using a helical scanner (Somatom Emotion 6; Siemens, Erlangen, Germany). The patients underwent CT scanning with a 16-bit 512 $\times$ 512 matrix with a slice thickness of 1.0 mm and a slice pitch of 1.0 mm. The DICOM data were reconstructed using 3D imaging software (Dolphin 3D Image Software; GC Ortholy, Tokyo, Japan).

The following 3D analysis was performed using Dolphin 3D Image Software. Skeletal and dentoalveolar landmarks, reference planes, and measurement parameters were defined as shown in Figures 3 and 4 (see Table 1 for definitions). A preliminary superimposition was processed automatically via three-point registration of the incisive foramen and greater palatine foramina.[15] A secondary superimposition by voxel-based registration of the hard palate structure was performed to obtain more accurate superimposition.[16] Then, the 3D coordinate system was defined as described in previous studies.[11,17] To evaluate changes in the alveolar bone and the amount of incisor movement, the landmarks on the incisor and alveolar bone were defined and the amount of root movement, displacement, changes in alveolar bone thickness, and the B/T ratio were measured.

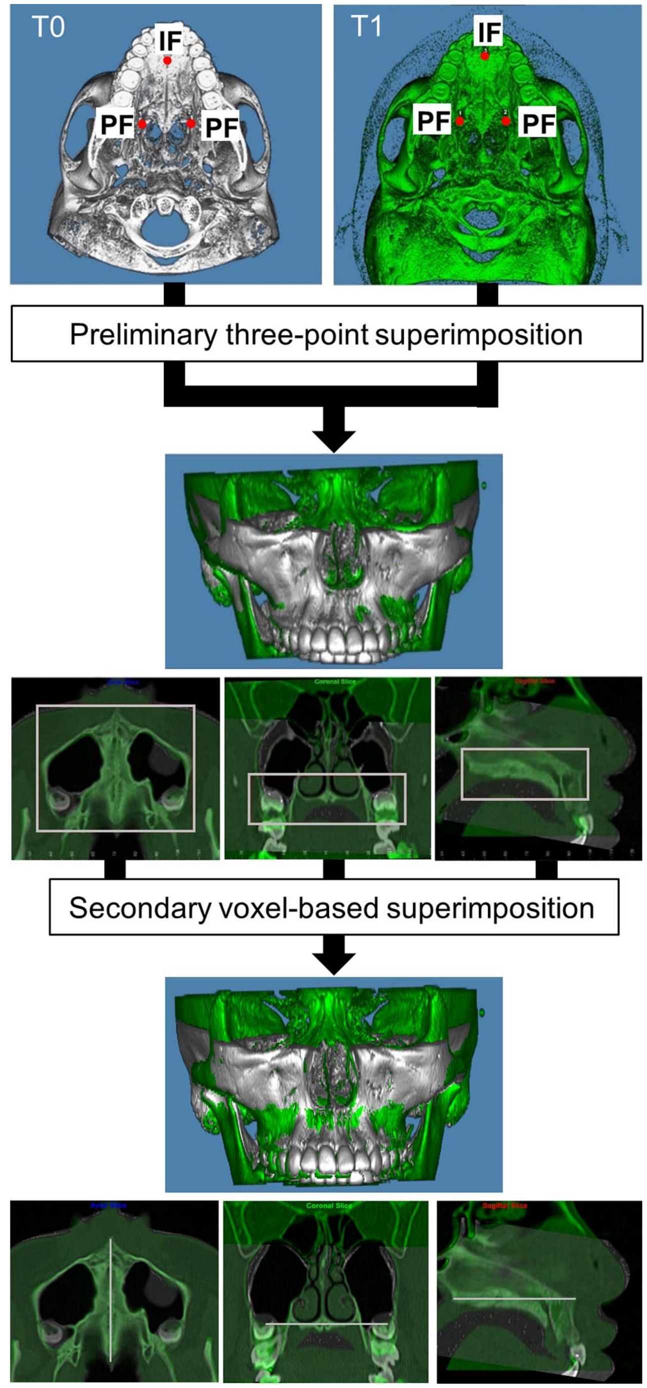

Figure 3. Flow chart of two-step superimpositions. The incisive foramen (PF) and greater palatine foramen (PF) were used for preliminary superimposition. The hard palate structure in the white rectangle was used for secondary superimposition.

To ensure the reliability of the measurements for statistical analysis, the same examiner repeated the measurements after an interval of 2 weeks. The method error was determined using Dahlberg's formula. The method error of the cephalometric analysis ranged from 0.176 mm to 0.481 mm for the linear

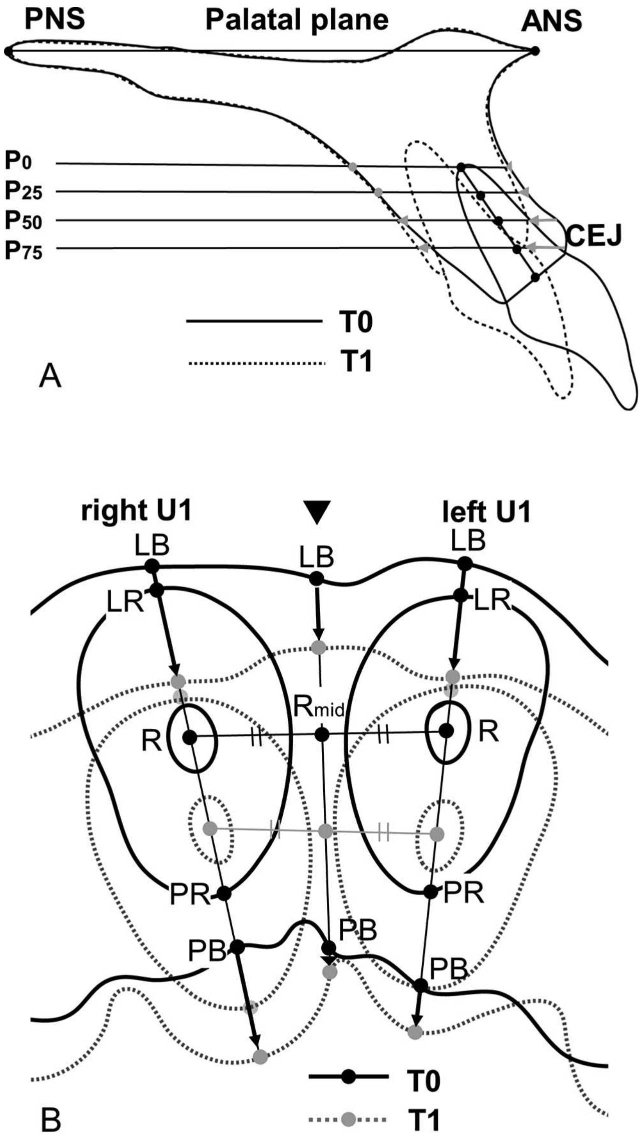

Figure 4. 3D analysis of root movement and morphologic changes in the alveolar bone. (A) Schematic drawing of CT image in the sagittal plane. (B) Schematic drawing of CT image in the horizontal plane (see Table 1 for definition). CT indicates computed tomography.

measurements and from 0.271° to 0.812° for the angular measurements. The method error of 3D CT analysis ranged from 0.02 mm to 0.56 mm. The reliability of the data was evaluated by calculating the intraclass correlation coefficient (ICC). The ICCs for cephalometric and CT measurements ranged from 0.96 to 0.99 and from 0.74 to 0.99, respectively.

JMP Pro software (version 16.0.0; SAS Institute Inc., Cary, NC, USA) was used for statistical analyses. The Shapiro-Wilk test was performed to evaluate the cephalometric and CT measurements. Measurements with a normal distribution were analyzed using the paired *t*-test, and Wilcoxon's signed-rank test was used for analysis of data with a non-normal distribution. As statistical analysis showed no significant differences between the right and left CT measurements, the means of bilateral values were analyzed. In addition, as there were no significant differences between the sliding and loop mechanics, the combined data of the two methods were analyzed. In all analyses, $P < .05$ was taken to indicate statistical significance.

RESULTS

The changes in skeletal measurements during the treatment were minimal (Table 2). In contrast, the dental measurements changed considerably. For example, the angle U1 to SN decreased from 110.2° to 98.7°, and the interincisal angle increased from 116.1° to 133.2°. Although the modes of molar and incisor movement varied among patients, the first molar moved mesially by 1.6 mm (Table 3). The incisal edge and root apex moved palatally by 7.2 mm and 3.0 mm, respectively. The central incisor translated palatally, and this was accompanied by palatal tipping and slight intrusion.

The maxillary anterior alveolar bone drifted in the palatal direction during treatment. The displacement of the alveolar bone around the incisors was larger on the labial side than the palatal side at all bone levels (Figure 5). The displacement was largest at the P_{75} level, and decreased progressively from the P_{75} to the P_0 level. The displacement of the interdental septum showed a tendency similar to that of the alveolar bone surrounding the incisor, but was smaller than that of the alveolar bone around the central incisor.

The thickness of the alveolar bone significantly increased at all levels on the labial side, and decreased at all levels on the palatal side (Table 4). Changes in the alveolar bone thickness were smaller on the labial side than on the palatal side, smallest at the P_{75} level, and approached the P_0 level on the labial and palatal sides.

The B/T ratio was significantly larger on the labial side than the palatal side at all levels (Table 4). The B/T ratios on the labial and palatal sides were significantly larger at the P_{75} level and decreased as they approached the P_0 level. The B/T ratios on the labial side ranged from 0.55 to 0.92, indicating that the amount of bone resorption was less than the root movement. In contrast, the B/T ratios on the palatal side were less than 0.36, indicating that the amount of bone apposition was substantially smaller than the root movement.

DISCUSSION

There are two anatomical structures used for superimposition: the tooth axis[4,5,7,8,10] and hard palate.[9,11] Superimposition on the tooth axis can be used to examine a relative change in the bone surrounding the root. However, because the measurement points

Table 1. Definitions of Landmarks, Reference Planes and Parameters on the CT Image

Variables	Definition
Skeletal landmarks	
Porion (Po)	Most superior point of the bony external auditory meatus
Orbitale (Or)	Most inferior point on the outline of the orbital margin
ANS	Most anterior point of the anterior nasal spine
PNS	Most posterior point of the posterior nasal spine
Incisive foramen (IF)	Most inferior point on the outline of the incisive foramen based on FH plane (Linkous et al., 2020)
Great palatine foramen (PF)	Most inferior point on the outline of the great palatine foramen based on FH plane (Linkous et al., 2020)
Dentoalveolar landmarks	
R	Center of the root canal of the maxillary central incisor
R_{mid}	Midpoint between right and left points R
LB	Intersection between the extension line of T0 and T1 of points R or R_{mid} and labial contour of the alveolar bone
PB	Intersection between the extension line of T0 and T1 of points R or R_{mid} and palatal contour of the alveolar bone
LR	Intersection between the extension line and labial surfaces of the root
PR	Intersection between the extension line and palatal surfaces of the root
Reference planes	
Frankfort horizontal (FH) plane	Plane connecting right and left Po and the midpoint of right and left Or
Palatal plane	Plane connecting ANS and PNS and paralleling to a line connecting right and left PF
P_{75}, P_{50}, P_{25}, P_0	Quadsecting points of the root axis of the central incisor connecting midpoint of cementoenamel junction line to the root apex (Okuzawa-Iwasaki et al., 2020)
Parameters	
Amount of root movement	Distance between T0 and T1 of points R of the central incisor
Displacement of the alveolar bone	Distance between T0 and T1 of points LB, and distance between T0 and T1 of points PB
Thickness of the alveolar bone	Distance between points LB and LR on the labial side. Distance between points PB and PR on the palatal side
B/T ratio	Quotient of the change in alveolar bone thickness divided by the amount of root movement (Eksriwong et al., 2021)

[a] B/T indicates bone remodeling/tooth movement.

of the alveolar bone shift as the tooth moves, measurements of the alveolar bone are greatly influenced by tooth movement, particularly tipping and vertical movement of the tooth. In addition, it is difficult to correlate the changes in alveolar bone position with tooth movement.[11] Thus, the relationship between bone remodeling and tooth movement can be more efficiently evaluated when using the hard palate for superimposition. For this reason, the hard palate was selected as a reference structure in the present study.

Concerning the type of tooth movement that occurs during incisor retraction, previous studies have shown

Table 2. Cephalometric Measurements at T0 and T1

Variable	T0 Mean ± SD	T1 Mean ± SD	*P* Value
Angular measurements (°)			
SNA	81.01 ± 3.64	80.89 ± 3.62	.27[a]
SNB	76.73 ± 3.73	76.38 ± 3.92	.08[a]
ANB	4.27 ± 2.00	4.50 ± 2.20	.19[a]
MP-SN	37.71 ± 4.90	37.57 ± 4.80	.57[a]
FMA	29.98 ± 5.13	29.78 ± 5.23	.45[a]
U1-SN	110.16 ± 9.03	98.73 ± 6.30	.00[a,**]
FMIA	53.94 ± 8.60	59.73 ± 6.15	.00[b,**]
L1-MP	96.07 ± 6.92	90.48 ± 4.46	.00[b,**]
Interincisal angle	116.06 ± 9.74	133.21 ± 7.77	.00[a,**]
Linear measurements (mm)			
S-N	71.44 ± 3.78	71.55 ± 3.82	.10[a]
N-Me	132.32 ± 7.66	133.38 ± 7.19	.05[a]
Me/NF	71.95 ± 5.03	73.02 ± 4.75	.03[a,**]
U1/NF	31.65 ± 2.32	32.47 ± 2.09	.03[a,**]

[a] Paired *t*-test was performed to compare between T0 and T1.
[b] Wilcoxon matched-pairs signed-rank test was performed to compare between T0 and T1.
* $P < .05$; ** $P < .01$ between T0 and T1.

Table 3. Amount of Tooth Movement in Cephalometric Coordinate System

Tooth Movement	Mean ± SD
$U1_{Edge}$ (x)	−7.23 ± 1.45
$U1_{Edge}$ (y)	0.83 ± 2.24
$U1_{Apex}$ (x)	−2.99 ± 2.00
$U1_{Apex}$ (y)	−0.79 ± 1.25
U6 (x)	1.61 ± 1.25
U6 (y)	0.03 ± 1.15

[a] x: labial and mesial movement was + value, y: extrusion was + value.

that the palatal inclination of the maxillary central incisor ranges from 6.4° to 10.9°.[4,5,7,10,11] Studies have reported incisor movement ranges of 3.3–7.6 mm at the incisal edge[4–7,9–11] and 0.6–3.9 mm at the root apex.[5–7,9,10] In the present study, the incisor tipped palatally by 11.4° while the incisal edge and root apex moved palatally by 7.2 mm and 3.0 mm, respectively. This indicates that the type of tooth movement included elements of translation and controlled tipping. These amounts were relatively large and consistent with previous studies in which TADs were used for incisor retraction.[4,6]

The data clearly indicated regional differences in changes in alveolar bone structure after incisor retraction. No previous studies evaluated alveolar bone displacement and, specifically, changes in the interalveolar septum after incisor retraction. Bone displacement was significantly larger on the labial side than the palatal side. This displacement was dependent on the bone level and progressively decreased from the crest to the apex level. This might reflect the influence of incisor movement. The null hypothesis that there would be no significant effect of tooth movement on the interalveolar septum morphology was rejected. Bone remodeling via orthodontic force is not restricted to the bone surrounding the root but can also occur in the spatially separated alveolar bone.

Bone thickness at all bone levels was significantly increased on the labial side and significantly decreased on the palatal bone. Studies that estimated alveolar bone thickness produced conflicting data and two recent meta-analyses[18,19] reported contrasting conclusions. One study[18] reported an increase in labial bone thickness at the crest level, although changes in thickness varied considerably on the palatal side. The other[19] reported that palatal bone thickness significantly decreased at the crest level. These inconsistences might be associated with differences in the types of malocclusion, the mechanics of tooth movement, amount and type of incisor movement, methods of superimposition, and follow-up duration.[10,11,18,19]

The current results concerning alveolar bone thickness were roughly consistent with two previous studies.[8,12] Zhang et al.[12] evaluated changes in alveolar bone using a geometric morphometric analysis. They reported an increase in bone thickness at all levels except for the crest level on the labial side, and a decrease in bone thickness at the crest and midroot level on the palatal side. Pianco et al.[8] reported similar results. These studies, along with the current study, had longer follow-up durations[8,12] than other studies that examined alveolar bone thickness before and after incisor retraction.[7,10,11] Over the long term, the process of bone remodeling passed through various stages during treatment, including initial leveling and

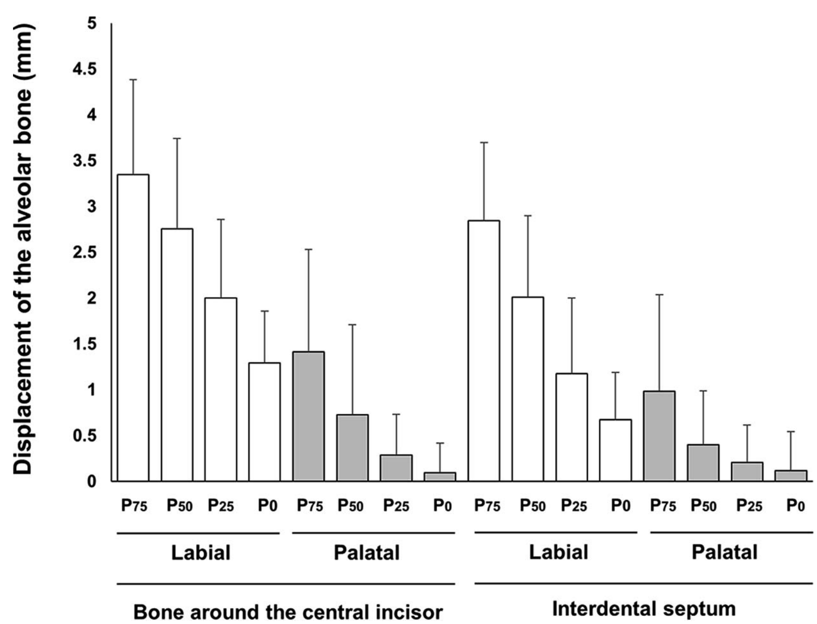

Figure 5. Displacement of the alveolar bone from T0 to T1.

Table 4. Thickness of the Alveolar Bone, Amount of Tooth Movement and Bone Remodeling/Tooth Movement Ratio (B/T ratio)

	Alveolar Bone Thickness				Amount of Tooth Movement (T)	B/T Ratio[a]
	T0	T1	T1–T0			
Level	Mean ± SD	Mean ± SD	Mean ± SD	*P* Value	Mean ± SD	Mean ± SD
Labial						
P_{75}	0.97 ± 0.47	1.24 ± 0.57	0.27 ± 0.49	.0113[b,*]	3.58 ± 0.94	0.92 ± 0.12
P_{50}	1.16 ± 0.43	1.68 ± 0.59	0.53 ± 0.38	.0001[c,**]	3.13 ± 1.02	0.86 ± 0.15
P_{25}	1.19 ± 0.49	2.15 ± 0.82	0.96 ± 0.64	.0002[b,**]	2.94 ± 1.09	0.66 ± 0.17
P_0	2.70 ± 0.97	4.24 ± 1.39	1.54 ± 1.02	.0003[b,**]	2.68 ± 1.39	0.55 ± 0.47
Palatal						
P_{75}	3.60 ± 1.39	1.46 ± 1.31	−2.14 ± 1.08	.0001[c,**]	3.58 ± 0.94	0.36 ± 0.28
P_{50}	4.56 ± 1.88	2.17 ± 1.70	−2.39 ± 1.22	.0001[c,**]	3.13 ± 1.02	0.20 ± 0.26
P_{25}	5.53 ± 1.62	2.88 ± 1.41	−2.65 ± 1.05	.0001[c,**]	2.94 ± 1.09	0.08 ± 0.13
P_0	9.65 ± 2.10	7.03 ± 2.69	−2.62 ± 1.24	.0000[b,**]	2.68 ± 1.39	0.03 ± 0.09

[a] B/T ratio = displacement of alveolar bone/amount of tooth movement.
[b] Paired *t*-test was performed to compare between T0 and T1.
[c] Wilcoxon matched-pairs signed-rank test was performed to compare between T0 and T1.
* $P < .05$; ** $P < .01$ between T0 and T1.

aligning, retraction, and detailing and finishing. These processes led to a large amount of incisor movement and change in alveolar bone morphology.

Very few previous studies on postincisor retraction changes in alveolar bone structure calculated the B/T ratio because they used the tooth axis as a reference.[5–8,10] However, two previous studies used the palate structure and calculated the B/T ratio.[9,11] One of those reported a B/T ratio of 0.5;[9] the other reported a B/T ratio near 1 for all root levels on the labial side and 0.2–0.4 on the palatal side.[11] In the current study, the B/T ratio was lower on the palatal side than the lingual side in a level-dependent manner, consistent with the latter study except for that corresponding to the labial side around the root apex. This disparity may have been related to differences in the observation period and the amount of root movement. The observation period in Eksriwong et al.[11] was short (7 months), and the amount of root apex movement was considerably less than 1 mm. The low B/T ratio on the palatal side in the present study indicated that the response of the alveolar bone to tooth movement was poor, and that the treatment thinned that bone. This thinning could cause fenestration and dehiscence. Accordingly, special consideration of the relationship between the root apex and the palatal cortex of the alveolar bone is necessary during retraction of the maxillary anterior teeth.

This study had some limitations. First, the morphologic changes in the alveolar bone around the lateral incisors could not be evaluated. The lateral incisors of the patients examined in this study frequently showed severe mesial root tipping at T0, which rendered such assessments difficult. Second, two different mechanics were applied for anterior tooth retraction in this study. Sliding and loop mechanics may have different effects on the alveolar bone changes. Finally, it is possible that skeletal growth may have affected bone changes during treatment, as the patients in this study included not only adults but also adolescents.

CONCLUSIONS

- The maxillary alveolar bone showed regionally different responses to treatment including anterior tooth retraction with TADs.
- The displacement and B/T ratio of the alveolar bone around the incisors were larger on the labial side than the palatal side, and decreased progressively from the crest to apex level.
- The alveolar bone thickness significantly increased on the labial side and decreased on the palatal side after treatment.
- Careful attention should be paid to bone remodeling on the palatal side of the alveolar bone, especially at the crest level.

REFERENCES

1. DeAngelis V. Observations on the response of alveolar bone to orthodontic force. *Am J Orthod.* 1970;58(3):284–294.
2. Edwards JG. A study of the anterior portion of the palate as it relates to orthodontic therapy. *Am J Orthod*. 1976;69(3): 249–273.
3. Handelman CS. The anterior alveolus: its importance in limiting orthodontic treatment and its influence on the occurrence of iatrogenic sequelae. *Angle Orthod*. 1996;66(2): 95–110.
4. Hung BQ, Hong M, Kyung HM, Kim HJ. Alveolar bone thickness and height changes following incisor retraction treatment with microimplants. *Angle Orthod*. 2022;92(4):497–504.
5. 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(2): 212–221.
6. Guo QY, Zhang SJ, Liu H, et al. Three-dimensional evaluation of upper anterior alveolar bone dehiscence after

incisor retraction and intrusion in adult patients with bimaxillary protrusion malocclusion. *J Zhejiang Univ-Sci*. 2011;12:990–997.

7. Sarikaya S, Haydar B, Ciğer S, Ariyürek M. Changes in alveolar bone thickness due to retraction of anterior teeth. *Am J Orthod Dentofacial Orthop*. 2002;122(1):15–26.
8. Picanço PRB, Valarelli FP, Cançado RH, de Freitas KM, Picanço GV. Comparison of the changes of alveolar bone thickness in maxillary incisor area in extraction and non-extraction cases: computerized tomography evaluation. *Dental Press J Orthod.* 2013;18(5):91–98.
9. Vardimon A, Oren E, Ben-Bassat Y. Cortical bone remodelling/tooth movement ratio during maxillary incisor retraction versus torque movements. *Am J Orthod Dentofacial Orthop*. 1998;114(5):520–529.
10. Yodthong N, Charoemratrote C, Leethanakul C. Factors related to alveolar bone thickness during upper incisor retraction. *Angle Orthod*. 2013;83(3):394–401.
11. Eksriwong T, Thongudomporn U. Alveolar bone response to maxillary incisor retraction using stable skeletal structures as a reference. *Angle Orthod*. 2021;91(1):30–35.
12. Zhang F, Lee SC, Lee JB, Lee KM. Geometric analysis of alveolar bone around the incisors after anterior retraction following premolar extraction. *Angle Orthod*. 2020;90(2): 173–180.
13. Bills DA, Handelman CS, BeGole EA Bimaxillary dentoalveolar protrusion: traits and orthodontic correction. *Angle Orthod*. 2005;75(3):333–339.
14. Melsen B. Biological reaction of alveolar bone to orthodontic tooth movement. *Angle Orthod.* 1999;69(2):151–158.
15. Linkous ER, Trojan TM, Harris EF. External apical root resorption and vectors of orthodontic tooth movement. *Am J Orthod Dentofacial Orthop*. 2020;158(5):700–709.
16. Bazina M, Cevidanes L, Ruellas A, et al. Precision and reliability of Dolphin 3-dimensional voxel-based superimposition. *Am J Orthod Dentofacial Orthop*. 2018;153(4): 599–606.
17. Okuzawa-Iwasaki M, Ishida Y, Ikeda Y, et al. Alveolar bone morphology in patients with a unilateral palatally displaced maxillary lateral incisor: a cone-beam computed tomography study. *Am J Orthod Dentofacial Orthop*. 2020;158(1): 28–34.
18. Domingo-Clerigues M, Montiel-Company JM, Almerich-Silla JM, et al. Changes in the alveolar bone thickness of maxillary incisors after orthodontic treatment involving extractions-a systematic review and meta-analysis. *J Clin Exp Dent.* 2019;11:e76–e84.
19. Guo R, Zhang L, Hu M, Huang Y, Li W. Alveolar bone changes in maxillary and mandibular anterior teeth during orthodontic treatment: a systematic review and meta-analysis. *Orthod Craniofac Res*. 2021;24:165–179.