Original Article

Geometric analysis of alveolar bone around the incisors after anterior retraction following premolar extraction

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ABSTRACT

Objective: To evaluate changes in shape and alterations in thickness and vertical marginal bone levels of the alveolar bone around the maxillary and mandibular incisors before and after orthodontic treatment with premolar extraction using geometric morphometric analysis.

Materials and Methods: Thirty-six patients with Class I bialveolar protrusion who underwent orthodontic treatment with premolar extraction were included. Cone-beam computed tomographic scans were obtained from the patients before and after treatment. Five fixed landmarks and 70 semilandmarks were used to represent the morphology of the alveolar bone around the maxillary and mandibular incisors. The coordinates of the landmarks of the alveolar bones were generated by Procrustes fit. The labial and lingual alveolar bone thicknesses around the maxillary and mandibular incisors and vertical marginal bone level were assessed quantitatively.

Results: There was a significant difference in shape change of the alveolar bone before and after treatment. The deformation grid of the thin plate spline showed that the thickness and vertical marginal bone decreased on the lingual side after treatment. Shape changes were greater for the lingual alveolar bone on the mandibular incisor than for the maxillary incisors.

Conclusions: Orthodontic treatment with premolar extraction might cause loss of alveolar bone around the maxillary and mandibular incisors. Careful consideration is needed to avoid iatrogenic degeneration of periodontal support around the incisors, particularly in the lingual area. (*Angle Orthod.* 2020;90:173–180.)

KEY WORDS: Geometric morphometric analysis; Alveolar bone; Premolar extraction

INTRODUCTION

Undesired periodontal changes after orthodontic treatment, such as gingival recession or alveolar bone loss, attract clinicians' attention prior to devising a treatment plan.[1–7] In previous studies[8–10] that concentrated on changes in the periodontal tissue of patients who received orthodontic treatment, resesarchers evaluated alveolar bone changes using bitewing or periapical radiographs. Owing to the limitations of two-dimensional images, technical shortcomings such as magnification, geometric distortion, and overlap of structures restricted the reliability of the results.[11] Since the introduction of cone-beam computed tomography (CBCT) to dentistry in 1998[12] CBCT has become an useful tool in the assessment of the condition of periodontal tissues. Sarikaya et al.[13] evaluated the thickness of alveolar bone after anterior teeth retraction using cephalogram and CT and they found that alveolar bone thickness decreased significantly, especially on the mandibular incisors. Lund et al.[14] investigated marginal alveolar bone before and after orthodontic treatment with premolar extraction using CBCT. The authors[14] used only linear measurements to evaluate how much the amount of alveolar bone was changed.

Few studies have focused on the whole configuration of the alveolar bone before and after treatment with premolar extraction. Geometric morphometric analysis,

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which was introduced in 1993, has been applied in the fields of palaeontology, anthropology, and zoology.[15,16] Geometric morphometric analysis is an approach that evaluates the shape using geometric coordinates that are capable of capturing morphologically distinct shape variables instead of linear or angular measurements.[17–19] The purposes of this study were to evaluate shape changes of the alveolar bone as a consequence of comprehensive orthodontic treatment in patients with biaveolar protrusion using geometric morphometric analysis and to evaluate changes in alveolar bone thickness and vertical bone height using CBCT images.

MATERIALS AND METHODS

This retrospective study was approved by the Chonnam National University Dental Hospital Institutional Review Board (Gwangju, Korea). The treatment records of CBCT data and lateral cephalograms from pre- and posttreatment assessments of 36 patients (16 males and 20 females; mean age, 20.6 ± 2.4 years; range 18–31 years) were included in the study. The orthodontic records were selected from the data collection in the Department of Orthodontics of the Chonnam National University Dental Hospital. The following inclusion criteria were applied: adult patients less than 34 years old diagnosed with skeletal Class I malocclusion with bialveolar protrusion treated with four premolar extractions and having generally healthy periodontal conditions. Patients diagnosed with skeletal Class II occlusion or other syndromes, severe craniofacial dysplasia, or missing teeth were excluded. Current smokers and patients with poor oral hygiene were also excluded. The mean orthodontic treatment period was 2.6 ± 0.7 years.

CBCT scans were obtained before (T0) and after (T1) treatment with an Alphard Vega (Asahi Roentgen Co, Kyoto, Japan) under the following conditions: 80 kV, 5 mA, voxel size of 0.39 × 0.39 × 0.39 mm, and field of view of 200 × 179 mm. The archived CBCT scan data were processed and reconstructed into three-dimensional (3D) images by a software program (OnDemand3D Application, version 1.0, CyberMed Inc, Seoul, Korea). Multiplanar reformatting images were used to evaluate the morphology of the alveolar bone around the maxillary and mandibular anterior teeth and to measure the thickness of the alveolar bone and vertical alveolar bone loss on both labial and lingual sides.[20] The sagittal plane was adjusted such that it was parallel and passed through the axis of each examined tooth and was perpendicular to the labial surface of the tooth. The tooth axis was defined as the line connecting the midpoint of the incisor edge and the root apex. For the purpose of revealing alveolar bone shape changes around the incisors and measuring the thickness of the alveolar bone and vertical marginal bone level, sagittal slices passing through the tooth axis were used for landmarks of digitization and measurements (Figure 1). The oriented sagittal slice of each tooth was captured and saved as a file. The sagittal images were imported into tpsDIG software (Department of Ecology and Evolution, State University of New York at Stony Brook, NY) to digitize landmarks representing the contour of the alveolar bone surrounding the incisors (Figure 2). The five fixed landmarks and 70 semilandmarks were designed to define the outline of the alveolar bone around the incisors. The definitions of the fixed landmarks are given in Table 1. Each fixed landmark was a point that could be placed on a biologically or geometrically homologous point on the structure. Each semilandmark was a point that was placed arbitrarily using an algorithm, often by defining endpoints at biologically homologous points and placing a specified number of semilandmarks between them. The digitized data of fixed and semilandmarks were saved as x, y coordinates. For the fixed landmark superimposition and semilandmark alignment, the coordinate data were imported into CoordGen8 (Department of Physics, Canisius College, NY). The Procrustes technique uses the least-squares method to superimpose a structure at corresponding landmarks by translation, rotation, and scaling onto a reference structure. The results are scattered across corresponding landmarks (Procrustes shape coordinates). The shape of a generalized Procrustes superimposed landmark configuration is defined by the all of its morphological coordinates. The metric in this shape space is called "Procrustes distance: d" (the sum of squares of homologous interlandmark distances between Procrustes superimposed specimens).

In order to measure the thickness of alveolar bone and vertical marginal bone level (VBL) on both the labial and lingual sides at T0 and T1 time points, the linear measurements were obtained from the same sagittal images. The root length of each examined tooth was measured and recorded as the perpendicular distance from the root apex to the cementoenamel junction (CEJ), which was constructed as the line connecting the CEJ on both the labial and lingual sides. The root length was evenly divided into five levels (level 0 represented CEJ; level 5 represented root apex). The measurements of alveolar bone thicknesses on the labial and lingual sides were recorded as the distances between the cortical plate and the root surface. To obtain the measurements of VBL, alveolar marginal bone crest (AC) and the CEJs were marked at the labial and lingual sides of all the examined incisors, and the distance between AC and

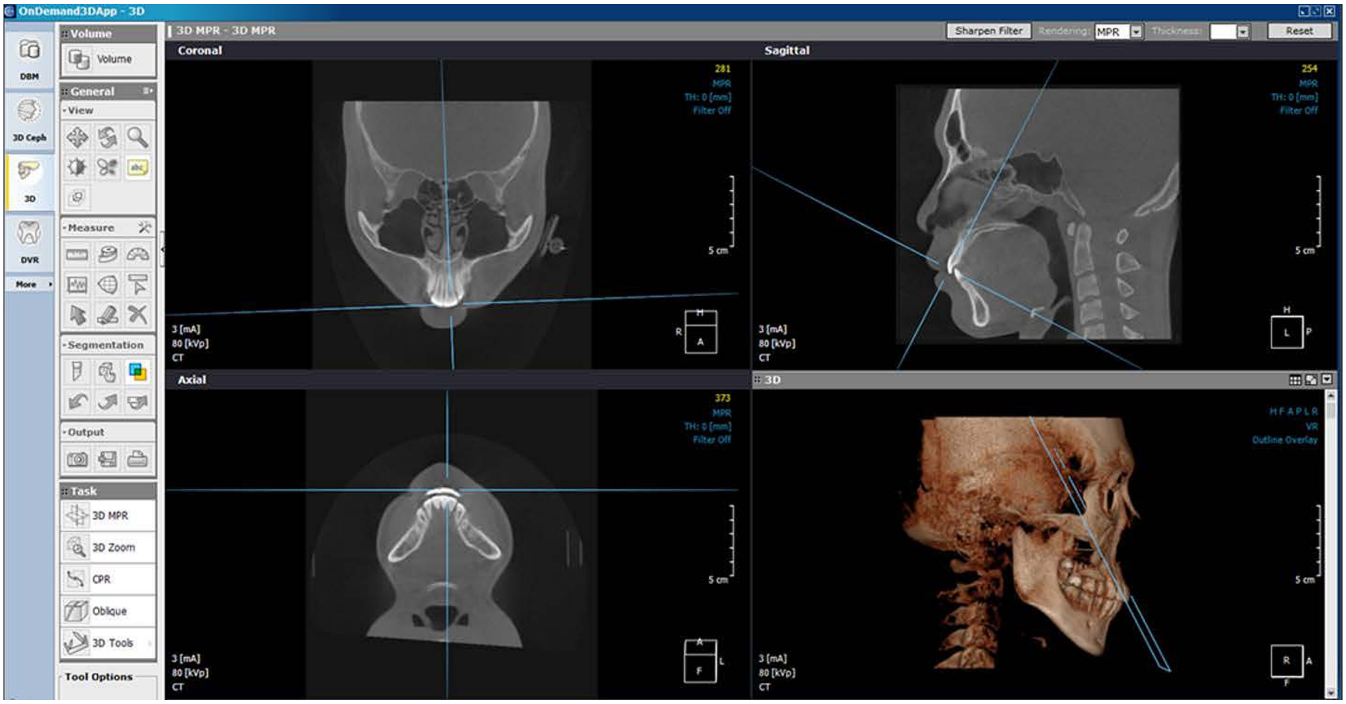

Figure 1. Orientation of CBCT scans for each maxillary and mandibular incisor. The sagittal plane was adjusted to pass through the axis of each tooth, where the tooth axis was defined as the line connecting the midpoint of the incisor edge and the root apex, and also to be perpendicular to the labial surface. Then the oriented sagittal image was used for measurement.

CEJ was measured (Figure 3). This value represented the extent of the vertical alveolar bone loss. All of the measurements mentioned above were compared at T0 and T1 time points of orthodontic treatment. In addition, cephalometric analysis was performed at T0 and T1 to evaluate the cephalometric changes in each patient during orthodontic treatment. Adopted linear and angular measurements of the cephalometric analysis were SNA, SNB, ANB, SN-MP, FMA, FMIA, IMPA, U1-FP, L1-FP, U1-SN, and interincisor angle.

Statistical Analysis

Processed data were imported into TwoGroup 8 (Department of Physics, Canisius College), and a data file of superimposed landmark coordinates was created for each of the two groups to be compared. The mean shape comparisons before and after treatment were carried out using Goodall's *F*-test.[18,19] The result of the Goodall's *F*-test was used to test the probability of the existence of significant differences in mean shape between the two groups. In addition, the shape comparison was also demonstrated using the deformation grid of thin plate spline (TPS) to visualize the differences before and after treatment. Since all fixed landmark and semilandmark digitization was done by one examiner, for reproducibility of the data, the data were obtained again after 2 weeks, and reproducibility was evaluated with multivariate analysis of variance by comparing data on landmarks and semilandmarks in all patients.[19]

The distributions of linear measurements comparing the difference in alveolar bone thickness at the five levels and the vertical marginal bone level on both the labial and lingual sides at T0 and T1 were initially tested for normality. The Shapiro-Wilk test showed a normal distribution of the measures at the two time points. A paired *t*-test was used to determine the differences in thickness and vertical bone level of the alveolar bone before and after treatment. Cephalometric changes according to the treatment were also analyzed. Statistical analyses were performed using the Statistical Package for Social Science for Windows (SPSS, version 22.0; IBM, Armonk, NY) at the 5% level of significance. All measurements were repeated after 2 weeks by the same examiner. The systematic intraexaminer error between the two measurements was determined by means of a paired *t*-test. In addition, the magnitude of that error was assessed by calculating the intraclass correlation coefficient (ICC). Sample size was calculated using the values of a pilot study in the G*power program (version 3.1.9.2; Heinrich-Heine-University, Dusseldorf, Germany). Thirty-three patients (effect size: 0.212) were determined to be necessary, and a sample size of 36 patients was chosen.

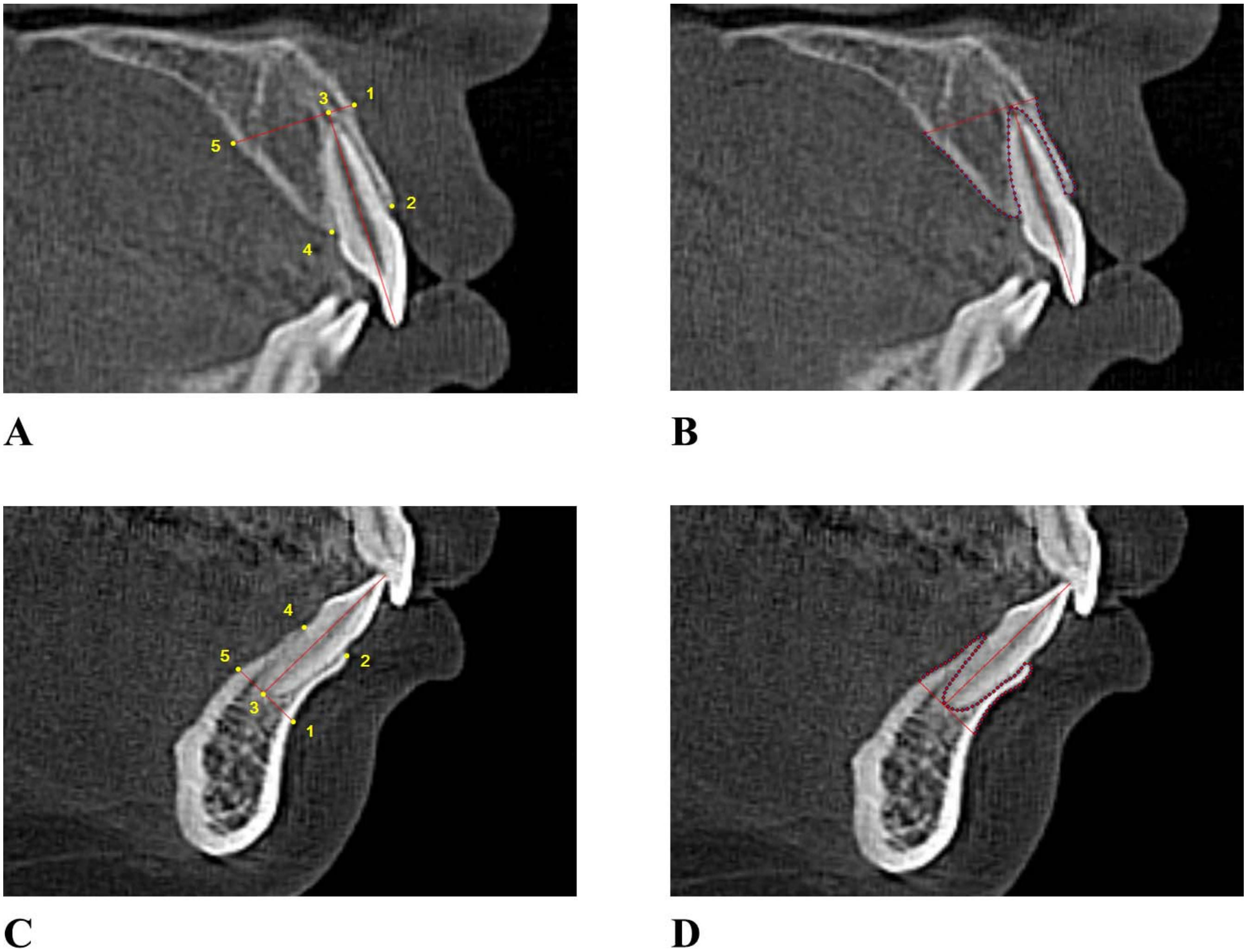

Figure 2. Five fixed landmarks and 70 semilandmarks were used to represent the morphology of the alveolar bone around the maxillary (A and B) and mandibular (C and D) incisors.

RESULTS

The power of the repeatability of the landmark and semilandmark digitization reached 91%. Regarding the linear measurements, intraexaminer error was found to be statistically insignificant. ICC measurement, showing a mean of 0.89 (ICC 0.78–0.92), indicated excellent reliability.

The cephalometric changes before and after treatment are shown in Table 2. The U1-SN, IMPA, FMIA, interincisor angle, U1-FP, and L1-FP decreased significantly after orthodontic treatment with premolar extraction (Table 2). Comparison of the alveolar bone before and after treatment revealed that the thickness of the alveolar bone decreased significantly after treatment on the lingual side (Figure 4A). The reduction in the vertical marginal bone level was not dramatically noticeable on the labial side of maxillary incisors, but it was clearly visible on the anterior mandibular alveolar bone. Significant vertical bone loss on the lingual side was evident in the mandibular incisors. The details of alveolar bone morphology change following treatment are depicted in the deformation grid of the TPS (Figure 4B). The results of Goodall's *F*-test indicated that there were statistically significant differences in alveolar bone shape around the incisors before and after treatment (Table 3).

The linear measurements of the changes in the alveolar bone around the maxillary and mandibular

Table 1. Definitions of Fixed Landmarks Used in This Study

Landmarks	Definition
1, 5	Labial and lingual intersections of the baseline with alveolar bone
2	Alveolar crest on the labial side
3	Intersection of the line (baseline) passing through the apex of the tooth and perpendicular with the axial of the tooth
4	Alveolar crest on the lingual side

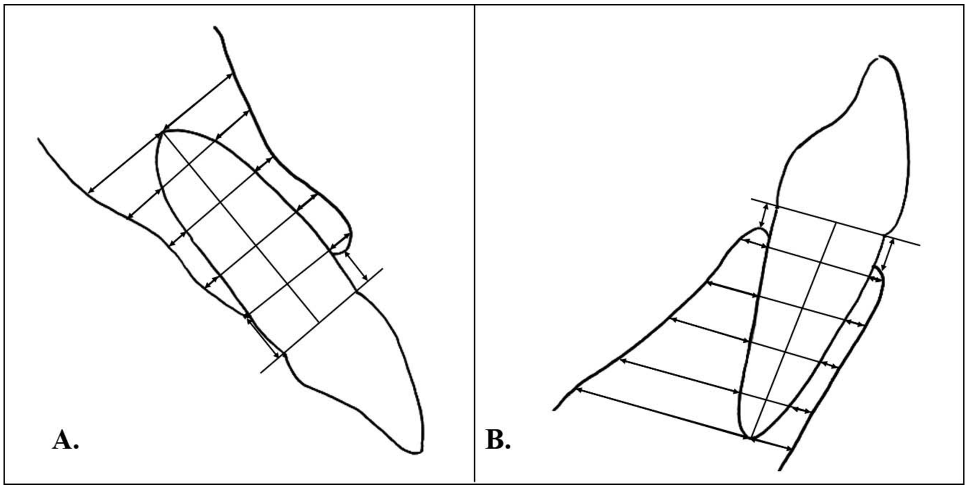

Figure 3. Measurements of the thickness of the alveolar bone and the vertical marginal bone levels on the labial and lingual sides of the maxillary (A) and mandibular (B) incisors were obtained. The roots of the examined teeth were divided into five levels. The vertical marginal bone levels were measured as the distance between the CEJ and the alveolar bone crest.

retracted incisors are shown in Table 4. Changes in the thickness on the labial side of the alveolar bone in both the maxilla and the mandible significantly increased at almost all levels, with the exception of level 1 in the maxilla and level 2 in the mandible. The VBL on the labial aspect of the maxillary incisor was maintained. However, the lingual side of the vertical bone was reduced significantly after anterior tooth retraction. In the mandible, the vertical bone was reduced significantly after anterior tooth retraction on both the labial and lingual sides. The results of the linear measurements taken to detect changes in the thickness and VBL of the alveolar bone around the examined incisors agreed with the visualized result of geometric morphometric analysis and the deformation grid of TPS. The root length of the maxillary incisor was resorbed 1.3 mm and the root length of the mandibular incisor root was resorbed 1.2 mm after treatment (Table 5).

Table 2. Cephalometric Changes Between Before (T0) and After (T1) Treatment[a]

	Before Treatment (T0)		After Treatment (T1)		
	Mean	SD	Mean	SD	*P*-Value
SNA, °	80.3	3.8	79.3	4.0	.08
SNB, °	76.8	3.6	76.4	3.57	.11
ANB, °	4.3	1.9	3.6	1.6	.09
SN-MP, °	39.2	4.5	39.8	4.9	.14
FMA, °	30.7	4.8	30.8	4.7	.71
FMIA, °	50.9	6.4	56.0	8.7	.00[b]
IMPA, °	98.5	5.5	92.5	6.7	.00[b]
U1-FP, mm	15.1	3.8	10.0	2.7	.00[b]
L1-FP, mm	10.8	3.3	6.4	2.8	.00[b]
U1-SN, °	109.5	8.5	103.2	6.6	.00[b]
Interincisor angle, °	112.7	8.9	124.0	6.7	.00[b]

[a] SD indicates standard deviation.
[b] $P < .01$.

DISCUSSION

During orthodontic treatment with premolar extraction, retraction of anterior teeth is required to achieve the treatment goal, specifically among patients whose chief complaint is protrusion. The increased possibility of iatrogenic damage to the cortical bone is known as an orthodontic barrier, and invasive resorption is a constant concern of orthodontists.[5] The aim of this study was to assess the changes in alveolar bone after tooth movement using geometric morphometric analysis.

Geometric morphometric analyses are performed on landmark coordinates defined by specific anatomic locations. Since there were not a sufficient number of anatomic locations to represent the absolute configuration of the alveolar bone, use of semilandmarks was necessary to determine the outlines of the alveolar bone and to obtain adequate spatial information concerning its shape.[18] As soon as all the semilandmarks were superimposed, their coordinates were considered as those of landmarks, which significantly expanded the available shape information regarding the alveolar bone.[18,21]

The deformation grid of TPS visually shows how the shape of the alveolar bone changed after orthodontic treatment. The TPS also provided detailed information on the alterations of the vectors of the fixed landmarks and semilandmarks, indicating that the overall configuration of the alveolar bone obviously changed after incisor retraction. Both the labial and lingual sides of the alveolar bone drifted with the movement of the teeth, and the fixed landmarks and semilandmarks that represented the lingual bone crest were displaced in the apical direction. On the pressure side of the alveolar bone around the retracted anterior teeth,

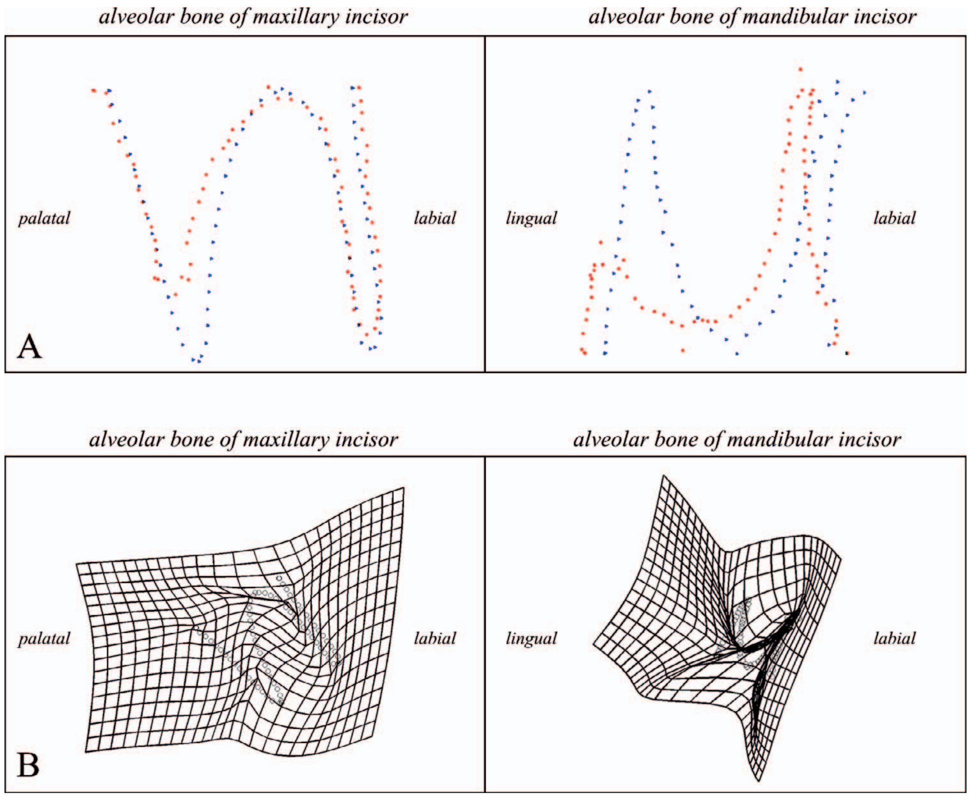

Figure 4. Visualization of the shape difference. (A) Comparison of the mean shapes of the alveolar bone around the maxillary and mandibular incisors before (blue) and after (red) treatment; (B) thin plate spline deformation and vectors of landmark displacement showing changes in shape from the mean shape before and after treatment in the alveolar bone around the maxillary and mandibular incisors.

obvious bone remodeling and reduction in the amount of bone were present, and the grids on the lingual side were dramatically deformed. In the results of the geometric morphometric analysis, significant shape changes in alveolar bone configurations were observed based on comparison of the mean shapes before and after treatment.

The results of linear measurements of alveolar bone thickness supported the results of the geometric morphometric analysis. A significant reduction in bone thickness and a decrease in the vertical marginal bone to nearly one-third of its original value were found on the lingual side. Thickness decreased significantly after treatment, and the VBL results revealed the same negative alteration. Yodthong et al.[22] studied alveolar bone thickness during maxillary incisor retraction and reported that labial bone thickness at the crestal level

Table 3. Statistical Comparison of Difference in the Mean Shape of Alveolar Bone Around Incisors Between Before and After Treatment Based on Procrustes Distance by Using Goodall's *F*-Test

	F Score	Degree of Freedom	Distance Between the Mean Shape	*P*-Value
Maxilla	66.63	146,11388	0.2693	.01*
Mandible	115.98	146,11388	0.5185	.01*

* $P < .05$.

significantly increased, whereas Sarikaya et al.[13] found that changes in alveolar bone thickness were not significant. However, their superimposition methods were not homologous before and after treatment, and they used only three levels to evaluate alveolar bone thickness; they also had a small sample size, which restricted and weakened the power of their conclusions. These differences may explain the contradiction between their results and the current findings. The present findings corresponded with the results of Lund et al.,[14] and these tendencies of alveolar bone shape change after treatment can also be interpreted as bone remodeling induced by orthodontic tooth movement. On the tension side, the remodeling process maintained the condition of the alveolar crest in the pretreatment state. Tensive periodontal ligaments mediated and activated osteoblasts to initiate the bone formation process. On the other hand, the pressure side exhibited a reduction in bone thickness and vertical bone loss, which were caused by the accumulated force generated from controlled tipping that mainly loaded on the peripheral region of the alveolar crest.

A similar alveolar bone shape change occurred in the mandible after incisor retraction, but it was more significant, particularly on the lingual side. On the labial

Table 4. Comparison of Alveolar Bone Thickness and the Vertical Marginal Bone Level Before and After Orthodontic Treatment with Premolar Extraction (Unit: mm)[a]

		Before Treatment (T0)		After Treatment (T1)		
		Mean	SD	Mean	SD	*P*-Value
Alveolar bone thickness (labial side)						
Maxilla	L1	0.70	0.34	0.67	0.58	.210
	L2	0.78	0.30	0.94	0.44	.034*
	L3	0.88	0.30	1.07	0.54	.036*
	L4	1.09	0.46	1.50	0.73	.003†
	L5	1.87	0.73	2.29	1.06	.024*
Mandible	L1	0.50	0.33	0.34	0.38	.017*
	L2	0.41	0.22	0.42	0.45	.520
	L3	0.55	0.32	0.75	0.66	.142
	L4	1.16	0.62	1.51	0.93	.009†
	L5	2.55	1.05	3.16	1.54	.010*
Alveolar bone thickness (lingual side)						
Maxilla	L1	1.23	0.58	0.51	0.58	.000†
	L2	2.03	0.87	1.06	0.96	.000†
	L3	2.89	1.14	1.79	1.49	.000†
	L4	4.09	1.33	2.86	1.92	.000†
	L5	5.97	1.70	4.55	2.37	.000†
Mandible	L1	0.39	0.42	0.04	0.21	.000†
	L2	0.97	0.58	0.19	0.38	.000†
	L3	1.40	0.76	0.44	0.73	.000†
	L4	2.20	0.92	0.89	0.96	.000†
	L5	3.48	1.18	2.13	1.30	.000†
Marginal bone level						
Maxilla						
Labial side		1.63	0.73	1.84	0.77	.058
Lingual side		1.24	0.62	3.13	2.72	.000†
Mandible						
Labial side		1.76	1.07	3.32	2.44	.000†
Lingual side		2.11	1.06	6.06	2.72	.000†

[a] SD indicates standard deviation.
* $P < .05$; † $P < .01$.

Table 5. Comparison of the Mean Root Lengths of the Retracted Anterior Teeth Before and After Orthodontic Treatment with Premolar Extraction (Unit: mm)

	Before Treatment (T0)		After Treatment (T1)		
	Mean	SD	Mean	SD	*P*-Value
Upper incisor	12.10	1.15	10.81	1.42	.000*
Lower incisor	11.13	1.16	9.92	1.29	.000*

[a] SD indicates standard deviation.
* $P < .01$.

side, thickness and bone height almost maintained their original values, except for a hardly noticeable thickness reduction around the crestal region, which was in agreement with the results of Sarikaya et al.[13] In the apical region, the thickness was significantly augmented at levels 4 and 5. On the other hand, on the lingual side, the vertical bone height dramatically decreased to one-third of its pretreatment height, the same result reported by Lund et al.[14] Bucco-lingual movement is more likely to invade the alveolar bone barrier during orthodontic treatment, especially for the mandibular incisor, as thinness of the labiolingual sides may be present in some patients congenitally and may increase the bone plate resorption.

It has been demonstrated that tipping movements of teeth cause more resorption of alveolar bone than do translational movements. In this study, most of the mechanics of tooth movement were tipping movements because the samples consisted of Class I bialveolar protrusion patients. Maxillary incisors moved 5.1 mm, and the amount of alveolar bone resorption on the lingual side was 1.09 mm, on average (L1, 0.72 mm; L2, 0.97 mm; L3, 1.1 mm; L4, 1.23 mm; and L5, 1.42 mm). Mandibular incisors moved 4.4 mm during treatment, and the amount of alveolar bone resorption on the lingual side was 0.95 mm, on average (L1, 0.35 mm; L2, 0.78 mm; L3, 0.96 mm; L4, 1.31 mm; and L5, 1.35 mm). Horizontal bone resorption occurred more in the maxilla, whereas vertical bone resorption was prominent in the mandible (1.05 mm in the maxilla and 2.76 mm in the mandible). It may be expected that the greater the tooth movement, especially tipping, the more that alveolar bone would be altered around the tooth; however, a direct relationship between the amount of tooth movement and alveolar bone resorption was not shown. Lee et al.[23] reported that there was no statistically significant correlation between the degree of incisor inclination change and the extent of alveolar bone change. Alveolar bone changes after tooth movement are related to biomechanical phenomena and are influenced by many factors, including a patient's periodontal environment or gingival type.[24] Thus, it might be possible that the extent of alveolar bone change is not mathematically or directly correlated with the degree of tooth movement or incisor inclination change.

In addition, vertical tooth movements such as intrusion or extrusion may affect alveolar bone changes after orthodontic treatment. In particular, intrusion of incisors may cause the vertical loss of alveolar bone. Atik et al.[25] investigated the changes in alveolar bone after maxillary incisor intrusion in deep-bite patients. They found that the amount of intrusion during upper incisor intrusion might increase the risk of alveolar bone loss.[25] Intrusive tooth movements should be attempted with bodily movements or slight linguoversion. Cho et al.[26] evaluated the optimal loading conditions for pure intrusion of the maxillary anterior teeth with miniscrews. They reported that when the same force was applied to maxillary anterior teeth being intruded, the degree of labial tipping of the anterior teeth increased as bone loss increased.[26] In this study, the patients enrolled did not undergo intrusion of the maxillary or mandibular incisors. Thus, the focus of the current study was on the effect of anterior retraction on the alveolar bone around the maxillary and mandibular incisors.

CONCLUSIONS

- With geometric morphometric analysis, the shape of the alveolar bone around the maxillary and mandibular incisors can be seen before and after orthodontic treatment.
- Changes in shape and alterations in thickness and vertical bone levels of the alveolar bone were found to be significant after orthodontic treatment with premolar extraction.
- Careful consideration is needed to avoid iatrogenic degeneration of alveolar bone support around the incisors, particularly on the lingual side.

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