Abstract: This study examined the relationship of vertical and horizontal changes in the alveolar bone crest with upper incisor movement after orthodontic treatment. Tooth movement was measured on lateral cephalograms. Vertical and horizontal changes in the median alveolar crest and distance from the cementoenamel junction and anterior nasal spine to the alveolar crest were measured with cone-beam computed tomography. The incisal edge moved distally, and the cervical point intruded significantly and moved distally. The median alveolar crest decreased by 3.80 ± 2.05 mm. The distance from the labial cementoenamel increased significantly, by 0.35 ± 0.38 mm. The vertical distance from the anterior nasal spine decreased significantly, and the alveolar crest moved distally. Vertical tooth movement was positively associated with change in the distance from the labial cementoenamel junction and inversely associated with vertical change in the distance from the anterior nasal spine on the labial and palatal sides. Lingual tooth movement was positively and negatively correlated with horizontal changes in the labial and palatal alveolar crest and vertical change in the palatal alveolar crest. The lingual movement of incisors was related to labial bone resorption. Greater lingual and extrusive movement of incisors led to a greater decrease in the alveolar bone crest.

Keywords: upper incisor movement; alveolar bone crest; orthodontic treatment; cone-beam computed tomography (CBCT).

Introduction
Root resorption and gingival recession are frequent side effects of orthodontic treatment. Although many studies have examined root resorption, few have carefully investigated gingival recession during orthodontic tooth movement, although it is an important problem affecting treatment results. Gingival recession can result in poor aesthetics and hyperesthesia and may increase caries risk. It often develops in persons with large tooth movement, thin alveolar bone, and periodontal disease, even when optimal orthodontic forces are applied (1,2). Gingival recession in such cases may require periodontal surgery (3). To improve prediction of gingival recession, the cause should be identified and addressed.

Bone resorption usually occurs on the pressure side, whereas bone apposition is seen on the tension side. Thus, the thickness of alveolar bone should be maintained at an almost constant level (4). Schwarz et al. (5) were able to identify only a few detailed studies of changes in alveolar bone. Most were limited investigations of alveolar bone adjacent to the tooth and periodontal ligaments related to tooth movement. Handelman (6) reported that undesirable phenomena such as fenestration, dehiscence, and root resorption should be considered in patients...
Picanço (7) and Sarikaya et al. (8) reported changes in the thickness of the alveolar bone after orthodontic treatment, and Garlock et al. (9) reported correlations between morphologic changes in the mandible and treatment. However, few reports have thoroughly studied changes in the amount of alveolar bone, alveolar bone height, and morphological changes in the labial and lingual bone plate in the maxilla.

Recently, cone-beam computed tomography (CBCT) has enabled precise measurement of features such as the periodontal ligament space in thin alveolar bone. Conventional dental panoramic radiographs yield insufficient information for diagnoses regarding anterior teeth, because of the limited information on patient head position. Xin Liang et al. (10,11) reported that, when used for medical imaging, the resolution of CBCT is higher than that of X-ray computed tomography. The present study used CBCT images and lateral cephalograms obtained before and after orthodontic treatment, to examine the relationship of vertical and horizontal changes in the alveolar bone crest with upper incisor movement.

**Materials and Methods**

We analyzed the records of 33 adult orthodontic patients (6 men and 27 women; 5 non-extraction cases and 28 premolar extraction cases; mean patient age 22.5 ± 5.2 years [mean ± SD], range 15.6-37.3 years) who were treated with multibracket appliances. Patients were excluded if they were younger than 15 years, had a maxillary or a central impacted supernumerary tooth, were treated with a rapid palatal expander, or if they had an upper central incisor dental prosthesis. Upper incisor movement was measured by using lateral cephalograms, and CBCT (3DXMulti Image Micro CT FPD8, Morita, Kyoto, Japan; 90 kV, 7.0 mA, 0.125-mm voxel size) was used to measure alveolar bone features. CBCT images were reconstituted with proprietary viewer software (i-VIEW, Morita). Image processing software (Photoshop Elements 12, Adobe Systems Japan, Tokyo, Japan) was then used to analyze the measurements described below, using a scaler. The analysis used CBCT images obtained during pre-treatment (T1) examinations for the purpose of diagnosis and post-treatment (T2) examinations for the purpose of observing root resorption and alveolar bone condition. To eliminate inter-examiner error, one examiner (W.M.) traced and measured all images. To reduce intra-examiner error, all tracings and measurements were performed at least three times, and the mean values were recorded and analyzed. The research protocol for this study was approved by the Ethical Committee of Nihon University School of Dentistry (EP2014-9).

**Measurement of central incisor movement**

After superimposing T1 and T2 lateral cephalograms, incisal edge movement (E1 and E2) was calculated vertically and horizontally from the Frankfort horizontal (FH) plane (Fig. 1). The measurement point of the cervical area (C1 and C2) was fixed at the midpoint of the line linking the points of the labial cementoenamel junction (CEJ) to the palatal CEJ (Fig. 2). The movement of the incisal cervical point was measured by using the FH plane registered at the anterior nasal spine (ANS) as the reference plane, and vertical and horizontal changes were calculated as coordinates on T1 and T2 CBCT images.
In total, 52 of the 66 images were of sufficient quality and were used for comparison of T1 and T2. In all cases, movements in the palatal and intrusive direction were defined as plus (+), and those in the labial and extrusive direction were defined as minus (−).

Measurement of changes in median alveolar bone
First, CBCT images of the median plane (T1 and T2) were superimposed at the palatal plane and incisive canal by using the image processing software Adobe Photoshop Elements 12. Then, change in the alveolar bone crest was measured on the basis of the shortest distance (Fig. 3).

Measurement of the distance from the CEJ to the alveolar crest
A modified version of the measurement method of Zachrisson and Baxter et al. (12-15) was used in this study. Alveolar bone height from the CEJ at the middle of the left and right central incisors—an indicator of alveolar bone changes around teeth—was measured on the CBCT image (Fig. 4). Differences between T1 and T2 on the labial and palatal sides were calculated.

Measurement of the distance from the ANS to the alveolar crest
To examine change in the alveolar crest in the maxilla, the distance from the ANS to the alveolar crest was measured by referring to the FH plane registered at the ANS (Fig. 5). The measurements were decomposed into vertical and horizontal movement, with movement in the palatal and intrusive direction defined as plus (+).

Statistical analyses
Statistical analyses were performed with SPSS for Windows, version 23 (IBM Japan, Tokyo, Japan). Differences in central incisor movement and change in the alveolar bone between T1 and T2 were evaluated by using the paired t-test. Pearson correlation coefficients were calculated to evaluate relationships between tooth movement and change in alveolar bone. A P value of less than 0.05 was considered to indicate statistical significance.
Results

Central incisor movements
The incisal edge intruded slightly (0.02 ± 1.58 mm) and moved distally (7.14 ± 3.83 mm). The central cervical point intruded significantly (0.69 ± 1.35 mm) and moved distally (3.57 ± 2.66 mm) (P < 0.05, Table 1, Fig. 6).

T1-T2 change in the alveolar bone crest
The median alveolar bone crest decreased by 3.80 ± 2.05 mm (Table 2, Fig. 3). The change in the distance from the labial CEJ (−0.35 ± 0.38 mm) was significant (P < 0.05), whereas the change in the distance from the palatal CEJ (−0.05 ± 0.64 mm) was not (Table 2, Fig. 4).

The vertical distance from the ANS to the labial alveolar bone crest decreased significantly (−0.46 ± 1.26 mm), and the alveolar bone crest moved distally (3.12 ± 2.08 mm) (P < 0.05). In addition, the vertical distance from the ANS to the palatal alveolar bone crest decreased significantly (−1.17 ± 1.61 mm), and the alveolar bone crest moved distally (3.31 ± 2.67 mm) (P < 0.05, Table 3, Fig. 5).

Correlation between tooth movement and change in the alveolar bone crest
There was no significant correlation between vertical tooth movement and change in the median alveolar crest; however, the correlation with horizontal tooth movement was significant and positive (P < 0.01). Increased distal movement of the central incisor was associated with a greater decrease in median alveolar bone (Table 4). Vertical tooth movement was significantly positively correlated (P < 0.01) with change in the distance from the CEJ to the alveolar crest on the labial side only; the correlation was not significant on the palatal side (Table 4).

Vertical tooth movement was negatively correlated (P < 0.01) with vertical change in the distance from the ANS to the alveolar bone crest on both the labial and palatal sides. Horizontal tooth movement was significantly negatively correlated (P < 0.01) with vertical change in the palatal alveolar bone crest and significantly positively correlated (P < 0.01) with change in the labial alveolar bone crest. As distal movement of the incisor increased, the alveolar bone crest decreased and moved distally. There was a significant positive correlation between vertical tooth movement at the cervical point and horizontal change in the palatal alveolar bone crest (P < 0.05): as the cervical point moved intrusively, the palatal alveolar bone crest tended to move distally. Finally, there was a significant positive correlation between horizontal tooth movement and horizontal change in the palatal alveolar bone crest (P < 0.01): as distal movement of the central incisor increased, the palatal alveolar bone crest moved more distally (Table 4).

Discussion
Periapical radiography and panoramic radiography have been used to evaluate resorption of alveolar bone. Detailed observation of alveolar bone is difficult on conventional 2-D radiography, but high-resolution images can now be obtained with CBCT. Misch et al.
(16) and Liang et al. (10) reported that CT images have good dimensional effectiveness, which suggests that even thinner bone, such as alveolar bone, can be accurately evaluated. Therefore, we used CBCT images to examine the relationship between tooth movement and change in alveolar bone.

**Movement of the central incisor**

The vertical movement of the incisal edge (E1-E2) ranged from −2.84 to 2.87 mm; intrusion or extrusion occurred in 16 of the 33 patients. Distal movement of the incisal edge was observed in most participants (0.00-13.17 mm), as 28 of the 33 patients had undergone extractions, and anterior expansion did not occur even in non-extraction cases. Intrusive movement was slightly greater and horizontal movement was smaller at the cervical point (C1-C2) than at the incisal edge (E1-E2) (Table 1). These results indicate that the typical maxillary central incisor moved distally and intruded.

**Change in the alveolar bone crest**

The change in the median alveolar bone crest was similar to that for C1-C2 and approximately half that for E1-E2 (Tables 1, 2).

Analysis of the distance from the CEJ to the alveolar bone crest showed that the distances to the labial and palatal alveolar bone crest changed from 1.45 mm (T1) to 1.80 mm (T2), and from 1.20 mm (T1) to 1.25 mm (T2), respectively, after orthodontic treatment (Table 2). Ezawa et al. (17) investigated anatomical features of alveolar bone (the thickness of labiolingual socket walls) near upper central incisors and reported that labial thickness was lowest at the point 1 mm from the alveolar bone crest (mean, 0.52 mm). Lingual thickness was greater on the labial side (0.75 mm). Lower labial thickness may be a reason why our data indicate that alveolar bone decreased only on the labial side. Boyle et al. (21) used X-ray radiography to investigate bone loss in clinically healthy individuals aged 11 to 70 years and found that it was only 0.017 mm per year. Therefore, the decrease in the alveolar bone crest attributable to orthodontic treatment was much greater than that associated with physiological change.

Analysis of the distance from the ANS to the alveolar bone crest showed that the amount of alveolar bone change was similar to that at C1-C2, which indicates that changes in the alveolar bone crest can be estimated by measuring C1-C2 (Tables 1, 3).

**Relationship between tooth movement and change in the alveolar bone crest**

Intrusion of the central incisor reduced the distance between the CEJ and the labial alveolar bone crest, which contradicted our expectations. Castro et al. (22) reported that the distance from the CEJ to the alveolar crest was not changed by orthodontic treatment of upper incisors. These differences in outcomes are likely a result of differences in the patients studied. Castro et al. studied non-extraction cases.

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**Table 4** Extent of tooth movement and change in alveolar bone crest

| Tooth movements | Change in alveolar bone crest | Change from CEJ | Change from ANS |
|-----------------|------------------------------|----------------|----------------|
|                 | Median | Vertical | Horizontal (distal) | Vertical | Palatal (n = 52) | Horizontal (distal) | Vertical | Palatal (n = 52) |
|                 | n = 33 | Labial (n = 66) | Palatal (n = 66) | Labial (n = 52) | Palatal (n = 52) | Labial (n = 52) | Palatal (n = 52) |
| Vertical Incisal edge | 0.072 | 0.464** | 0.208 | −0.540** | −0.405** | 0.001 | 0.028 |
| Cervical | −0.004 | 0.400** | 0.215 | −0.884** | −0.702** | 0.094 | 0.311* |
| Horizontal Incisal edge | 0.724** | 0.117 | −0.211 | −0.058 | −0.474** | 0.703** | 0.656** |
| Cervical | 0.448** | 0.093 | −0.12 | −0.172 | −0.504** | 0.822** | 0.970** |

*P < 0.05, **P < 0.01, CEJ: cementoenamel junction, ANS: anterior nasal spine
cases, whereas most of our patients had undergone extractions. Non-extraction cases have less tooth movement than do extraction cases. Lund et al. (23) investigated patients who had undergone extractions and reported that the alveolar bone crest in the incisor area decreased on the medial, buccal, and palatal sides. Thus, the amount of tooth movement is clearly related to changes in the alveolar bone.

The distances from the ANS to the extruded central incisor and labial and palatal alveolar bone crests tended to increase (Table 4). Changes in the distance from the CEJ when the incisors extruded indicate that tooth movement and change in alveolar bone increased, but not at a 1:1 ratio. Studies of monkey upper incisors (23-26) indicate that, in extrusion cases, changes in the alveolar bone represented approximately 80% of the extent of tooth movement, whereas bone and tooth changes were similar in degree in intrusion cases. The present results show a similar tendency. Horizontally, distal movement of the central incisors increased, the palatal alveolar bone crest tended to decrease, and the labial and palatal alveolar bone crest tended to move distally (Table 4).

Our results thus show that the alveolar bone crest was decreased by orthodontic treatment. When incisors were intruded, the distance from the CEJ to the alveolar bone crest decreased, and alveolar bone seemed to increase. However, when the incisors were extruded, that distance increased. Gingival recession may frequently occur, because the alveolar bone crest tends to decrease when incisors are extruded and move distally.

Some studies reported that relapse may develop immediately after treatment when the alveolar bone crest is decreased, because bone reformation on the tension side remains insufficient (27,28). Therefore, careful consideration of patient age, the magnitude of orthodontic force, and the speed of tooth movement is necessary in order to reduce alveolar bone recession. In cases of major alveolar bone changes on post-treatment CBCT images, an extension of the retention period—to recover the original alveolar bone height and prevent relapse—should be considered.

In conclusion, lingual movement of the incisors reduced the labial, but not the lingual, alveolar bone crest. In addition, greater lingual and extrusive movement of the incisors further decreased alveolar bone. Therefore, incisor tooth movement should be decreased when pre-treatment CBCT images indicate reduced alveolar bone level.

Conflict of interest
The authors declare no conflicts of interest.
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