Abstract: We investigated the effects of proximity of the root apex to the maxillary labial cortical plate, palatal cortical plate, and incisive canal cortical plate on apical root resorption. Cone-beam computed tomography was used to measure the amount of root resorption and root apex movement around maxillary right and left central incisors in 30 adults who underwent four-bicuspid extraction followed by treatment with multibracket appliances. The patients were divided into three groups on the basis of the direction of root apex movement, after which the correlation between the amount of root resorption and root apex movement was determined. Mean apical root resorption was 1.80 ± 0.82 mm (range, 0.18-3.96 mm). The amount of root apex movement was positively correlated with the amount of root resorption on the side of pressure. Root apex proximity to the maxillary labial cortical plate, palatal cortical plate, and incisive canal cortical plate was associated with apical root resorption. Orthodontic treatment plans should carefully consider root proximity to the maxillary cortical plate. (J Oral Sci 58, 231-236, 2016)

Keywords: apical root resorption; cortical plate; incisive canal cortical plate; cone-beam computed tomography.

Introduction

Root resorption after orthodontic treatment is an unfavorable iatrogenic disorder. Ketcham et al. (1) first reported apical root resorption accompanying orthodontic treatment, in the 1920s. Since then, a number of studies have investigated factors related to root resorption (2-8). Brezniak et al. (3) reviewed more than 120 reports on root resorption associated with orthodontic treatment and classified the putative causes as biological factors, mechanical factors, and complex factors. They explained that this system was necessary because of the considerable variety of classifications used in previous reports. Makedonas et al. (7) reported that apical root resorption was more frequent in maxillary teeth, particularly incisors. Another study (5) reported that apical root resorption of upper incisors was related to decreasing alveolar bone width and proximity to the cortical plate and root apex.

Handelman et al. (4) described the maxillary cortical plate as “orthodontic walls”—an anatomical limit to the leveling of the upper incisor root apex during orthodontic treatment. These orthodontic walls are considered a danger zone because of the increased risk of iatrogenic root resorption. Kaley et al. (2) reported that the quantity of apical root resorption significantly increased when the root apex was close to the palatal cortical plate during orthodontic treatment. Proximity of the root apex to the maxillary labial cortical plate and incisive canal cortical plate may also affect apical root resorption. However, to our knowledge no report has described root resorption in relation to proximity to the maxillary labial cortical plate and incisive canal cortical plate.

We therefore investigated the effects on apical root
resorption of proximity of the root apex to the maxillary labial cortical plate, incisive canal cortical plate, and palatal cortical plate. Two-dimensional evaluation using periapical radiography and panoramic radiography has been used to assess root resorption. However, in periapical radiography, the accuracy of tooth length measurement is affected by the angle formed by the tooth axis and the film (9,10). One report (11) found that apical root resorption after orthodontic tooth movement was underestimated when evaluated on panoramic radiography. Cone-beam computed tomography (CBCT) is a useful diagnostic method that complements conventional radiography. In the present study, CBCT was used to measure labial and palatal movement of the root apex in patients who underwent four-bicuspid extraction followed by treatment with multibracket appliances. Correlations between movement of the root apex and the amount of root resorption were estimated. Apical root resorption was measured by comparing CBCT images before and after orthodontic treatment. CBCT images were obtained at pre- and post-treatment examinations for orthodontic diagnosis were evaluated (3DX Multi Image Micro CT FP-D8, Morita, Kyoto, Japan; 90 kV, 7.0 mA, 0.125 mm voxel size). CBCT images were reconstituted using proprietary viewer software (i-VIEW, Morita). Then, using a scaler, we utilized Adobe Photoshop Elements 12 to analyze the measurements. The research protocol was approved by the ethical review board of Nihon University School of Dentistry (EP2012-1). All experiments on human subjects were conducted in accordance with the Declaration of Helsinki, and all procedures were carried out with the adequate understanding and written consent of all participants.

**Measurement of apical root resorption**

First, CBCT images of the maxillary central incisors obtained before and after orthodontic treatment were superimposed and aligned by using the labial and palatal cement-enamel junctions (CEJ) (Fig. 1A). Next, the amount of apical root resorption was calculated as the distance between the root apex before and after orthodontic treatment on the tooth axis of the central incisor (Fig. 1B-a). The area of root resorption was measured using image-processing software (Photoshop Elements 12, Adobe Systems, Tokyo, Japan) and classified as labial and palatal after identifying the tooth axis. The ratio of labial root resorption was defined as the ratio of the area of labial root resorption to the whole root resorption area (a/b+c), and the ratio of palatal root resorption was defined as the ratio of the area of palatal root resorption to the whole root resorption area (c/b+c).

**Materials and Methods**

**Patient selection and CBCT scan setup**

We examined 30 adults (8 males and 22 females; mean age, 21 years 11 months ± 5 years 10 months) who underwent four-bicuspid extraction followed by treatment with multibracket appliances around the maxillary right and left central incisors. Patients with endodontically treated teeth, immature tooth apices, or maxillary centrally impacted supernumerary teeth were excluded. CBCT images were obtained at pre- and post-treatment examinations for orthodontic diagnosis were evaluated (3DX Multi Image Micro CT FP-D8, Morita, Kyoto, Japan; 90 kV, 7.0 mA, 0.125 mm voxel size). CBCT images were reconstituted using proprietary viewer software (i-VIEW, Morita). Then, using a scaler, we utilized Adobe Photoshop Elements 12 to analyze the measurements. The research protocol was approved by the ethical review board of Nihon University School of Dentistry (EP2012-1). All experiments on human subjects were conducted in accordance with the Declaration of Helsinki, and all procedures were carried out with the adequate understanding and written consent of all participants.
root resorption (Fig. 1C-c) to the area of resorption for the whole root.

**Measurement of root apex movement**

First, CBCT images were superimposed on maxillary alveolar bone, using the positions of the anterior nasal spine (ANS) and the bottom of the maxillary bone in the nasal cavity. During measurement of root apex movement, the position of the root apex is affected by root movement as well as root resorption. Thus, we estimated the position of the root apex after tooth movement by replacement of CBCT images before tooth movement, as described by Baumrind et al. (12), who measured “pure” root apex movement using this replacement technique with CBCT images (Fig. 2).

**Classification**

The patients were divided into three groups according to the direction of root apex movement. In the labial movement (LM) group (9 patients with maxillary central incisors on both sides; \( n = 18 \)), the root apex of the maxillary central incisors moved labially (Fig. 3A). In the palatal movement (PM) group (16 patients with maxillary central incisors on both sides; \( n = 32 \)), the root apex moved palatally (Fig. 3B). Patients in the midline shift (MS) group (5 patients with maxillary central incisors on both sides; \( n = 10 \)) were classified after determination of an observation section, i.e., the horizontal plane at the posterior border of the incisive canal opening (Fig. 4A-a). On the observation section, we measured the distance from the midline sagittal plane, which proceeds along the ANS (Fig. 4B-b), to the center of the right and left maxillary central incisors (Fig. 4B-c). The overall mean distance, \( d \) (Fig. 4B-d), was 0.50 ± 0.61 mm. The MS group comprised patients with values greater than 1 SD above the mean.

**Statistical analysis**

All measurements were repeated after 2 weeks, to ensure reproducibility. Spearman rank-correlation coefficients were calculated to assess the relationship between the amount of apical root resorption and either root movement. Differences in the amount of mesial and distal root resorption in the MS group were evaluated by the Wilcoxon signed-rank test. All analyses were performed using SPSS (ver. 16.0; SPSS Japan, Tokyo, Japan).

**Results**

To evaluate measurement error, CBCT images of the apical root resorption, area of root resorption, and root apex movement were measured twice, with an interval of 2 weeks. There were no significant differences between the first and second measurement values.
Apical root resorption (30 patients with maxillary central incisors on both sides; \( n = 60 \)) was 1.80 ± 0.82 mm (range, 0.18-3.96 mm) (Table 1). In the LM group (\( n = 18 \)), root apex movement was 0.63 ± 0.61 mm and apical root resorption was 1.67 ± 0.89 mm. In the PM group (\( n = 32 \)), root apex movement was 2.07 ± 1.80 mm and apical root resorption was 1.80 ± 0.82 mm (Table 2). The amount of apical root resorption was not associated with age, sex, treatment period, Angle’s classification, or cephalogram values.

In the LM group, root apex movement was significantly correlated with area of labial root resorption (\( r = 0.66, P < 0.01 \)) and area of whole root resorption (\( r = 0.60, P < 0.01 \)). In the PM group, root apex movement was significantly correlated with area of whole root resorption (\( r = 0.60, P < 0.01 \)), area of labial root resorption (\( r = 0.52, P < 0.01 \)), and area of palatal root resorption (\( r = 0.62, P < 0.01 \)) (Table 3).

The ratio of labial root resorption (50%) was equal to the ratio of palatal root resorption (50%) in the LM group. The ratio of labial root resorption was significantly greater in the LM group (50%) than in the PM group (42%) (\( P < 0.05 \)), and the rate of palatal root resorption was significantly greater in the PM group (58%) than in the LM group (50%) (\( P < 0.05 \)) (Fig. 5).

In the MS group (\( n = 10 \)), the distance of midline shift (Fig. 4B-d) was 1.66 ± 0.22 mm. The amount of apical root resorption was 2.49 ± 0.61 mm on the side proximate to the incisive canal and 1.51 ± 0.49 mm on the contralateral side (\( P < 0.05 \)) (Table 4). The rate of palatal root resorption (62%) on the proximate side was significantly greater than that on the contralateral side (51%) (\( P < 0.05 \)) (Fig. 6).

**Discussion**

Apical root resorption is an important problem that affects outcomes of orthodontic treatment. Previous studies have identified a number of factors that may be associated with apical root resorption, including age (13,14), sex (15), treatment period (13,15), tooth type

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**Table 1** Apical root resorption in the participants

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.80</td>
<td>0.82</td>
<td>3.96</td>
<td>0.18</td>
</tr>
</tbody>
</table>

\( n = 60 \), Unit: mm

**Table 2** Amount of root apex movement and apical root resorption in the LM and PM groups

<table>
<thead>
<tr>
<th>Direction of root apex movement</th>
<th>Root movement</th>
<th>Root resorption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>LM</td>
<td>0.63</td>
<td>0.61</td>
</tr>
<tr>
<td>PM</td>
<td>2.07</td>
<td>1.80</td>
</tr>
</tbody>
</table>

Unit: mm, LM: Labial movement group, PM: Palatal movement group

**Table 3** Correlations between direction of root apex movement and area of root resorption

<table>
<thead>
<tr>
<th>Direction of root apex movement</th>
<th>Area of whole root resorption</th>
<th>Area of labial root resorption</th>
<th>Area of palatal root resorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM</td>
<td>0.48**</td>
<td>0.66**</td>
<td>0.42**</td>
</tr>
<tr>
<td>PM</td>
<td>0.60**</td>
<td>0.52**</td>
<td>0.62**</td>
</tr>
</tbody>
</table>

\(*P < 0.05\), \(**P < 0.01\)

**Table 4** Amount of mesial and distal root resorption in the MS group

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesial</td>
<td>2.49</td>
</tr>
<tr>
<td>Distal</td>
<td>1.51</td>
</tr>
</tbody>
</table>

Unit: mm, *\( P < 0.05 \)

Mesial: side proximate to the incisive canal of the central incisor, Distal: side contralateral to the incisive canal of the central incisor

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![Fig. 5](image-url) Rate of labial and palatal root resorption, according to direction of root apex movement.

![Fig. 6](image-url) Rate of labial and palatal root resorption on the mesial and distal sides of the incisive canal in the MS group.
(16), root apex form (14,17), tooth extraction (18-20), amount of tooth movement (19,21,22), and presence of endodontically treated teeth (17). Root apex contact with the cortical plate is another putative factor in apical root resorption (2,4,5). The present study carefully evaluated the relationship between root apex proximity to the cortical plate and root resorption.

Periapical radiography and panoramic radiography have been used to measure apical root resorption after orthodontic treatment. However, one report (23) found that areas of buccal and lingual root resorption could not be observed with two-dimensional images. Another study (11) reported that panoramic radiography underestimated apical root resorption after orthodontic tooth movement. Therefore, we used CBCT to evaluate apical root resorption. In addition to conventional linear measurements, the amounts of palatal and labial root resorption were calculated.

Image-processing software was used to measure the amount of root resorption, using CBCT images obtained before and after orthodontic treatment. In addition, the area of root resorption was evaluated by painting over the resorbed region of the root and counting the number of involved pixels, as previously described (24). Local root resorption was carefully evaluated on the lingual and labial sides, and the ratio to the area of whole root resorption was calculated. To ensure accurate measurement of root apex movement, we estimated the position of the root apex after tooth movement by replacement of CBCT images before tooth movement, as previously described (12).

The patients were classified according to the direction of root apex movement. In this manner, we were able to examine the characteristics of apical root resorption, which depends on the effects of root apex movement and proximity to the labial and palatal cortical plates.

In the LM group, in which the root apex moved labially, root proximity to the labial cortical plate induced labial root resorption. In the PM group, in which the root apex moved palatally, root proximity to the palatal cortical plate induced palatal root resorption. Therefore, the amount of root apex movement was positively correlated with the amount of root resorption on the side of pressure. In addition, we investigated local root resorption on the labial and lingual sides, and the ratio to the area of whole root resorption was calculated according to the direction of tooth movement. The ratios of palatal and labial root resorption indicated that root apex proximity to the cortical plate induced partial apical root resorption on the proximate side.

Horiuchi et al. (5) reported that apical root resorption of maxillary central incisors was associated with root proximity to the palatal cortical plate during orthodontic treatment. Kaley et al. (2) reported that in Class III patients root resorption was severe when the root apex was proximate to the palatal cortical plate. The authors hypothesized that maxillary incisors tip forward to compensate for the Class III jaw relationship and that the roots are forced against the palatal cortical plate during orthodontic treatment. Our results also suggest that root apex proximity to the cortical plate is a factor in root resorption on the side of pressure.

In the MS group, root resorption was significantly greater on the side proximate to the incisive canal than on the contralateral side. In addition, the rate of palatal root resorption on the proximate side was significantly greater than that on the distal side. The difference between right and left resorption in maxillary central incisors might be related to the proximity of the root apex to the incisive canal cortical plate. Partial apical root resorption was observed along the incisive canal cortical plate on CBCT images (Fig. 4A). Like root proximity to the labial and palatal cortical plates, root apex proximity to the incisive canal cortical plate may be a factor in apical root resorption.

The present findings highlight the importance of clinical examination of the relationships of root apex position with the labial, palatal, and incisive canal cortical plates. Treatment plans should consider the direction of tooth movement and root proximity to the maxillary cortical plate, in the event premolar extraction is necessary.

In conclusion, the amount of root apex movement was positively correlated with the amount of root resorption on the side of pressure. In addition, root apex proximity to the maxillary labial cortical plate and palatal cortical plate was associated with root resorption on the side of pressure. Finally, root apex proximity to the incisive canal cortical plate is a factor affecting apical root resorption.

Acknowledgments
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References
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