

Comparison of root resorption after bone-borne and tooth-borne rapid maxillary expansion evaluated with the use of microtomography

Mucahid Yildirim^a and Mehmet Akin^b

Konya and Antalya, Turkey

Introduction: Root resorption was compared between bone-borne and tooth tissue-borne rapid maxillary expansion patients with the use of microtomography. **Methods:** The study included 20 patients (ages 11–16 years) requiring fixed orthodontic treatment who underwent extraction of their first premolars after rapid maxillary expansion with the use of modified appliances. One side of the appliance covered the teeth with acrylic, while the other side was fixed to the palatal bone by means of a miniscrew. After 3 months' retention, the appliance was removed and teeth were extracted and examined with the use of microtomography. **Results:** When the apical, middle, and cervical thirds, as well as the buccal and lingual sides, were compared, the volume loss was significantly higher in the tooth tissue-borne group than in the bone-borne group ($P < 0.01$). The least volume loss occurred on the cervical third lingual surface in the tooth tissue-borne group and on the middle third buccal surface in the bone-borne group. In the former group, least resorption occurred on the cervical third and highest resorption on the buccal side. In the latter group, surfaces showed no significant changes. **Conclusions:** More root resorption occurred in the tooth tissue-borne group, mostly in the apical and middle thirds. The amount of resorption on the buccal surface was higher than that on the lingual surface. (Am J Orthod Dentofacial Orthop 2019;155:182-90)

An abnormal buccolingual relationship between the buccal tubercles of maxillary teeth and those of the mandibular teeth is expressed as posterior crossbite.¹ Rapid maxillary expansion (RME), used in the treatment of posterior crossbite, is a treatment method with important orthopedic and orthodontic effects. In this method, midpalatal suture separation and buccal tipping over the alveolar base in the teeth are observed after the expansion force is applied to the maxilla. Thus, an expansion occurs in the transversal direction in the upper arch and in the basal bone bearing the

alveolar base. The orthopedic effect obtained with the separation of the midpalatal suture results from applying a strong force (unilateral 0.9–4.5 kg) over a short period of time.² However, because of the heavy forces required to open the midpalatal suture, buccal tipping and gingival recession may occur in the abutment teeth and palatal mucosa, and fenestration in the buccal bone and resorption in the abutment teeth may occur as well.³ The idea of expanding the maxilla by providing only bone support has been suggested by researchers to minimize such side-effects.³⁻⁵

Tooth root resorption occurring after orthodontic tooth movement is observed as root shortening in the apical regions on x-ray images.⁶ To date, researchers have examined the root resorption occurring after orthodontic treatment with the use of 2-dimensional radiographic methods,⁷ histologic methods,⁸ scanning electron microscopy (SEM),⁹ cone-beam computerized tomography (CBCT),^{10,11} and microtomography (micro-CT).¹² It is difficult to acquire accurate results via 2-dimensional examinations of 3-dimensional (3D) resorption lacunas, although there are advantages in using this approach, namely, panoramic and periapical radiographs are commonly

^aDepartment of Orthodontics, Faculty of Dentistry, Konya Necmettin Erbakan University, Konya, Turkey.

^bDepartment of Orthodontics, Faculty of Dentistry, Alanya Alaaddin Keykubat University, Antalya, Turkey.

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Address correspondence to: Mucahid Yildirim, Ortodonti AD, Necmettin Erbakan Üniversitesi Diş Hekimliği Fakültesi, 42050, Karatay/Konya, Turkey; e-mail, mucahidyildirim@konya.edu.tr.

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available, can be used in vivo, and deliver only low doses of radiation.⁶ There are disadvantages to the use of SEM, such as the need for advance preparation and damage to the dental tissue during such preparations,¹³ the need for the extraction of teeth for examination,¹¹ and the impossibility of obtaining volume measurements.¹⁴ Although with the use of CBCT, images are obtained quickly, have high resolution, and result in a minimal radiation dose compared with conventional tomography, they have drawbacks, such as high cost, the presence of methods by which higher-resolution images can be obtained, their inadequacy for the monitoring of dental morphology, and the fact that they are affected by metal artifacts.¹⁵ Micro-CT, which is regarded as the successor to histologic examination and which also allows detailed 3-dimensional imaging of hard tissues, is rapidly becoming the criterion standard for examining the morphology and contents of hard structures, such as bone, teeth, and microimplants. Simultaneously, compared with a conventional microscope, which can examine only 2-dimensional images, micro-CT allows 3-dimensional microscopic imaging.¹³ The need for extraction of the tooth to allow micro-CT examination is the primary disadvantage of the method.¹¹

The aim of the present study was to examine the amount of root surface resorption occurring in patients who underwent bone-borne and tooth-borne RME using a micro-CT device on the premolar teeth that were extracted after the retention period; and to compare it with previously published results.

MATERIAL AND METHODS

This study was approved by the Ethics Committee of the Selcuk University Faculty of Medicine (Number: 2015/28). Patients and their parents provided written informed consents after having received detailed information about the treatment.

The G-Power power analysis program (version 3.1.2; Franz Faul Universitat, Kiel, Germany) was used to determine the number of patients required. With the use of a 0.30 effect size, $\alpha = 0.05$ significance level, 2 groups, and 2 repetitive measurements, the sample size was 20 patients, with an 86% power.

In total, 20 participants (11 female and 9 male, overall mean age 14.31 ± 1.36 years), who applied to our department for treatment, were included in this study. The inclusion criteria are listed in [Table I](#).

Patients were primarily treated with the use of a modified RME appliance. One side of this modified appliance covers the teeth with acrylic, and the other side of the appliance is fixed to the palatal bone with a screw ([Fig 1](#)). Furthermore, although the occlusal region was covered with acrylic on the bonded RME side of the

Table I. Inclusion criteria

| |
|--|
| Patients aged 11-16 years |
| No previous orthodontic treatment |
| Insufficiency in the transverse direction in the maxillary apical base |
| Indication for extraction of the upper first premolar teeth during fixed treatment to be performed after rapid maxillary expansion |
| Indication for extraction of upper first premolar teeth during fixed treatment to be performed after rapid maxillary expansion |
| Good oral hygiene |
| Absence of any oral or systemic disease |
| Absence of a history of continuous drug use and smoking |

appliance, the tooth surface was left open on the side where the miniscrew was applied. Patients were fitted with this unilateral occlusion elevated mandibular Essix plate to prevent expansion of teeth in this region ([Fig 2](#)). Before manufacturing this appliance, Neoanchor Plus (KJ Meditech, Seoul, South Korea) miniscrews of 1.6-10 mm were applied with an angle of 15° - 20° with the occlusal plane 6-8 mm beyond the palatal gingival margin of the second premolar and first molar in the palatal region on one side. After the expansion process, the hyrax screw was stabilized with the use of a ligature wire. The acrylic appliance was left in the mouth for 3 months ([Fig 3](#)). After this period, the appliance was removed, and fixed orthodontic treatment was started. The extracted teeth were placed in deionized water. The teeth were subsequently examined with the use of a high-definition micro-CT device (Scanco Medical μ CT 50; Bassersdorf, Switzerland) and the amount of root resorption was calculated from 3D images with the use of the Mimics program (Materialise, Leuven, Belgium; [Fig 4](#)). The roots were vertically separated into the buccal and lingual regions, horizontally separated into the cervical, middle, and apical third regions with the use of the Mimics program, and these surfaces were examined. Simultaneously, the roots segmented in this manner were also examined on 6 surfaces: the apical third buccal (AB), apical third lingual (AL), middle third lingual (ML), middle third buccal (MB), cervical third lingual (CL), and cervical third buccal (CB) surfaces ([Fig 5](#)). Examinations were performed on the basis of not only absolute volume loss, but also percentage change. The total volumes of the root surfaces, the crater volumes of which were filled, and their crater volumes were calculated with the use of the Mimics program; the percentage value was obtained, and further comparisons were made.

Because this study was a thesis study, the first investigator measured half of the samples in both groups again in the Mimics program after 3 weeks. The same measurements were repeated by the second investigator. Inter- and intra-author correlations were observed to be >0.992 .

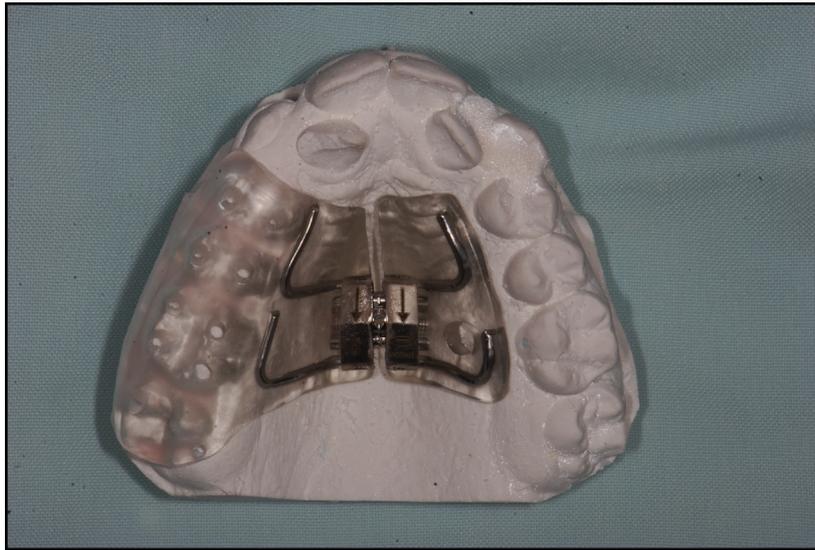


Fig 1. Modified rapid maxillary appliance design.



Fig 2. Mandibular Essix appliance.

Data analyses were performed with the use of the Statistical Package for Social Sciences (SPSS 17.0; Chicago, Ill). The normality of the data was assessed with the use of the Shapiro-Wilk test, and it was determined that the data did not fit the assumptions of normality. Therefore, nonparametric tests were used in the analyses. In this study, the Mann-Whitney U test, Kruskal-Wallis test, and Dunn test were used for the

statistical analyses. P values of <0.05 were considered to indicate statistically significant differences.

RESULTS

Intragroup comparisons

The results of intragroup evaluation of the volume differences (mm^3) on the surfaces are presented in



Fig 3. **A,** Just after the expansion appliances were placed. **B,** At the end of expansion treatment. **C,** After the removal of the expansion appliances.

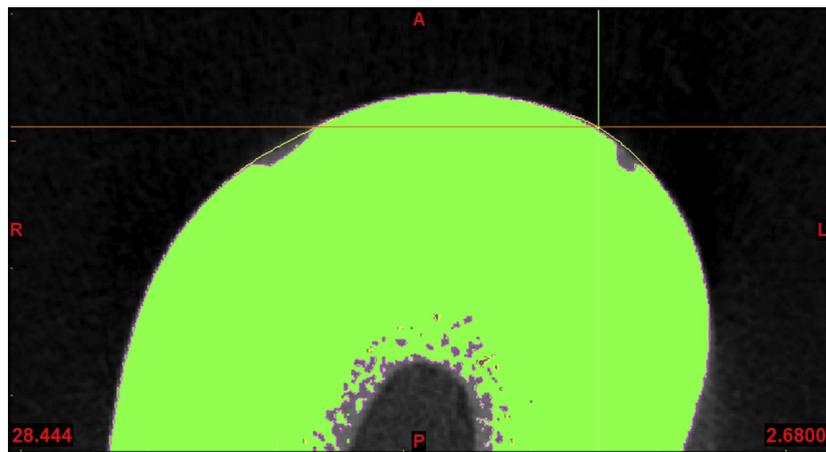


Fig 4. Determining the amount of root resorption on software program.

Table II. According to the findings obtained, the volume losses on the AB surface and MB surface were significantly different from that of the CL surface ($P < 0.001$) in the tooth-borne RME group. No significant differences were observed among the other surfaces ($P > 0.05$). In the bone-borne group, the volume losses on the AL surface and on the MB surface were significantly different ($P < 0.01$).

The total volume losses occurring on the apical, middle, and cervical thirds and the buccal and lingual surfaces in the tooth tissue-borne group are compared in **Table III**. The volume losses occurring in the apical and middle third were significantly more than that occurring in the cervical third ($P < 0.01$). There was significantly less volume loss on the lingual surface than on the buccal surface ($P < 0.01$). When the same surfaces

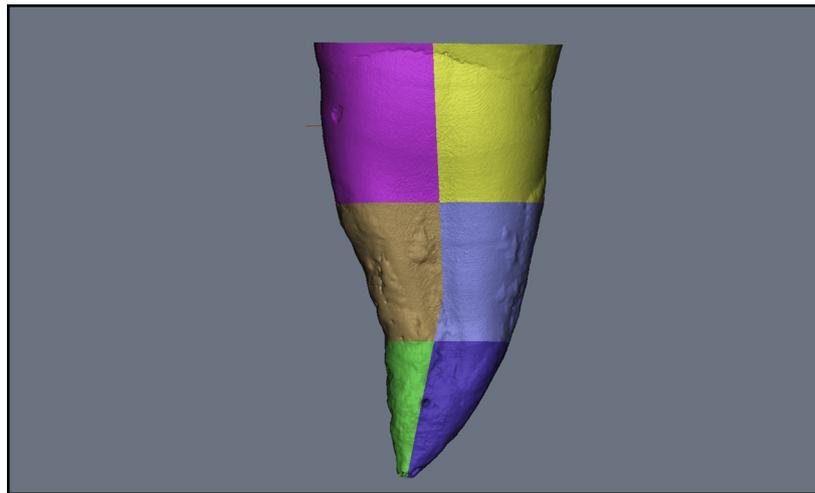


Fig 5. Segmentation of root into 6 pieces.

Table II. Results of Kruskal-Wallis tests, used to compare intragroup crater volumes (mm^3), and Dunn tests, for multiple comparisons

| Group | Surface | Mean | SD | Median | Min | Max | P value | Multiple comparison |
|--------------------|---------|-------|-------|--------|-------|-------|--------------------|---------------------|
| Tooth tissue-borne | AL | 0.359 | 0.395 | 0.290 | 0.000 | 1.700 | <0.001* | – |
| | AB | 0.511 | 0.430 | 0.510 | 0.020 | 1.500 | | CL |
| | ML | 0.347 | 0.522 | 0.015 | 0.000 | 1.430 | | – |
| | MB | 0.676 | 0.637 | 0.480 | 0.000 | 1.980 | | CL |
| | CL | 0.055 | 0.070 | 0.015 | 0.000 | 0.180 | | AB, MB |
| | CB | 0.300 | 0.513 | 0.070 | 0.000 | 1.450 | | – |
| Bone-borne | AL | 0.025 | 0.019 | 0.020 | 0.000 | 0.050 | 0.010 [†] | MB |
| | AB | 0.050 | 0.080 | 0.015 | 0.000 | 0.240 | | – |
| | ML | 0.019 | 0.037 | 0.000 | 0.000 | 0.120 | | – |
| | MB | 0.009 | 0.018 | 0.000 | 0.000 | 0.060 | | AL |
| | CL | 0.010 | 0.021 | 0.000 | 0.000 | 0.070 | | – |
| | CB | 0.015 | 0.026 | 0.000 | 0.000 | 0.080 | | – |

P < 0.05 was considered to indicate statistical significance: **P* < 0.001; [†]*P* < 0.01. AL, Apical third, lingual side; AB, apical third, buccal side; ML, middle third, lingual side; MB, middle third, buccal side; CL, cervical third, lingual side; CB, cervical third, buccal side.

were examined in the bone-borne group, there was no significant difference between the volume losses on the various surfaces ($P > 0.05$).

Intergroup comparison findings

A comparison of root resorption in the 6 regions among the groups is presented in Table IV. The amounts of volume losses on the MB, AB, AL, ML, and CB surfaces were significantly greater in the tooth tissue-borne group than in the bone-borne group ($P < 0.05$). Only the amount of volume loss occurring on the CL surface was not significantly different between the 2 groups ($P > 0.05$).

The results obtained when the root surfaces were examined as apical, middle, and cervical thirds are presented in Table V. The amount of volume loss

occurring on each surface was significantly greater in the tooth tissue-borne group than in the bone-borne group ($P < 0.05$). However, the amount of volume loss was significantly greater in the middle and apical thirds than in the cervical third. The buccal and lingual sides of the roots are also presented in Table V. The amount of volume losses occurring on the buccal and lingual surfaces were significantly greater in the tooth tissue-borne group than in the bone-borne group ($P < 0.05$).

The total root resorption volumes occurring in the roots of the teeth are listed in Table VI. According to these evaluations, whereas the average volume loss was 2.249 mm^3 on the bone-borne side, it was determined to be 0.128 mm^3 on the tooth tissue-borne side. When the total tooth volume was compared with the resorption volume, this ratio was found to be 6.285% on the tooth tissue-borne side and 0.392% on

Table III. Results of Kruskal-Wallis (and Dunn for multiple comparisons) and Mann-Whitney *U* tests used for intra-group comparison of volume losses (mm³) occurring on the apical, middle, and cervical thirds and the lingual and buccal surfaces for tooth tissue–supported and bone-supported sides

| Group | Surface | Mean | SD | Median | Min | Max | P value | Multiple comparison | |
|--------------------|---------|-------|-------|--------|-------|-------|---------|---------------------|-------|
| Tooth tissue–borne | A | 0.871 | 0.720 | 0.745 | 0.020 | 3.020 | 0.008* | C | |
| | M | 1.023 | 1.047 | 0.715 | 0.000 | 2.910 | | C | |
| | C | 0.355 | 0.535 | 0.135 | 0.000 | 1.580 | | A, M | |
| | L | 0.761 | 0.667 | 0.560 | 0.000 | 2.200 | | 0.010 [†] | |
| | B | 1.487 | 1.112 | 1.265 | 0.060 | 4.230 | | | |
| Bone–borne | A | 0.075 | 0.094 | 0.050 | 0.000 | 0.290 | 0.059 | – | |
| | M | 0.028 | 0.045 | 0.000 | 0.000 | 0.140 | | | |
| | C | 0.025 | 0.030 | 0.010 | 0.000 | 0.080 | | | |
| | L | 0.054 | 0.051 | 0.040 | 0.000 | 0.150 | | | 0.640 |
| | B | 0.074 | 0.083 | 0.040 | 0.000 | 0.240 | | | |

P* < 0.01; [†]*P* < 0.05.Table IV.** Results of Mann-Whitney *U* tests used to compare volume losses (mm³) occurring on the surfaces on bone- and tooth tissue–borne sides

| Surface | Tooth tissue–borne | | | | Bone–borne | | | | P value |
|---------|--------------------|-------|-------|-------|------------|-------|-------|-------|---------------------|
| | Mean | SD | Min | Max | Mean | SD | Min | Max | |
| AL | 0.359 | 0.395 | 0.000 | 1.700 | 0.025 | 0.019 | 0.000 | 0.050 | 0.001* |
| AB | 0.511 | 0.430 | 0.020 | 1.500 | 0.050 | 0.080 | 0.000 | 0.240 | <0.001 [†] |
| ML | 0.347 | 0.522 | 0.000 | 1.430 | 0.019 | 0.037 | 0.000 | 0.120 | 0.021 [‡] |
| MB | 0.676 | 0.637 | 0.000 | 1.980 | 0.009 | 0.018 | 0.000 | 0.060 | <0.001 [†] |
| CL | 0.055 | 0.070 | 0.000 | 0.180 | 0.010 | 0.021 | 0.000 | 0.070 | 0.157 [‡] |
| CB | 0.300 | 0.513 | 0.000 | 1.450 | 0.015 | 0.026 | 0.000 | 0.080 | 0.035 [‡] |

**P* < 0.01; [†]*P* < 0.001; [‡]*P* < 0.05.

the bone–borne side. Significantly more resorption was found on the tooth tissue–borne side than on the bone–borne side (*P* < 0.05).

DISCUSSION

In conventional RME methods, the applied forces are transmitted to the sutures by way of the teeth and palatal mucosa, thus leading to expansion. However, undesirable complications, such as buccal tipping, root resorption in the teeth, fenestrations in the buccal bone, and gingival recessions, may occur during this force transmission. To avoid these effects, orthodontists have introduced “bone–borne RME” appliances that receive support from the bone in the palatal region instead of from the teeth. Researchers have placed distractors on the bone with this method, but the use of distractors has not become widespread, because they are expensive, invasive, and unhygienic. Subsequently, various appliances have been designed that use noninvasive and cheap miniscrews, and they have become widely implemented.¹⁶

Root resorption occurring during tooth movement is affected by genetic¹⁷ and systemic¹⁸ factors. In the

present split-mouth study, the effect of 2 different methods on the roots was examined by inserting different appliances on the right and left sides of the same patient to minimize the possibility that individual differences would confound our results. Ho et al¹⁹ stated that the right and left upper first premolar teeth gave similar resorption results, such that these teeth can act as controls for each other. That investigation¹⁹ was taken into consideration in the planning of our study approach.

The regions where the maximum resorption was observed in the teeth on the side treated with tooth–borne RME were the MB and AB surfaces. The amount of resorption was significantly greater on those surfaces than on the CL surface. When we examined the teeth by separating them into 3 horizontal regions (apical, middle, and cervical thirds), it was found that most of the resorption occurred in the middle third, followed by the apical third, and the amount of volume loss was significantly more in those 2 regions than in the cervical third. When we analyzed the buccal and lingual surfaces separately, the amount of resorption was significantly more on the buccal surface than on the lingual surface. These findings are consistent with those of previous studies.^{8,20–22}

Table V. Results of Mann-Whitney *U* tests used to compare volume losses (mm³) occurring on the apical, middle, and cervical thirds and the lingual and buccal sides between the tooth tissue-borne and bone-borne groups

| Surface | | Tooth tissue-borne | | | | Bone-borne | | | | P value |
|---------|---|--------------------|-------|-------|-------|------------|-------|-------|-------|--------------------|
| | | Mean | SD | Min | Max | Mean | SD | Min | Max | |
| Third | A | 0.871 | 0.720 | 0.020 | 3.020 | 0.075 | 0.094 | 0.000 | 0.290 | <0.001* |
| | M | 1.023 | 1.047 | 0.000 | 2.910 | 0.028 | 0.045 | 0.000 | 0.140 | <0.001* |
| | C | 0.355 | 0.535 | 0.000 | 1.580 | 0.025 | 0.030 | 0.000 | 0.080 | 0.017 [†] |
| Side | L | 0.761 | 0.667 | 0.000 | 2.200 | 0.054 | 0.051 | 0.000 | 0.150 | <0.001* |
| | B | 1.487 | 1.112 | 0.060 | 4.230 | 0.074 | 0.083 | 0.000 | 0.240 | <0.001* |

P* < 0.001; [†]*P* < 0.05.Table VI.** Results of Mann-Whitney *U* tests used to compare the volumetric (mm³) and percentage (%) total volume losses occurring in teeth between the tooth tissue-borne and bone-borne groups

| Loss | Tooth tissue-borne | | | | Bone-borne | | | | P value |
|---------------------------|--------------------|-------|-------|--------|------------|-------|-------|-------|---------|
| | Mean | SD | Min | Max | Mean | SD | Min | Max | |
| Volume (mm ³) | 2.249 | 1.552 | 0.550 | 5.550 | 0.128 | 0.113 | 0.000 | 0.340 | <0.001* |
| Percentage (%) | 6.285 | 5.019 | 1.480 | 19.120 | 0.392 | 0.353 | 0.000 | 1.000 | <0.001* |

**P* < 0.001.

In the side treated with bone-borne RME, it was determined that significantly more resorption occurred on the AL surface (0.025 mm³) than on the MB surface (0.009 mm³). As presented in Table II, the maximum average value observed on the AB surface was 0.050 mm³. However, the probable reason for this change not reaching statistical significance is that the median value of the AB group (0.015 mm³) was lower than that of the AL group (0.020 mm³). Because the statistical analysis was performed with the use of nonparametric tests in this study, the group with the highest crater volume was determined by the median value, not the mean value. Consequently, when the bone-borne side was evaluated within the group, a higher amount of resorption was seen to occur on the AL and AB surfaces than on the other surfaces.

Segal et al²³ reported that the amount of root resorption occurring in the apical region was significantly more than in the middle and cervical regions. They observed that the amount of resorption occurring in the apical region of the tooth was directly associated with the amount of movement of this region within the bone. Feller et al²⁴ attributed the greater amount of root resorption in the apical region to the following reasons: the presence of a thicker and more rigid bone in the apical region, despite the presence of a thinner and more flexible bone structure in the cervical third region, the fact that the forces transmitted to the root during tooth movement were concentrated in a narrower region in the apical third region than in

the cervical third, and a greater force per unit of surface area.

The reason for the excessive resorption craters on the buccal surfaces is that the force was applied to the tooth in the buccal direction. Simultaneously, compression occurs on the buccal surfaces of the root, while tension occurs on the lingual surfaces. Root resorption may occur during the elimination of the hyalinization tissue on the compressed side.²⁵

In the between-group evaluations of the tooth roots in the 6 regions, the root resorption occurring on all surfaces, except for the CL surface, was significantly more on the tooth tissue-borne side than on the bone-borne side. The AB and MB surfaces showed greater changes between the tooth tissue-borne group and bone-borne group (*P* < 0.001). The lack of statistically significant differences in root resorption on the CL surface between the groups is likely because the CL surface was the least affected by the force.

When the amounts of root resorption on the apical, middle, and cervical third surfaces of the tooth tissue-borne and bone-borne groups were compared, the amount of root resorption on all surfaces was found to be significantly higher in the tooth tissue-borne group than in the bone-borne group. No significant differences were found on the buccal and lingual surfaces. These results are consistent with the findings of previous studies,^{4,10,26} which found that the resorption that may occur in the roots of the teeth may be reduced by means of RME appliances receiving

support from both teeth and tissues. Other researchers have designed novel RME appliances that receive support from miniscrews placed in the palatal region instead of receiving support from the teeth.^{3,27,28} They aimed to decrease the dental effects of RME treatment by removing the tooth support of the appliance, thus eliminating the forces that cause undesirable effects on the teeth. Some of these undesirable effects are buccal fenestration of the roots, buccal tipping of the teeth, gingival recession, and root resorption. Our results confirm the hypotheses of those researchers.

When the total volume losses occurring in the teeth were examined, the volume losses in this study were 2.249 mm³ and 0.128 mm³ in the tooth tissue-borne and bone-borne groups, respectively. The resorption rates determined by percentage were 6.285% in the tooth tissue-borne group and 0.392% in the bone-borne group. In previous studies, volume losses of 7.21%¹⁰ and 4.76%¹¹ were found in the first premolar teeth. The percentages of root resorption obtained in those studies were found to be similar to those of the tooth tissue-borne side in our study.

The 2D images of the teeth, obtained with the use of a micro-CT device, were reconstructed into 3D images with the use of the Mimics program. That program can calculate the whole root volume of the teeth by separating it into regions. The volume of the teeth was again calculated with the use of the same methods after the process of filling the resorbed areas. Thus, initial volumes can not be measured before treatment. To minimize the occurrence of this situation, individuals without previously orthodontic treated and systemic disease were included in our study. The resorption volumes found with the use of this program are calculated by filling only the resorption craters occurring in the roots of the teeth. Therefore, the resorption areas that may occur, especially in the buccal areas, are not crater shaped, but are more inclusive and distort the root contours. Furthermore, the root length shortening that may occur in the apical regions could not be evaluated in our study. In addition, the resorption that may be present in the teeth before the treatment can not be determined during drawing. Simultaneously, although the teeth were extracted by precise surgical methods and controlled after the extraction, the total volume of the teeth may have decreased by a small amount owing to possible fractures in the apical region that were too small to be seen. These are some of the factors that make it difficult to obtain precise results in calculating the volume of the resorbed regions. These are the main limitations of our methodology, which will persist

until technology for intraoral micro-CT imaging is developed.

CONCLUSIONS

In the tooth tissue-borne RME side, more resorption was observed on the buccal surface than on the lingual surface, and more resorption was observed in the apical and middle thirds than in the cervical third. In contrast, in the bone-borne RME side, root resorption was observed even though support was not provided by the teeth. However, this resorption was not exhibited in significant quantities. Significantly more root resorption occurred in the tooth tissue-borne RME treatment group than in the bone-borne RME group. When maxillary transverse deficiency was treated with the use of tooth tissue-borne RME, more root resorption occurred in the cervical, middle, and apical thirds and on the buccal and lingual sides than with the use of bone-borne RME. Bone-supported appliances for RME treatment may decrease the amount of potential root resorption, which represents an advantage compared with tooth tissue-borne appliances.

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