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Root Resorption after Orthodontic Intrusion and Extrusion:

An Intraindividual Study

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ABSTRACT

The aim of this investigation was to compare root resorption in the same individual after application of continuous intrusive and extrusive forces. In nine patients (mean age 15.3 years), the maxillary first premolars were randomly intruded or extruded with a continuous force of 100 cN for eight weeks. Eleven maxillary first premolars from six randomly selected orthodontic patients served as controls. Root resorption was determined using scanning electron microscopy. Quantitative assessment of the percentage of resorbed area of the total root surface was performed on composite micrographs. The severity of root resorption was also assessed by visual scoring of the roots. Root resorption mainly occurred at the apical part of the roots in both experimental groups. A significant difference in root resorption was found between the intruded and the control teeth ($P = .006$) but not between the extruded and the control teeth. However, the mesial and distal root surfaces showed resorption on $5.78 \pm 3.86\%$ of the root surface of the intruded teeth and $1.28 \pm 1.24\%$ of the root surface of the extruded teeth, and this difference was significant ($P = .004$). In addition, a large individual variation was found. From this study, it can be concluded that intrusion of teeth causes about four times more root resorption than extrusion. Because the amount of root resorption due to intrusion or extrusion in the same patient is correlated, every clinician should be aware that the extrusion of teeth might also cause root resorption in susceptible patients.

KEY WORDS: Orthodontics, Corrective, Tooth movement, Root resorption, Extrusion, Intrusion.

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Root resorption is a common iatrogenic consequence associated with orthodontic treatment. It has received considerable attention but the causes remain essentially unknown.¹ An extensive review by Brezniak and Wasserstein^{2,3} indicated that multiple factors are involved, such as genetic and systemic factors, sex, tooth movement type, orthodontic force magnitude, duration and type of force. Other authors categorized these risk factors as patient-related and treatment-related factors.⁴ Many recent studies aimed to elucidate the causal relationship between force application, tooth movement, and root resorption.^{5–9} Studies using scanning electron microscopy (SEM) revealed that root resorption is time and force dependent, and the type of tooth movement also seems to play a role.^{5,6} The type of vertical movement that is most predictive for external apical root resorption appeared to be an intrusive movement.^{7–9} This article will focus on tooth movement in the vertical plane as a treatment-related causative factor of root resorption.

Previous investigations primarily evaluated root resorption after the application of intrusive forces.³ Some intraindividual studies revealed that the extent of root resorption varies with the magnitude of the applied intrusive force.^{5,6} Other authors could not confirm this in interindividual studies, but they noted that large individual variations were present.^{10,11} It has also been demonstrated in a finite element model that intrusive forces can induce apical root resorption mainly because the root shape concentrates the pressure at the conical apex.¹²

Compared with intrusive tooth movement, extrusive orthodontic tooth movement is easier to accomplish. However, there are very few studies on root resorption in relation to extrusive forces, probably because it is generally considered not to induce root resorption. Only some dealt with the subject in trauma cases.^{13,14} Weekes and Wong¹⁴ observed that root resorption occurred at the interproximal region of the cervical third part of the root after extrusion, demonstrating that orthodontic extrusion is not without risk. The lack of data on this subject indicates that further research on root resorption in relation to extrusion is still required. Moreover, to our knowledge, no studies exist comparing root resorption after the application of continuous extrusive and intrusive forces in the same individual.

The aim of this study, therefore, was to compare root resorption after the application of intrusive and extrusive forces on first premolars in the same individual. SEM was used to determine the root resorption areas and their locations on the root surface.

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Subjects

The material consisted of 18 maxillary first premolars from nine patients (five females and four males), aged 12.7–20 years (mean 15.3 years). The orthodontic treatment plan included extraction of upper premolars. The inclusion criteria were periodontally healthy upper premolars with normally shaped and completely developed roots, bimaxillary protrusion without severe crowding, and a lower mandibular plane angle ($<26^\circ$) because an anterior bite block (see below) could increase the mandibular plane angle. All selected patients received written information about the purpose and the protocol of the study and signed an informed consent.

Eleven upper premolars were obtained from six randomly selected orthodontic patients as control material. The premolars were extracted before active orthodontic treatment started as part of the treatment plan and had no preexisting root resorption. The age of these patients ranged from 12 to 20 years.

Methods

The appliance used to deliver the force to the upper premolars was comparable with that of Acar et al.¹⁵ In our experiments we used a 0.017 × 0.025-inch stainless steel utility arch in the maxilla and a 0.018-inch stainless steel utility arch in the mandible. A palatal arch with an anterior bite block soldered to the upper first molars was applied to disengage the occlusion ([Figure 1](#)). A button was bonded on the buccal surface of the upper premolars. To avoid dissipation of the applied force, the proximal surfaces of the premolars to which the force was applied were ground with a diamond strip.

The upper premolar of one side of each patient was selected randomly for intrusion, and the contralateral premolar was used for extrusion. On each side, an elastic band that delivered a tipping force of approximately 100 cN (=100 g) was worn 24 h/d. On the intrusive side, the elastic band was worn between the button bonded on the premolar and the upper lateral utility arm. On the extrusive side, the elastic band was worn between the button and the lower lateral utility arm. The patients changed the elastic band every day. The experimental period lasted eight weeks. Every week, the investigator checked the force produced by the elastic band with a force gauge. When the initial force had decreased as a result of tooth movement, the patient got new elastics with a smaller diameter to ensure an initial force of approximately 100 cN.

At the end of the eighth week, the experimental teeth were extracted and prepared for SEM. All teeth were immersed in 5% sodium hypochlorite for four hours to remove the nonmineralized organic components. They were subsequently rinsed three times in phosphate-buffered saline. Then, the roots were separated from the crown, dehydrated in a series of ascending acetones, and dried in air. After a slow-drying process, they were vacuum-coated with palladium and gold, and examined in a JOEL 6310 scanning electron microscope (JOEL LTD, Tokyo, Japan) at 10 kV.

The distal and mesial sides of every specimen's root surface was scanned and photographed at low magnification (15×) for measurement of the root resorption area. Higher magnification scanning (40 to 200×) was used to evaluate the morphology and the location of the lesions. Every composite low-magnification (15×) electron micrograph of the distal or mesial root surface was composed from four to six micrographs with Adobe Photoshop software (ADOBE, San Jose, Calif). The total root surface area on each side and the resorption-affected areas were measured by IMAGE J software (NIH, Bethesda, Md). The resorbed root area of each tooth was calculated as a percentage of the total root area. Furthermore, a qualitative assessment of apical root resorption of the experimental teeth was performed using a modification of the method of Malmgren et al.¹⁶ for radiographs. In this scoring system, the severity of root resorption is scored on a scale from 1 to 4:

0 = no resorption;

1 = irregular root contour, root length not affected;

2 = minor resorption, scalloping and blunting of the apex;

3 = severe resorption, root resorption less than one third of the original root length;

4 = extreme resorption, root resorption exceeding one third of original root length.

Statistics

To calculate the interobserver measurement error for the image analysis of the SEM pictures, 20 out of a total of 56 composite images were selected randomly and measured by two independent observers (Dr Han and Dr Von den Hoff). The Pearson correlation coefficient was calculated to express the reliability of the method. The absolute random interobserver error was calculated from the standard deviation of the difference in scoring (random error = $SD/\sqrt{2}$). To calculate the interobserver measurement error for the visual scoring, all experimental teeth were scored by two independent observers (Dr Han and Dr Kuijpers-Jagtman). The weighted kappa was calculated to indicate the reliability of the method.

The Pearson correlation coefficient of relative root resorption area between the two experimental groups was calculated to determine the correlation between extrusion and intrusion. The Pearson correlation coefficient of the visual scoring and the image analysis was also calculated to determine the correlation between the two methods.

After measuring the samples, means and standard errors were calculated for the percentages of resorbed areas in the three groups. A paired *t*-test was performed to compare the relative resorption areas of the intrusion and the extrusion group. Unpaired *t*-tests were used to compare the relative resorption areas between the control group and the intrusion or the extrusion group. A $P = <.05$ was considered significant.

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The interobserver reliability coefficient of the image analysis method was 0.96. The absolute random interobserver error was 0.6%. The interobserver reliability coefficient of the visual scoring method was 0.79, and the weighted kappa was 0.62.

Root resorptions were observed in all experimental teeth. In the control group, six specimens showed no root resorption. The mean percentages of resorbed root area in the control, extruded, and intruded teeth were $0.52 \pm 0.39\%$, $1.28 \pm 0.43\%$, and $5.75 \pm 1.38\%$ (mean \pm SE), respectively ([Figure 2](#)). The difference between intruded and extruded teeth was significant ($P = .004$). The correlation of the relative root resorption area between intrusion and extrusion in the same patient was 0.774 ($P = .024$). Compared with the control group, the mean percentage of resorbed root area of the intrusion group was significantly higher ($P = .006$). No significant difference was found between the extrusion and the control group.

Visual scoring of the nine extruded premolars did not show any resorption in two premolars, four had an irregular root contour (score 1) and three roots showed only minor resorption (score 2). All intruded teeth showed signs of resorption, ie, two premolars had a score of 1 and five roots showed only minor resorption, whereas two roots were more severely affected (score 3). Nine of the control teeth did not show root resorption but, two teeth showed an irregular root contour (score 1). The correlation between the visual scoring and the image analysis method was 0.71 ($P = .002$).

Within the three groups, the extent and location of root resorption varied markedly. In the control group, three of the roots showed tiny superficial cavities scattered over the whole root surface, and only one root showed several larger superficial cavities, up to a total of 4.03%. In contrast, deep resorptions were found in all intruded teeth. Most extruded teeth showed superficial root resorption. Most of the root resorptions in experimental teeth were located in the apical parts of the roots ([Figure 3a through c](#)).

Considerable differences in the extent and depth of root resorption were observed between the intruded and extruded teeth ([Figure 4a,b](#)). In extruded teeth, most of the resorption lacunae showed superficial and limited cavities that were mainly located close to the apical foramen. The contour of the root apices was normal. The root surfaces of intruded teeth displayed much deeper and more extensive resorptions. Compared with the contralateral extruded premolar, the number of resorbed areas was much higher, and wider and deeper resorptions were seen in the apical and interradicular areas. Most of the apices of the intruded roots revealed very deep lacunae covering most of the apical surfaces ([Figure 5](#)). Some resorption lacunae extended deep into the dentin, causing loss of the apical contours. Diffuse resorption cavities were also found in the middle part of the root but less often and more superficial than those on the apical third. Very few resorptions were found in the cervical part of the roots. Although all the individual subjects were treated in the same method, the severity of root resorption varied markedly within the same test group ([Figure 6a,b](#)).

This clinical investigation deals with the association between tooth movement in the vertical plane and root resorption. In a split-mouth design, the effect of intrusive and extrusive forces on root resorption was compared. In clinical research, an intraindividual study is considered to be a reliable design to investigate the effects of external factors on root resorption. In this manner, individual variations such as susceptibility, predisposition, and systemic biological factors can be excluded.^{6,17} In most clinical studies, root resorption measurements are performed on radiographs, either panoramic or periapical because these are still the only clinical tools that can be used in regular clinical practice. On this type of radiographs, only apical root resorption can be assessed, whereas root resorption areas on the middle and cervical parts at the mesial and distal root surface are not detected unless they are very extensive. Buccal and lingual root resorption defects are not visible with currently used imaging techniques. Furthermore, it has been shown that the use of panoramic films may overestimate the amount of the root resorption by 20% or more.¹⁸ For these reasons SEM was used in this study, which is more accurate to detect root resorption.

The percentage of resorbed area of the total root surface at the mesial and distal side was calculated to quantify the extent of root resorption. However, the depth of root resorption, which also reflects the severity of root resorption, cannot be measured on a two-dimensional micrograph. A new SEM method for the measurement of resorption crater volume was published recently.¹⁹ This method is based on two separate SEM pictures of each resorption crater taken at a slightly different angle. Image analysis software is used to determine the crater volume. Although this method appears to be highly accurate for the analysis of small numbers of resorption craters, it might not be very suitable for more extensive studies. Every single crater requires two separate SEM pictures and, as in our study, each tooth might have five to 10 resorption craters.

This study is the first one comparing root resorption in the same individual after application of continuous intrusive and extrusive forces of the same magnitude. The quantitative analysis indicates that an intrusive force of 100 cN induces nearly four times more severe root resorption than that of an extrusive force of 100 cN. Previous studies also indicated that intruded teeth generally showed more and deeper resorption cavities than control teeth, and these cavities were mainly located at the apical part of the roots.^{6,20,21} Extruded teeth mostly did not show root resorption or very minor and limited resorption.^{22,23}

It has been suggested that the location of root resorption may be related to the density and hardness of cementum and dentine. An investigation on the physical properties of root cementum revealed that apical cementum was considerably softer than middle or cervical cementum.²⁴ In this study, the resorptions are mainly present at the apical part of the experimental roots, which may be because of the relatively softer cementum and other factors, such as the presence of fewer Sharpey fibers and a better blood supply.²⁰ The occurrence of resorption lacunae in the control teeth probably is a naturally occurring physiological phenomenon.²⁵ The extent of root resorption found in this study might have been affected by normal repair processes. Repair activity can be detected histologically when acellular cementum is replaced by cellular cementum.²⁶ Repair occurs mainly when the orthodontic force is removed or reduced, but Faltin et al²⁰ already had observed repair after intrusion for four weeks. The extent of resorption found in this study after eight weeks, might therefore be an underestimation of the actual extent.

The study of Acar et al¹⁵ in which a similar appliance for intrusion was used showed that resorption cavities tended to widen in the middle and cervical portion of the buccal root surface compared with the apical region. In contrast, our investigations showed root resorption mainly on the apical third of the root both in the intrusion and the extrusion group. However, as noted earlier, Acar et al¹⁵ measured root resorption at the buccal surface of the root, which could present a different pattern of root resorption because of buccal tipping of the teeth with this appliance design. Furthermore, in their study, both upper and lower premolars were used and, in the data analysis, they were treated as being equivalent. However, there is some evidence in the literature showing that different tooth types respond differently with respect to root resorption.⁸ Our results comply with finite element analysis showing that intrusive and extrusive forces concentrate stresses at the apex.¹²

This investigation, in agreement with previous studies,^{10,11,27} revealed that individual variation was considerable within the same experimental group, both regarding the occurrence and the severity of root resorption. Owman-Moll et al^{10,11} stated that individual reactions may even be more important than force magnitude and type or duration of force application. This was also demonstrated in this study because an interesting finding was that the amount of root resorption of the intruded and extruded premolar in the same patient was highly correlated. This implies that there is an individual susceptibility for root resorption. It also means that extrusion of teeth is not without risk in those patients who are susceptible to root resorption anyway. Therefore, each clinician should inform the patients about the risk of root resorption as a consequence of orthodontic treatment.

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From this study, it can be concluded that intrusion of teeth causes about four times more root resorption than extrusion. Because the amount of root resorption as a result of intrusion or extrusion in the same patient is correlated, every clinician should be aware that extrusion of teeth might also cause root resorption in susceptible patients.

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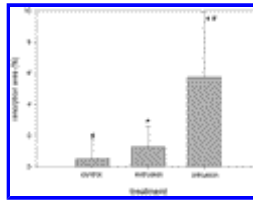
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FIGURE 1. The appliance used to deliver the orthodontic force. A 0.017 × 0.025–inch stainless steel utility arch is used in the maxilla. The premolar is intruded by an elastic delivering a force of 100 cN



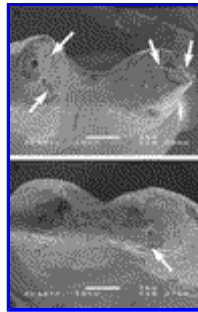
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FIGURE 2. Mean percentage and standard errors of resorbed root area (% of total root surface area) in the control, extruded, and intruded teeth. * Statistically significant difference between intrusion and extrusion ($P = .004$). # Statistically significant difference between intruded and control teeth ($P = .006$)



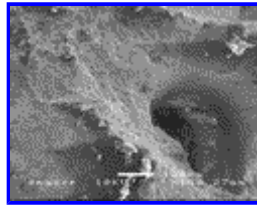
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FIGURE 3. (a) Representative pictures of a control root. (b) An intruded root. (c) An extruded root. The magnification is 15x. Bar = one mm. The arrows show the resorption areas



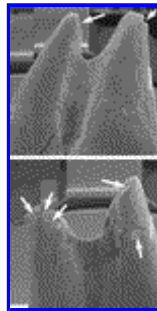
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FIGURE 4. The severity of root resorption of intruded and extruded teeth in one patient (20×). (a) At the apical part of the intruded root deep and extensive resorptions were close to the foramen and in the interradicular area. The arrows indicate the root resorption areas. (b) At the apical part of extruded root superficial and limited cavities (see the arrows) are seen around the apical foramen



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FIGURE 5. Higher magnification of a resorption lacuna on the intruded root surface (160×). Active resorption characterized by smooth multilocular surfaces, cementum is undermined by Howship lacunae



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FIGURE 6. Varying severity of root resorption in intruded teeth (15×). (a) Minor root resorption (see the arrows). (b) Severe root resorption (see the arrows)

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