Effect of continuous versus intermittent orthodontic forces on root resorption:
A microcomputed tomography study

Nurhat Ozkalayci; Ersan Ilsay Karadenizb; Selma Elekdag-Turkc; Tamer Turkd; Lam L. Cheng; M. Ali Darendelilerf

ABSTRACT
Objectives: To compare the extent of root resorption and the amount of tooth movement between continuous orthodontic force and intermittent orthodontic force that was activated in a similar way to a 4-week orthodontic adjustment period.

Materials and Methods: Twenty-five patients who required the extraction of upper first premolars were recruited in this study. A buccally directed continuous force of 150 g was applied to the upper first premolar on one side for 15 weeks. A buccally directed intermittent force (28 days on, 7 days off) of the same magnitude was applied to the contralateral first premolar. The teeth were extracted at the end of the experimental period and processed for volumetric evaluations of resorption craters. The degree of tooth movement and rotation were measured on the study models.

Results: Continuous force application displayed significantly higher root resorption volume than the intermittent force application (P < .05), particularly on the buccal and lingual surfaces (P < .05) and the middle third of the root (P < .01). There was more tipping and rotational movement in the continuous force group.

Conclusions: In a 4-week orthodontic adjustment period, intermittent force significantly reduced the amount of root resorption compared with continuous force. Although there was less degree of tooth movement with intermittent force, unwanted rotational movement was avoided. This is crucial in patients who are predisposed to orthodontically induced inflammatory root resorption, and the use of this intermittent regimen should be considered. (Angle Orthod. 2018;88:733–739.)

KEY WORDS: Root resorption; Continuous; Intermittent; Orthodontics

INTRODUCTION

Orthodontically induced inflammatory root resorption (OIIRR) is a common unwanted side effect of orthodontic tooth movement. Genetic characteristics, biological factors, and orthodontic treatment techniques can affect the degree and amount of root resorption. Mechanical factors in orthodontic treatment techniques can be controlled by the clinician. These include the duration of force application, amount of applied force, and type of orthodontic force.1

Since the start of the 20th century, many studies have investigated the relationship between orthodontic force and OIIRR.2–6 The current data suggested that pausing orthodontic forces can reduce the amount of OIIRR, likely due to cementum repair during the inactive period.3,7,8 This is extremely important in individuals who are biologically and genetically prone to root resorption. It has been suggested to take radiographs 6–12 months into treatment for detection
of early OIIRR. A 2- to 3-month pause in treatment with passive archwires has been recommended for patients who have early OIIRR. In other studies, intermittent forces have also been used to reduce the extent of OIIRR, but at the expense of less effective tooth movement. Several intermittent force regimens have been investigated, and all required frequent reactivations. This is cumbersome for patients in a clinical setting because they need to attend for orthodontic adjustment every day, every week, or every second week. The aim of modern orthodontic therapy is to achieve efficient tooth movement with less root resorption. Therefore, the aim of the present study was to evaluate and compare the extent of root resorption and effective tooth movement between continuous force application and intermittent force application (28 days on, 7 days off) that would simulate a 4-week orthodontic adjustment period.

MATERIALS AND METHODS

The sample included 50 maxillary first premolars from 25 orthodontic patients (14 boys and 11 girls; age range, 13.08 to 17.58 years; mean, 14.77 years) who required bilateral maxillary first premolar extractions as part of their orthodontic treatment. They were recruited according to strict selection criteria as follows:

1. No previous reported or observed dental treatment to the teeth to be extracted;
2. No previous reported or observed trauma to the teeth to be extracted;
3. No previous reported or observed orthodontic treatment involving the teeth to be extracted;
4. No past or present signs or symptoms of periodontal disease;
5. No past or present signs or symptoms of bruxism;
6. No significant medical history that would affect the dentition;
7. No physical abnormality concerning the anatomy of the craniofacial or dentoalveolar complex; and
8. Completed apexification.

Ethics approval was obtained from the Medical Faculty Ethics Committee of the University of Ondokuz Mayis (2007/146). All subjects and their guardians consented to participate in this study after receiving verbal and written explanations.

In each subject, a buccally directed continuous tipping force of 150 g was applied to the maxillary first premolars (MFP) on one side for 15 weeks. On the contralateral side, a buccally directed intermittent force (28 days on, 7 days off) of the same magnitude was applied for 15 weeks. The type of force application was assigned randomly to eliminate any allocation bias.

The 0.022-in slot SPEED premolar brackets and molar tubes (Strite Industries, Cambridge, Ontario, Canada) were bonded on the buccal surfaces of the MFP and maxillary first molars, respectively. The forces were induced using 0.017” × 0.025” TMA cantilever springs (Beta III Titanium, 3M Unitek, Monrovia, Calif) (Figure 1). The force magnitude was measured with a strain gauge (Dentaarm, Ispringen, Germany). Light-cured band cement (Transbond Plus Light Cure Band Adhesive, 3M Unitek) was placed on the occlusal surfaces of the mandibular first permanent molars to minimize deformation of the TMA springs and allow buccal tipping of the MFP while avoiding occlusal interferences. On the intermittent force side, the TMA springs were removed at 28, 63, and 98 days after the first activation. Seven days after the spring removal (except after 98 days), the springs were replaced and the force level was calibrated to the original amount. On the continuous force side, the TMA springs were checked and reactivated to the original level on the 35th and 70th day of the experiment (Figure 2).

At the end of the experimental period, the experimental teeth were extracted by an oral surgeon who was instructed to avoid forceps contact on the cervical cementum. The extracted teeth were immediately stored in tubes containing sterilized deionized water (Milli-Q, Milipore, Bedford, Mass) until evaluation. Prior to evaluation, the teeth were treated for 20 minutes in an ultrasonic bath (Transonic Digital, Singen, Germany) at 22°C with a 100% vibration level. All visible signs of the periodontal ligament and soft-tissue fragments on the extracted teeth were removed with a damp gauze, before they were scanned by a desktop x-ray micro-CT system (SkyScan-1172, Aartselaar, Belgium). After acquisition, several software programs, NRecon 1.4.2 (Aartselaar, Belgium), VG Studio Max 1.2 (Volume Graphics, GmbH, Heidelberg, Germany), and Convex Hull 2D (CHull2D; University of Sydney, Sydney, Australia), were used to create axial two-dimensional sliced images, to reconstruct the three-dimensional images, and to calculate the volume of the resorption craters on the root surface, respectively.

Dental plaster models were obtained before and after the experimental period. Casts of the maxillae were scanned with an Epson Expression 1600 flatbed color image scanner (Epson, Chatswood, Australia), and the images were printed on paper for ease of measurement. A reference line passing through the raphe palatina mediana was constructed. The distances of the buccal and lingual cusps of the first premolars were measured to calculate the buccal movement of the
Statistical Analysis

Wilcoxon test was used to compare the volumes of root resorption craters between the continuous and intermittent force groups, the different surfaces (buccal, lingual, mesial, and distal), and the different levels (cervical, middle, and apical) of the root. Friedman and Wilcoxon tests with Bonferroni correction were used to determine the significant differences among the root surfaces and the vertical thirds within the groups. Wilcoxon test was used to compare the amount of buccal tooth movements and the degree of rotations of the experimental teeth between the continuous and intermittent force group. The significance level of all tests was set at 5%. The statistical analysis was undertaken using SPSS (IBM SPSS Statistics for Windows, version 21.0. IBM Corp, Armonk, NY).

RESULTS

The mean resorption crater volume (MRCV) for the continuous force group (0.788 ± 0.440 mm³) was higher than the MRCV for the intermittent force group (0.639 ± 0.572 mm³) (Table 1, Figure 4). This difference was statistically significant \( P < .05 \). The MRCVs on the buccal surfaces and the lingual surfaces were also significantly greater in the continuous force group compared with the intermittent force group \( P < .05 \). At the middle third level of the root, the differences in the MRCVs was highly significant \( P < .01 \) with the continuous force group displaying a greater MRCV.

When comparing the MRCV at different regions of the premolar root, the buccal cervical, buccal middle, and lingual middle regions displayed significantly higher MRCVs in the continuous force group compared with the intermittent force group \( P < .05, P < .05, P < .01 \), respectively) (Table 2, Figure 5).

Intragroup comparisons among different root surfaces for continuous force and intermittent force revealed the following for both groups, that is, the mesial surface had the highest MRCV while the lingual surface had the least MRCV. The differences in MRCV between the mesial surface and all other surfaces were highly statistically significant \( P < .01 \) (Table 3).

Intragroup comparisons among different root levels for the continuous force and intermittent force sides showed that, in both groups, the lowest MRCV was found at the apical level. The difference in MRCV...
between the apical level and other levels was highly statistically significant ($P < .01$) (Table 4). There was a trend of gradual increase in MRCV from the apical level to the cervical level, especially in the continuous force group.

The amount of buccal tooth movement and the degree of rotation was statistically significantly greater in the continuous force group compared with the intermittent force group ($P < .001$) (Table 5, Figure 5).

**DISCUSSION**

Many studies have reported that by pausing the force or the treatment, cementum has the potential to repair resulting in less OIIRR.$^{1–3,8,9,11,12}$ This correlated with the results of the present study, that is, there was significantly less MRCV in the intermittent group compared with the continuous group. The 1-week inactive period allowed the reversible defense mechanism to initiate the reparative process on the root surface.$^{13}$ Therefore, the MRCV was reduced in this group.

The MRCV was more severe on the mesial and buccal root surfaces than the lingual and distal surface in both force groups. This could be explained by the orthodontic pressure concentration associated with the direction of the force produced by the spring. The buccal tipping movement induced a pressure zone at the buccal side and tension at the lingual side of the alveolar bone. Due to the morphology of the premolar and the rotational nature of the cantilever spring, a pressure zone was also detected in the mesial surface.

### Table 1. Comparison of Resorption Crater Volumes (mm$^3$) on the Whole Root surface, Different Root Surfaces and Different Root Levels Between Continuous and Intermittent Forces

<table>
<thead>
<tr>
<th></th>
<th>Continuous Force</th>
<th></th>
<th>Intermittent Force</th>
<th></th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SD</td>
<td></td>
<td>Mean SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total crater volume</td>
<td>0.788 0.440</td>
<td>0.639 0.572</td>
<td>0.25*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total buccal volume</td>
<td>0.221 0.171</td>
<td>0.125 0.087</td>
<td>0.19*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total lingual volume</td>
<td>0.036 0.048</td>
<td>0.014 0.019</td>
<td>0.30*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mesial volume</td>
<td>0.388 0.303</td>
<td>0.373 0.501</td>
<td>0.150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total distal volume</td>
<td>0.143 0.120</td>
<td>0.128 0.192</td>
<td>0.231</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cervical volume</td>
<td>0.334 0.262</td>
<td>0.262 0.164</td>
<td>0.264</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total middle volume</td>
<td>0.341 0.193</td>
<td>0.227 0.171</td>
<td>0.005**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total apical volume</td>
<td>0.113 0.102</td>
<td>0.150 0.362</td>
<td>0.443</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^* P < .05; ** P < .01.$
of the alveolar bone. Resorption craters seemed to be more evident in the pressure zone due to the increase in clastic cell activity in the nearby bone in an attempt to remove bone during orthodontic tooth movement. When looking at the MRCV at different regions of the root, the continuous force group was shown to induce greater MRCV on the buccal cervical, buccal middle, and lingual middle regions than the intermittent group. Jimenez-Pellegrin and Arana-Chavez found that the greatest area of resorption following rotational movement was in the middle third level of the root. This meant that the greater MRCV found in these regions in the continuous group could be justified by the greater rotational and buccal tipping movement displayed.

Interestingly, when looking at the MRCV at all root surface levels, the intermittent force group showed greater MRCV at the apical level than the continuous force group. This difference was not statistically significant. This could potentially be explained by the fact that, during the 7-day inactive period when no wire was in place, some degree of relapse of tooth movement occurred. This relapse caused a lingual pivotal movement that created a pressure zone at the apical area leading to further OIIRR. Therefore, when applying intermittent force during orthodontic treatment, it is important to have a passive archwire during the inactive phase so that further apical root resorption can be avoided. Clinically, this can be achieved by deactivating the cantilever spring with segmental mechanics or extending the review appointment interval to include at least 7 days of non-active force when straight-wire mechanics are used. With the advance of new technologies, a passive wire may be easily fabricated at the chairside from a three-dimensional image acquired by an intraoral scanner in the very near future.

Different intermittent force regimens have been investigated previously. Ballard et al. utilized the intermittent force period of 4 days of active force and 3 days of passive retention. Aras et al. compared the two different intermittent force regimens of either 11 or 18 days of activation and 3 days of rest with no force. Both studies showed similar results in that less root resorption was found in the intermittent force groups compared with the continuous force groups. However, the 3-day inactive period meant that the patients had to attend their orthodontic adjustment appointment quite often, and this could be clinically inconvenient for both clinicians and patients. Therefore, this study specifically aimed to look at a new intermittent force regimen that was convenient for the patient and efficient for the clinician. Generally, clinicians see patients at 6- to 8-week intervals for their orthodontic adjustment. However, Paetyangkul et al. showed statistically significant greater amount of root resorption following 8 weeks of force application compared with 4 weeks of force application. Therefore, the decision was made to have 4 weeks of active force for the intermittent force group to keep the amount of OIIRR at its lowest. As mentioned before, the short 3-day inactive period required frequent visits to the clinic, which could be quite troublesome to the patients. A 7-day inactive period was chosen for this experiment to make the visit frequency more acceptable. From a biological perspective, the longer inactive period would allow more time for the cementoblasts to be recruited and to initiate the reversible defense mechanism, that is, the reparative process. This was clearly evident in the result of the present study that there was significantly less OIIRR in the intermittent force group.

### Table 3. P Values on the Differences in Mean Root Resorption Crater Volume Between Different Root Surfaces for Continuous and Intermittent Forces

<table>
<thead>
<tr>
<th>Surface</th>
<th>Buccal</th>
<th>Lingual</th>
<th>Mesial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous force</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lingual surface</td>
<td>0.00012****</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesial surface</td>
<td>0.005354**</td>
<td>0.000022****</td>
<td></td>
</tr>
<tr>
<td>Distal surface</td>
<td>0.054374</td>
<td>0.000239***</td>
<td>0.000733***</td>
</tr>
<tr>
<td>Intermittent force</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lingual surface</td>
<td>0.000017****</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesial surface</td>
<td>0.000602***</td>
<td>0.000012****</td>
<td></td>
</tr>
<tr>
<td>Distal surface</td>
<td>0.459336</td>
<td>0.000174***</td>
<td>0.000808***</td>
</tr>
</tbody>
</table>

** P < .01; *** P < .001; **** P < .0001.

### Table 4. P Values on the Differences in Mean Root Resorption Crater Volume Between Different Root Levels for Continuous and Intermittent Forces

<table>
<thead>
<tr>
<th>Surface</th>
<th>Cervical</th>
<th>Middle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous force</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle level</td>
<td>.427000</td>
<td></td>
</tr>
<tr>
<td>Apical level</td>
<td>.000090****</td>
<td>.000013****</td>
</tr>
<tr>
<td>Intermittent force</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle level</td>
<td>.253000</td>
<td></td>
</tr>
<tr>
<td>Apical level</td>
<td>.000602***</td>
<td>.001302**</td>
</tr>
</tbody>
</table>

** P < .01; *** P < .001; **** P < .0001.

### Table 5. Comparison of the Buccal Cusp Movements (mm), Lingual Cusp Movement (mm), and Rotations (Degree) Between Continuous and Intermittent Forces

<table>
<thead>
<tr>
<th></th>
<th>Continuous Force</th>
<th>Intermittent Force</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buccal cusp</td>
<td>3.91 1.58</td>
<td>2.44 1.04</td>
<td>.0000182****</td>
</tr>
<tr>
<td>Lingual cusp</td>
<td>5.47 1.74</td>
<td>3.19 1.28</td>
<td>.000002****</td>
</tr>
<tr>
<td>Rotation</td>
<td>25.76 10.94</td>
<td>14.64 6.55</td>
<td>.000055****</td>
</tr>
</tbody>
</table>

**** P < .0001.
The force of the spring in the continuous force group was reactivated to the original level every 35 days. This was to match the reactivation in the intermittent group following the 7-day rest. Therefore, the force induced by both groups was standardized and made the groups more clinically comparable. In order to extrapolate the results of the present study in a clinically significant way, the experimental duration was extended from 12 weeks to 15 weeks. This allowed 3 inactive periods to overcome the shortcoming found in the previous study by Aras et al.,² where the intermittent force experimental period was 12 weeks with only two inactive periods.

Continuous force application resulted in greater tooth movement, as indicated by buccal cusp movement and lingual cusp movement, which correlated with previous studies that have shown that continuous forces produced greater tooth movement than other types of forces.³,¹⁹,²⁰ However, there was a greater unwanted rotational tooth movement in the continuous group compared with the intermittent group. This could mean that more treatment time would be required to de-rotate the tooth and hence less effective tooth movement. Moreover, this greater tooth movement in the continuous group was at the expense of more severe root resorption. This information is critical to the patients who are biologically and genetically prone to OIIRR,²¹ and continuous force should not be used in these patients.

Weltman et al.² suggested a 2- to 3-month pause in the treatment for patients with early detected OIIRR to allow cementum healing. In a standard treatment of 18 months, a 2- to 3-month pause for every 3 to 6 months of treatment would be an additional 4 to 15 months of treatment time. Perhaps, intermittent force of 28 days on and 7 days off could be a more effective way to move teeth and yet be less detrimental on the root surface for individuals who are prone to OIIRR. The key is to retain with a passive archwire during the inactive period to prevent further OIIRR at the root apex.

Further investigations with an improved clinical setup and experiment design will be beneficial to overcome the shortcomings of the present investigation and highlight the clinical relevance. A transpalatal arch should be considered to enhance the molar anchorage unit. This will ensure that the force applied to each experimental premolar is consistent. The experiment period should be defined by the distance moved instead of a set time frame. It is understood by the result of the present investigation that intermittent force resulted in less OIIRR and less tooth movement. However, one would question whether the extent of OIIRR would still be less if the tooth is moved the same distance because the treatment time would be longer. Therefore, it would be more clinically meaningful to compare the extent of OIIRR and the required treatment time for the experimental tooth to move to a desired position between the two force regimens (continuous vs intermittent).

CONCLUSIONS

- Continuous force causes greater OIIRR than intermittent force (28 days on, 7 days off) in 15 weeks.
- Continuous force results in faster tooth movement than intermittent force. However, this is accompanied by greater unwanted rotational movement and OIIRR.
- The unwanted rotational movement results in more root resorption in the middle third level of the tooth root.
- Intermittent force of 28 days on and 7 days off is an effective way to move teeth for an individual who is prone to OIIRR. Passive archwires during the inactive periods are highly recommended.

ACKNOWLEDGMENT

This study was submitted as Dr Nurhat Ozkalayci’s PhD thesis in the Department of Orthodontics, at the Ondokuz Mayis University in Samsun, Turkey.

REFERENCES