Physical properties of root cementum: Part 22. Root resorption after the application of light and heavy extrusive orthodontic forces: A microcomputed tomography study

Vanessa C. Jimenez Montenegro, Allan Jones, Peter Petocz, Carmen Gonzales, and M. Ali Darendelier
Sydney, Australia

Introduction: Extrusive tooth movement has been overlooked in the literature on root resorption. The aims of this study were to quantify the effects of light and heavy controlled extrusive forces on root resorption and to localize the sites of prevalence in premolars. Methods: Ten patients (7 girls, 3 boys) who required bilateral maxillary first premolar extractions as part of their orthodontic treatment participated in this study. The total sample consisted of 20 maxillary first premolars. Light (25 g) or heavy (225 g) forces were applied to the right or left first premolar for 28 days. After the experimental period, the teeth were extracted without root damage and analyzed with microcomputed tomography. Each specimen was studied in 3 dimensions, and specially designed software was used to measure the volume of each crater. Wilcoxon signed rank tests were used for the statistical analysis. Results: There was a significant difference in the total root resorption caused by light and heavy forces ($P = 0.037$). The discrepancy between the light and heavy groups was not significant for the cervical, middle, and apical regions separately. Only the distal surfaces were significantly different between the light and heavy forces ($P = 0.008$). Conclusions: Greater root resorption was observed after heavy extrusive forces when compared with light forces. The distal surfaces of the tooth root were significantly more affected than other root surfaces and might be influenced by root morphology and initial angulation of the tooth. There was no significant difference in the cervical, middle, and apical thirds in relation to root resorption after light or heavy extrusive forces. (Am J Orthod Dentofacial Orthop 2012;141:e1-e9)
making the literature limited on this type of tooth movement. Most published data on extrusion are related to traumatized teeth; this introduces bias in relation to root resorption because of its high incidence in dental trauma.

Reitan considered root resorption in controlled extrusive movement to be an exception after he evaluated premolars under light microscopy. He justified the presence of minor craters with the possibility of lesions before treatment and the difficulty in avoiding tipping while attempting pure extrusion. Han et al reported similar conclusions. They stated that root resorption from extrusive forces was limited and not significantly different from the control group. When compared with intrusive forces, they suggested that teeth were 4 times more susceptible to root resorption after intrusive forces than with extrusive tooth movement. Weekes and Wong evaluated the response of the periodontal ligament to orthodontic extrusion using light microscopy and scanning electron microscopy. After 4 to 6 weeks of extrusion and 12 weeks of retention on endodontically treated incisors of beagle dogs, they described root resorption and repair in the cervical region.

Several methods have been implemented in the study of orthodontically induced root resorption. Traditionally, radiographs are the most popular tool for evaluation of treated teeth. They can only detect root resorption if it has occurred in large amounts, and buccal and lingual root resorptions are not assessed with this technology. Therefore, the information is assessed in only 2 dimensions, although it is a 3-dimensional (3D) process. Dedic et al aimed to validate the use of digitized periapical radiographs in evaluating orthodontically induced apical root resorption against microcomputed tomography scanning as the standard test. The radiographic method showed specificity of 78% and sensitivity of 44%; this means that less than half of the instances of root resorption detected with a microcomputed tomography scanner were identified by radiography. Conventional light microscopy and scanning electron microscopy are other 2-dimensional (2D) methods described in the literature. The downside of these technologies relates to the possible need of sectioning the sample; this is technique sensitive and might underestimate the results. Three-dimensional approaches include stereo imaging, scanning electron microscopy, and computed tomography. Because root resorption is a 3D problem, these last approaches were claimed to be more precise, since the tooth and its craters are evaluated in 3 dimensions.

The aims of this research were to investigate and compare the effects of different force magnitudes on the volumes of root resorption craters and the sites of prevalence after controlled extrusion of the maxillary first premolars. Our study is a continuation of a series of investigations on the physical properties of root cementum and root resorption at the University of Sydney in Australia.

MATERIAL AND METHODS

The study was conducted on 20 teeth obtained from 10 adolescent patients (7 girls, 3 boys) who required extraction of maxillary first premolars as part of their orthodontic treatment and were selected according to the strict criteria previously described. Their ages were between 12 and 18 years. Ethics approval was obtained from the Ethics Review Committee of the Sydney South West Area Health Service (protocol no. X09-0110). Written and verbal informed consents were obtained from the subjects and their parents or guardians. On each patient, a light (25 g) controlled extrusive orthodontic force was randomly assigned to the maxillary first premolar on one side and a heavy (225 g) force on the contralateral tooth. The extrusive forces were in place for 4 weeks.

The experimental period and the force levels used in this research were chosen to comply with previous protocols carried out in the Department of Orthodontics at the University of Sydney.

Extrusive forces were applied on the buccal and palatal sides to reduce as much secondary tipping as possible. Therefore, each force magnitude (25 and 225 g) was divided by 2 (buccal and palatal sides) to obtain the same amount of force on either side. Laboratory tests were performed to determine the force delivery system. Several wires were tested by using the Mach-1 mechanical tester (BioMomentum, Laval, Québec, Canada), varying the interbracket distances and the activations. According to those tests, the light extrusive force would be achieved by using the core strand of 0.016-in SPEED Supercable archwire (Strite Industries, Cambridge, Ontario, Canada) producing 12.5 g of force at an 8-mm span and a 1.8-mm activation. This is a 7-strand coaxial wire of superelastic nickel titanium. On the opposite side, the heavy extrusive force was achieved by an intact 0.016-in SPEED Supercable wire producing 112.5 g of force at an 8-mm span and a 1.8-mm activation (Fig 1).

The appliance consisted of an acrylic block covering the maxillary first and second molars to disengage the occlusion and prevent occlusal interference. The acrylic block was connected to a 0.021 × 0.025-in stainless steel stabilizing wire (3M Unitek, Monrovia, Calif), which was bent passively and bonded to the lateral incisor or the canine as convenient. The archwire delivering the extrusive force was inserted through tubes welded to the stabilizing wire. These tubes were attached 8 mm apart.
mesially and distally to the first premolar. Bondable buttons were bonded to the crown on the buccal and palatal sides of the first premolar to which the archwire was engaged to exert the force desired. The maxillary first premolars were previously prepared with 0.2 mm of interproximal reduction to prevent any contact with neighboring teeth that could interfere with the extrusion movement. The same operator (V.J.M.) treated all patients, and the duration of the experiment was 28 days. During this period, no reactivation of the experimental setup was performed (Fig 2).

The teeth were extracted after the experimental 28 days; the surgery was carried out with careful attention not to damage the root cementum. After the extractions, the teeth were immediately stored in individual containers of sterilized deionized water (Milli Q; Millipore, Bedford, Mass), which was tested as an appropriate storage medium.34 The teeth were thoroughly cleaned by placing them in an ultrasonic bath, followed by mechanical cleaning with a damp gauze cloth. This removed all traces of the periodontal ligament and any soft-tissue fragments on the root surface. Extreme care was taken to prevent damage of the cementum. Finally, the teeth were disinfected in 70% alcohol for 30 minutes and then bench dried.

The samples were analyzed by using a compact desktop system for x-ray microtomography. The SkyScan 1072 desktop x-ray microtomograph (SkyScan, Aartselaar, Belgium) allows nondestructive 3D reconstruction of the tooth’s inner structure from 2D x-ray shadow projections. Each tooth was scanned, and the procedure lasted approximately 60 minutes per tooth. During scanning, the teeth were rotated 360° around the vertical axis with a single rotation step at 0.23°. The x-ray tube was operated at 60 kV and a current of 167 µA without filters. All teeth were scanned from the cementoenamel junction to the apex with a resolution of 17.2 µm. The images were acquired and saved as 16-bit tagged image format (TIFF) files. Axial slice-by-slice reconstruction was achieved using Necon (version 1.4.2; SkyScan, Aartselaar, Belgium). It uses the set of acquired angular projections to create a set of cross-section slices through the tooth. Reconstructed slices were saved as bitmap pixel files. The image reconstruction phase involved beam-hardening correction, alignment optimization, and ring artefact correction. The next step was visualization of the tooth surface in 3 dimensions. It required VG Studio Max software (version 1.2; Volume Graphics, Heidelberg, Germany), which gathers the axial 2D slices to form a 3D image of the tooth (Fig 3, A).

Each tooth was divided into thirds (cervical, middle, and apical) in the vertical dimension from the cementoenamel junction to the apex, and into fourths when viewed axially indicating the 4 surfaces of the tooth (buccal, lingual, mesial, and distal). Each crater would be isolated and classified according to its location. Craters were then isolated and volumetrically measured by using Convex Hull software (CHULL 2D) developed by the Australian Centre for Microscopy & Microanalysis at the University of Sydney. This program applies 2D convex hull algorithms to each axial slice of the crater data set. The interruption of the tooth surface is detected, and CHULL 2D connects the borders of the lacunae. The volume of root resorption craters is calculated on each axial slice (Figs 2, C, and 3, B). The resorption craters were measured individually, and then the root resorption volumes for each tooth on each surface were calculated.

**Statistical analysis**

Descriptive statistics and statistical analyses were performed by using PASW Statistics for Windows (version 18; PASW, Chicago, Ill). The means, standard deviations, and ranges of these measurements were calculated. Wilcoxon signed rank tests were performed to determine the levels of significance between light and heavy forces and at the different tooth surfaces and thirds. A P value of ≤0.05 was considered significant.
Craters were isolated and measured 3 times for 15% of the sample. Repeated measurements were taken 2 and 3 months after the initial analysis. The measurement error was calculated as the standard error from repeated measurements followed by 1-way analysis of variance (ANOVA). The standard error of the measurements in the groups was 0.00031; this resulted in a coefficient variation of 2.2% (coefficient variation = 100*SD/mean). When the data were analyzed by vertical thirds, the standard deviation was 0.000182 with a coefficient variation of 3.8%.

**RESULTS**

Wilcoxon signed rank tests were performed to analyze the data, since light and heavy forces were applied on the same patient. There was a significant difference in the total root resorption caused by light and heavy forces ($P = 0.037$) (Fig 4). The mean volumes of the resorption craters were 0.19 mm$^3$ in the heavy force group and 0.063 mm$^3$ in the light force group (Table I).

When the sample was analyzed by vertical thirds, the calculations indicated that the difference between the light and heavy groups was not significant for the
cervical, middle, and apical regions separately ($P = 0.50, 0.14, \text{ and } 0.17$, respectively). The mean volume for each group is shown in Table II; it was highest on the middle third in the heavy force group (Fig 5).

When we evaluated the different tooth surfaces, only the distal surface was significantly different between light and heavy forces ($P = 0.008$). A heavy force seems to produce more root resorption than a light force at the mesial and distal surfaces, but the opposite was observed at the buccal and lingual surfaces (Fig 6; Table III).

**DISCUSSION**

Root resorption is an unpredictable consequence of orthodontic tooth movement. The etiology has been defined as multifactorial, and some contributory factors are mechanical in origin. It is known that the severity of root resorption is associated with stress distribution in the root, periodontal ligament, and alveolar bone. Hohmann et al.\textsuperscript{16} evaluated the hydrostatic stress distribution after the application of a continuous force and reported that regions showing increased hydrostatic pressure correlated well with the locations of root resorption craters.

Different vectors of force create diverse stresses throughout the root of the tooth; hence, root resorption distribution can vary with different types of tooth movements. At the University of Sydney, we have been assessing each type of tooth movement individually.\textsuperscript{20,33,35,36} In relation to extrusive tooth movement, the literature clearly recognizes it as the least detrimental.\textsuperscript{21-23}

**Table I.** Estimated mean volumes of root resorption ($\text{mm}^3$) for the light and heavy groups

<table>
<thead>
<tr>
<th>Force</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>0.063</td>
<td>0.069</td>
</tr>
<tr>
<td>Heavy</td>
<td>0.185</td>
<td>0.177</td>
</tr>
</tbody>
</table>

**Table II.** Estimated mean volumes by vertical thirds ($\text{mm}^3$) for the light and heavy groups

<table>
<thead>
<tr>
<th>Force</th>
<th>Light</th>
<th>Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>0.020</td>
<td>0.022</td>
</tr>
<tr>
<td>Middle</td>
<td>0.020</td>
<td>0.108</td>
</tr>
<tr>
<td>Apical</td>
<td>0.023</td>
<td>0.056</td>
</tr>
</tbody>
</table>

**Fig 4.** Distribution of root resorption craters on light and heavy groups. *RR*, Root resorption.

**Fig 5.** Distribution of resorption craters according to vertical thirds.

Preceding publications on root resorption after extrusive tooth movement have not provided 3D quantitative analyses on the volume of root loss.\textsuperscript{21,23,24} In addition, the substantive methodologic differences make comparisons difficult. We evaluated force magnitudes during short-term controlled tooth extrusion and analyzed quantitatively all surfaces of the teeth.

The results of this investigation agree with previous findings of increased volume of root resorption craters when heavy forces are applied.\textsuperscript{16,17,20,22,33,35,36} Our results showed statistically significant differences between the light and heavy force groups. The mean volume of the heavy group was significantly higher when compared...
with the light group, and the heavy group showed almost 3 times more root resorption than did the light group. Orthodontically induced inflammatory root resorption is associated with local compression of the periodontal membrane. Overcompression of the periodontal ligament will result in tissue hyalinization.\(^1\) The nearby outer surface of the root (cementoblast layer covering the cementoid) can be damaged during removal of the hyaline zone.\(^37\) The resorption process continues until no hyaline tissue is present, or the force level decreases. Despite many studies on the mechanism of orthodontically induced inflammatory root resorption, its exact means is not fully understood.

The role of force magnitude in the severity of root resorption has been demonstrated in the literature.\(^16\) An optimal force is characterized by maximal cellular response while maintaining the vitality of the tissues. Schwarz\(^2\) proposed that the optimal force for tooth movement should be within the levels of capillary pressure. Contradictory findings stated that force magnitude is not correlated to increased root resorption,\(^11\) but differences in methodology and measurement instruments could be responsible for this discrepancy. Histologic studies do not consider the 3D aspect of root resorption, and a wide variety of force magnitudes have been used in these investigations.

In our study, 25 g was used as a relatively light force, and a 9-fold greater force of 225 g was considered relatively heavy. The force range matches previous resorption studies; this allows further comparisons.\(^20\) Force magnitude was measured by using the mechanical tester, and the intraoral appliances were constructed accordingly in a standardized manner. This was considered reliable, although minor human error could have occurred during construction of the appliances.

From our results, the differences between light and heavy extrusive forces were not statistically significant when the vertical thirds of the roots were analyzed. There was a clear trend indicating the middle and apical thirds were the most affected, and the cervical third suffered the least resorption. Our outcome differs from that of Weekes and Wong,\(^24\) who used light microscopy to study endodontically treated incisors on dogs after extrusive tooth movements. They observed loss of root structure on the cervical interproximal areas, but the forces were applied by an extrusive loop on the buccal side of the tooth. Contradictory results were reported by Han et al,\(^23\) who observed root resorption mainly near the apical foramen in spite of also having applied the extrusive force on the buccal side only. This type of force delivery system would have allowed for some buccal crown tipping, since the force was applied buccally to the center of resistance of the tooth. With tipping tooth movements, high pressure is frequently located at the alveolar crest level\(^18\);\(^41\) consequent root resorption can be expected to increase in this area when compared with the apex. Henry and Weinmann\(^42\) claimed that the apical third of the root is more susceptible to root resorption than the cervical section. Hohmann et al\(^16\) suggested that the different blood sources for vascularization of the periodontal ligament in both parts might be related. The cervical third is also nourished by the supraperiosteal arteries, whereas the apical portion of the periodontal ligament is supplied by the arteria dentalis. The distribution of the capillary blood pressure along the periodontal ligament is unknown but might also contribute to the differences. Additionally, apical cementum is softer than cervical cementum, and there are fewer Sharpey’s fibers; this might play a part in resorption susceptibility.\(^31\)
Another factor that could have influenced the variety of results in the literature is the duration of the experiments. The length of treatment has been directly related to the extent of root resorption, although it is unsupported by the results of Dermaut and De Munck. Our experimental period was 4 weeks, whereas others have had longer experimental times, and some have allowed retention.

Different results can be expected when comparing root resorption after continuous and intermittent orthodontic forces. Han et al described most of their resorption lacunae as superficial with limited cavities close to the apical foramen. Intermittent extrusive forces were applied in their experiment, and they changed the elastic band dimension to maintain the force values as constant as possible while the tooth was extruding. Our results showed a wide range of lacunae volumes on every surface evaluated. The force delivery in this study was not reactivated during the experimental time, to replicate the clinical situation and eliminate compliance as an influencing factor. The different methodologies might explain the discrepancies in results, since the depths of the resorption lacunae do not vary between constant and intermittent force applications. However, perimeter, area, and volume of the resorption lacunae with continuous force application are 140% greater than with intermittent forces. Maltha et al experimented on dogs and corroborated these results, concluding that intermittent forces resulted in 40% to 70% less root resorption than continuous forces.

In our study, root resorption, found on every tooth surface, was greater toward the mesial and distal surfaces but significant only on the distal surfaces when light and heavy forces were applied. Regardless of our efforts, this study had certain limitations. We attempted to minimize dental tipping by applying buccal and palatal forces, but the experimental setup could not control mesiodistal tipping, since the forces applied were a single contact system on the buccal and palatal sides; therefore, some mesiodistal tooth movement might have occurred. Another contributing factor was that the treated teeth were in malocclusion and crowded positions before the experimental phase; consequently, the forces applied might not have been exclusively along the longitudinal axis of the tooth. Harris et al described similar results. Another related factor is root morphology; straight dental roots are present in 9% to 37% of maxillary first premolars, whereas roots inclined distally are present in 36% to 79%. As explained by Oyama et al in a finite element model of different root shapes, when intrusive and lingual tipping forces were applied to the model with a dilacerated root, the stress concentrated at the mesial and distal surfaces of the root apex during intrusive force application, and at the labial and lingual surfaces when a lingual force was applied. In other words, 3 main factors can increase the risk of root resorption on the distal root surfaces after extrusive forces: secondary tipping from uncontrolled tooth movement in the mesiodistal dimension, original tooth position, and root morphology.

Orthodontic tooth movement involves a series of biologic reactions to the force applied; this makes teeth vulnerable to root resorption. Although much care was taken to ensure a sound research methodology, there were confounding factors such as individual variations that were evident while analyzing the data. Individual susceptibility can be so unpredictable that incidence and severity cannot be estimated.

Finite element analysis of extrusive tooth movement reports that it has similar behavior to intrusive movements, since most of the stress concentrates at the apex of the tooth. On the other hand, Shaw et al claimed that concentration of stress and its distribution in extrusive tooth movements might vary from those of intrusion. Further investigations are needed to elucidate the stress distribution in maxillary premolars after extrusive force application.

Ethical and practical constraints in human clinical research led us to a sample of 10 patients and 20 premolars in each group. Further studies should include a larger sample, which will allow the analysis of certain factors such as age, sex, and ethnicity. Currently, preexisting root resorption cannot be assessed, since the high radiation dose of microcomputed tomography has restricted its usage to the study of inanimate objects. More accurate results might be obtained as high resolution scans with a low radiation dose become available.

Extrusive tooth movement offers less resistance than other types of tooth movement; in spite of this, a significant difference in root resorption was found when heavy and light forces are compared. Extrusion is particularly performed on teeth that are impacted or ectopic and when forced extrusion is needed for prosthetic or esthetic reasons. In these cases, the tooth movement might not be a pure extrusive force, since the tooth position and the appliance used could allow for tipping while extruding at the same time. Therefore, it is relevant for the clinician to be aware of the vector of force application and the amount of force applied, especially in patients who need a large amount of extrusion.

**CONCLUSIONS**

When controlled light and heavy extrusive forces were applied to maxillary first premolars for 28 days, the following conclusions were drawn.
1. Greater root resorption was observed after heavy extrusive forces when compared with light forces.
2. The distal surfaces of the tooth roots were significantly more affected than other root surfaces.
3. There was no significant difference in the cervical, middle, and apical thirds in relation to root resorption after light and heavy extrusive forces.

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REFERENCES


