Orthodontically induced cervical root resorption in humans is associated with the amount of tooth movement

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Summary

Introduction: The aim of this study was to investigate the variation in the amount of the orthodontically induced cervical root resorption and the association with several factors, such as the amount of tooth displacement, location of tooth in the maxilla or mandible, and presence of an interference that may influence the amount of root resorption.

Subjects and methods: This study included 30 subjects (20 females, 10 males) with an age range of 11.3 to 43.0 years. Using a standardized experimental orthodontic tooth movement, 59 premolars were moved buccally during 8 weeks with application of 1 N force. Fifty-eight contralateral premolars not subjected to orthodontic tooth movement served as controls. At the end of the experimental period the teeth were carefully extracted, scanned in a micro-computed tomography scanner with a resolution of 9 μm, and the reconstructed images were processed for volumetric evaluation of resorption craters at the cervical part of the root surface. Data were analyzed using unpaired t-test and the Pearson’s correlation.

Results: Higher amount of cervical root resorption was detected in the orthodontically moved teeth (0.00055 mm³) compared to controls (0.00003 mm³; P < 0.001). Moderate correlation was found between root resorption in the two experimental teeth within the same individual (R = 0.421, P = 0.023). Teeth located in the mandible presented more resorption than those in the maxilla (P = 0.046). The amount of root resorption was correlated to the amount of tooth movement (R = 0.318, P = 0.016).

Conclusion: Application of a 1 N force over a 2-month period provokes severe root resorption at the compression cervical sites. Resorption is correlated with the amount of tooth movement and the location of the teeth.

Introduction

External apical root resorption is a common, undesirable side effect of orthodontic treatment (1–4). Loss of apical root material is unpredictable and when, extending into the dentin, irreversible (5). Several predisposing factors, alone or in combination may contribute to the initiation and progression of root resorption: the type of orthodontic appliances used, the type of tooth movement, the applied forces, treatment duration, a previous history of dentofacial trauma, pre-existing root resorption, hypofunctional periodontal ligament associated with non-occluding teeth, systemic factors, genetic factors, adverse habits, and stage of root formation at onset of treatment (6).

Several previous investigations examined the effect of the applied orthodontic force on root resorption (7–9). In most of these studies, the magnitude and the type of the applied force (light versus heavy force and/or continuous versus intermittent force) was evaluated in
relation to both the amount of tooth movement and root resorption. No significant difference was observed in the rate of tooth movement and the severity of root resorption between light and heavy continuous force application (50 cN versus 100 cN) (10). When a 4-fold larger force (200 cN) was applied, it resulted in an increased mean horizontal crown movement as compared to the light force. However, root resorptions registered in histologic sections of the extracted teeth, showed no significant difference in frequency and severity between the two forces (11).

Since force application causes tooth movement, an association between root resorption and amount of tooth movement may be expected. However, few studies have analysed this relationship directly. A weak correlation was found between the loss of root length evaluated radiographically and the amount of tooth movement in adult patients during orthodontic fixed appliance therapy (12). However, root resorption may have been underestimated when evaluated radiographically (13). More recently, a correlation was found between the amount of linear tooth movement and the area and volume of the resorption evaluated with confocal laser scanning microscope when teeth moved freely i.e. without the presence of an obstacle that could impede their movement (14). This information that was based on a free tooth movement does not reveal the possible influence of the presence of an obstacle during tooth displacement which could lead to a jiggling effect of the tooth under displacement. Therefore, it is an open question if the application of an orthodontic force on teeth that cannot be displaced freely, results in the same amount of root resorption as on teeth that can be freely displaced. Furthermore, in the same study, the position of the tooth in the maxillary or mandibular arch did not reveal any significant influence on the amount of root resorption, thus the maxillary and mandibular teeth were analysed as one group. These findings did not confirm previous studies which showed that the maxillary teeth are at higher resorptive risk than the mandibular (9,15). In a previous study, we have shown that when teeth can move freely, the amount of displacement is higher in the maxilla than in the mandible (16). This, could at least in part explain the higher level of root resorption in the maxilla than that in the mandible. Clinically, individual variations in tooth movement as well as in frequency and severity of root resorption can be observed. In certain cases, the location of the teeth in the mandible or the maxilla and/or the presence of an intra-arch or inter-arch interference could be in part responsible for these variations.

Recently, the micro-computed tomography technique has been shown to be a rapid and accurate method with high resolution, providing enhanced visual and perspective assessment. The method has been widely used to visualize and quantify the resorption craters on teeth that can be freely displaced, results in the same amount of root resorption as on teeth that can be freely displaced. Furthermore, in the same study, the position of the tooth in the maxillary or mandibular arch did not reveal any significant influence on the amount of root resorption, thus the maxillary and mandibular teeth were analysed as one group. These findings did not confirm previous studies which showed that the maxillary teeth are at higher resorptive risk than the mandibular (9,15). In a previous study, we have shown that when teeth can move freely, the amount of displacement is higher in the maxilla than in the mandible (16). This, could at least in part explain the higher level of root resorption in the maxilla than that in the mandible. Clinically, individual variations in tooth movement as well as in frequency and severity of root resorption can be observed. In certain cases, the location of the teeth in the mandible or the maxilla and/or the presence of an intra-arch or inter-arch interference could be in part responsible for these variations.

In the present study, our hypothesis was that in an experimentally induced orthodontic tooth movement, the amount of root resorption is correlated to the amount of tooth movement. Furthermore, we hypothesized that the amount of root resorption is the same in the maxilla and the mandible and that the presence of an inter-arch or intra-arch obstacle can reduce the amount of root resorption. By using the experimental clinical model applied by Owman-Moll et al., (11) our aims were: (1) to explore potential associations of cervical root resorption with the amount of tooth displacement, (2) to study the variations of orthodontically induced cervical root resorption between and within individuals, and (3) to identify factors, such as location of the tooth in the maxilla or the mandible and the presence of an intra-arch or inter-arch obstacle that could influence the amount of root resorption.

Materials and methods
Participants
The study sample consisted of 30 patients (20 females, 10 males; mean age 16.7 years; range, 11.3–43 years) who required two or four premolar extractions in order to start orthodontic treatment in our University Clinics. The subject selection criteria have been described previously (16). Briefly, all subjects were in good general and dental health with no restored or endodontically treated teeth and they were periodontally healthy with probing depth ≤3 mm and no radiographic evidence of bone loss. No history of previous dental trauma was reported. All subjects completed the written informed consent and the Medical Ethics Committee of our University approved the study.

Standardized experimental orthodontic tooth movement
Prior to the start of the orthodontic tooth movement, a prophylaxis phase with professional tooth cleaning and oral hygiene instructions was provided. The premolars scheduled for extractions were assigned randomly to an experimental and a control group. The experimental group included 59 premolars that were moved in a buccal direction during 8 weeks in a standardized way as previously described (16). The used mechanics included a transpalatal or lingual arch as an anchorage unit and a cantilever mechanics for tooth movement (019 x 025 TMA sectional wire with 1N of initial buccal activation). The cantilever arm was attached through a ligature to the premolar bracket (one-point contact without engaging the wire into the bracket slot). This allowed us precise force measurement (statically determinate force system) and resulted in the buccal tipping of those premolars. The patients were seen after 4 weeks in order to examine if there was any failure of the appliance. Furthermore, the amount of force was checked and if necessary re-adjusted by the reaction force of the appliance. However, after the 4 weeks, the force level did not drop below 50 cN for any of the cases. The control group included 58 premolars, which were also bonded with a bracket, but were not moved orthodontically.

Micro-scanner image acquisition and reconstruction
After the 8 weeks of experimentation, teeth from both the experimental and control groups were removed carefully. The SkyScan 1076 micro-scanner was used (SkyScan, Aartselaar, Belgium) to scan the samples and to acquire images at 9 µm resolution. The acquired images were further processed using a classical Feldkamp cone-beam algorithm for the reconstruction of the cross-sectional images and a medical imaging software Osirix for the 3D reconstructions (version 2.7, open-source DICOM viewer) (13). All procedures were preformed at the Institute of Translational Molecular Imaging of the University of Geneva (https://www.unige.ch/medicine/itmi/institute-of-translational-molecular-imaging-itmi).

Root resorption volume assessment
Using the Osirix software, each crater on the buccal side of the cervical part of the root was determined by defining manually on the corresponding axial slices the hull or outer limit of the resorbed area. The definition of the upper and lower axial limit of the crater
allowed subsequently the automatic calculation of the total crater volume by the software (Figure 1A and B).

Statistics
Differences in cervical root resorption between the experimental and control groups were tested by a non-parametric Mann–Whitney U test.

For the experimental teeth, the Pearson’s correlation coefficient was calculated in order to test the correlation between the severity of root resorption (square root transformation) and the amount of tooth movement. At the individual level, the correlation between the amount of cervical root resorption in matched teeth was expressed by the Pearson’s correlation coefficient.

The influence of tooth location (upper versus lower arch) and the presence of an obstacle on the amount of cervical root resorption within the same individual were tested with a paired t-test.

Multiple linear regression analysis was performed to determine associations between cervical root resorption (square root transformation), displacement, and tooth location.

The statistical analysis was processed with IBM® SPSS® Statistics (Release 23.0.0, SPSS Inc. an IBM company, Chicago, USA).

Results
The whole material concerning the individual patient characteristics, the amount of cervical root resorption and the amount of tooth movement in the two experimentally moved teeth is provided in Table 1. No failure of the appliance was observed during the course of the study. Results on the amount of tooth displacement and the factors related to that have already been reported (16,23). In summary, the range of tooth movement varied substantially between individuals. Age and presence of an intra-arch or inter-arch obstacle were found to be major factors associated with these variations, as older subjects and the presence of an obstacle decreased the amount of tooth displacement. Furthermore, in a subgroup of patients where no obstacle was affecting the displacement, slow and fast movers were identified; the location of the teeth in the maxilla or the mandible was in part responsible for these variations among subjects. One patient was excluded from the study because of insufficient quality of the three-dimensional reconstruction of the extracted teeth; the resorbed volume could not be quantified. Therefore, data from 29 patients were analyzed and presented.

Significant differences were observed in the amounts of cervical root resorption between the orthodontically moved teeth (n = 57) and the controls (n = 56): the former showed a mean resorption of 0.00055 mm³ (standard deviation [SD] = 0.00037) and the latter showed a mean resorption of 0.00003 mm³ (SD = 0.00010; U = 245, P < 0.001; Figure 2). After 2 months of force application, the range of cervical root resorption varied substantially in the experimentally displaced teeth.

The amount of cervical root resorption of the experimentally moved teeth within the same individual were significantly correlated (R = 0.421, P = 0.023).

Concerning the influence of location, whether the experimental teeth were located in the maxilla or the mandible, in 21 patients, one tooth was moved in the upper arch and the other was moved in the lower arch. The teeth located in the mandible showed significantly more resorption than those located in the maxilla: 0.00062 mm³ (SD = 0.00032) versus 0.00047 mm³ (SD = 0.00042), respectively, 95% confidence interval (CI): −0.00029, −0.00001, P = 0.046. In this calculation, both teeth with and without obstacle were included, but the presence of an obstacle almost evenly affected the maxilla or the mandible.

In 12 patients, one experimental tooth encountered an obstacle while moved, whereas the other tooth did not. No significant difference on the amount of root resorption was observed between the two groups: 0.00065 mm³ (SD = 0.00041) versus 0.00075 mm³, respectively (SD = 0.00043), 95% CI: −0.00021, 0.00041, P = 0.499.

For the entire experimental group (N = 57), the amount of tooth displacement and the amount of root resorption (square root transformation) were significantly correlated (R = 0.318, P = 0.016). In order to exclude the presence of an obstacle as a confounding variable when only teeth without obstacle were included (N = 34), the correlation slightly increased (R = 0.382, P = 0.026).

When including only patients with both experimental teeth moving without obstacle (N = 11), the multiple regression analysis showed that the amount of cervical root resorption (square root transformation) was associated with the displacement and the location of the moved teeth (maxilla/mandible; adjusted R = 0.54, P = 0.036; Table 2).

Discussion
The present study showed variations in the amount of orthodontically induced cervical root resorption between healthy individuals, whereas within the same individual the amount of root resorption was significantly correlated. Part of the variation was explained by the location of the teeth in the maxilla or the mandible; teeth in the lower arch being more prone to resorption than teeth of the upper jaw. The presence of an obstacle that could decrease the amount of

Figure 1. (A) Reconstructed image of a micro-CT scan of an experimentally moved premolar: presence of root resorption craters in the cervical area of the root. (B) Example of the volumetric quantification of the resorption craters of an experimentally moved premolar. CT, computed tomography.
tooth movement does not seem to decrease substantially the amount of root resorption. The amount of tooth movement was correlated to the amount of root resorption.

By using the experimental model described by Owman-Moll (11), an experimental tooth movement was conducted in 30 patients during 8 weeks allowing us to study the effect of the same type of tooth movement (buccal tipping) on root resorption. This model was initially used for the evaluation of root resorption in previously moved and finally extracted premolars, and root resorption was evaluated by histology and conventional radiographic method. Later, it was used by others for the evaluation of orthodontically induced root resorption using the micro-computed tomography technique (13,17–19, 24).

A buccal tipping was exerted during 8 weeks in all experimentally moved teeth. We did not have the possibility to estimate the amount of the apical root resorption, thus we have focused to evaluate root resorption in the cervical part of the root, hypothesizing that the resorption is equal in these two parts of the root. When buccal tipping forces are exerted, the buccal cervical and lingual apical regions are under compression, whereas the buccal apical and lingual cervical are under tension (5, 25–26). These high-pressure zones seem to be more susceptible to resorption: significantly more resorption has been reported to be on the buccal cervical and lingual apical regions on the root surfaces than on other regions (8).

Furthermore, it has been shown that under buccal tipping forces, higher compressive stress on the lingual apical regions caused similar amounts of root resorption per unit area with those on the buccal cervical regions (27).

Individual variations have been reported to be an important factor for both tooth movement and root resorption (7,9,11,14,16,28). The present clinical study confirms these findings. Furthermore, a correlation was found between the amount of tooth movement and the amount of cervical root resorption with a correlation coefficient.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Gender</th>
<th>Displacement (mm)</th>
<th>Resorption (mm³)</th>
<th>Location</th>
<th>Obstacle</th>
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<td>1</td>
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<tr>
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</tr>
<tr>
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<td>−</td>
</tr>
<tr>
<td>5</td>
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<td>1.8</td>
<td>0.00101</td>
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</tr>
<tr>
<td>6</td>
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</tr>
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<td>0.00005</td>
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</tr>
<tr>
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<td>M</td>
<td>3.9</td>
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<tr>
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<td>Maxilla</td>
<td>+</td>
</tr>
<tr>
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<td>F</td>
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</tr>
<tr>
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<td>+</td>
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</table>

Figure 2. Box plots based on the medians, quartiles, and extreme values for the amounts of cervical root resorption of the experimental and control teeth. The asterisks show the extreme values.
Table 2. Multiple regression analysis to test the significance of displacement and location on the amount of cervical resorption (square root transformation). Significance of the model: \( R = 0.543, R^2 = 29\% \), adjusted \( R^2 = 22\% \), \( P = 0.036 \). Multiple regression analysis: \( Y = b_0 + b_1 \) displacement + \( b_2 \) location. Independent variables: displacement + location (0: maxilla/1: mandible). \( b_0 = \) constant; \( b_1, b_2 = \) regression coefficients; \( R = \) correlation coefficient; \( R^2 = \) percentage of explained variance.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient ( b )</th>
<th>Standard error</th>
<th>Significance</th>
</tr>
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<td>0.001</td>
<td>( P = 0.034 )</td>
</tr>
<tr>
<td>Location</td>
<td>0.008</td>
<td>0.004</td>
<td>( P = 0.039 )</td>
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</table>

\( r \) being 0.34 which is comparable to previous studies (0.36 and 0.20, respectively) (14,12). The correlation increased (0.54) when the location on the experimental teeth was included in the model as a confounding factor.

Several studies have attempted to identify patient-related factors responsible for external apical root resorption, in particular of the maxillary incisors related to orthodontic tooth movement. A meta-analysis based on 8 clinical studies in humans concluded that apical displacement was highly correlated with the mean apical root resorption \( (r = 0.822) \) as evaluated by cephalometric or panoramic X-rays (29).

In our study, large variations on the amount of cervical root resorption were found between individuals. However, within the same individual the amount of root resorption in the two experimentally moved teeth was correlated. Part of this variation was explained by the location of the teeth in the maxilla or the mandible: we found that teeth located in the mandible showed significantly greater resorption than those located in the maxilla. Until now, ambiguous results from previous studies have been reported, thus it was difficult to conclude whether the teeth in the maxilla or the mandible are more susceptible to root resorption. No significant differences in root resorption were found between the maxillary and the mandibular teeth evaluated either radiographically (30) or by using a micro-computed tomography scan for direct volumetric measurements (14,31–33). On the other hand, in a clinical study in which a controlled light and heavy force in a buccal direction was applied for 12 weeks, it was found that the maxillary first premolars were more likely to suffer from orthodontically induced inflammatory root resorption than the mandibular premolars. The authors attributed these differences to the better vascularity and the recruitment of more inflammatory cells into the resorption areas in the maxillary spongy bone rather than the amount of tooth displacement (9). The method used for measuring the root resorption as well as the measured area on the root surface, may account for these discrepancies.

Several factors such as bone density, bone turnover, and some anatomic features have been identified to be different between the maxilla and the mandible, thus may influence the susceptibility of root resorption in each jaw. When bone is denser, more force application is required to induce tooth movement and more resorption may be induced (33). Bone turnover differs between the jaws with significantly higher rate of bone formation in the mandible compared with the maxilla (34). In an animal study in rats, Verna and Melsen (35) showed that high bone turnover increased the amount of orthodontically induced tooth movement compared with normal or low bone turnover but had no effect on root resorption. Only in the group with low bone turnover, a significantly larger amount of resorption was observed on roots that were not submitted to mechanical loading. The authors suggested that in subjects where decreased bone turnover rate is expected, the risk of root resorption could be increased (36). On the other hand, the maxilla is composed of relatively thin cortices compared with the mandible and has a higher rate of bone resorption which consequently initiates more rapid bone turnover (37). Factors, such as the amount of alveolar bone around the tooth, the thickness of the cortical bone, and the density of the trabecular network have failed to show any correlations with the amount of root resorption (38). Furthermore, as the total surface area of a mandibular premolar is less than the maxillary premolar, we may assume that when a force is applied, the amount of force per unit of area is greater in the mandibular premolar than in the maxillary premolar.

Although in a previous study using the same material we found that the presence of an obstacle decreases the amount of tooth movement (16), it does not seem to decrease the amount of root resorption. Probably only the force application may be sufficient enough to start the root resorption process, independently to how extensive may be the tooth movement. In the present study, the amount of root resorption was found to be correlated to the amount of tooth movement under both presence or absence of an obstacle. The continuity of the force could also play an important role in the amount of root resorption, as suggested by Lundgren et al. (28) and Owman-Moll et al. (10,11), who used the same experimental design as in this study but with weekly archwire reactivations to prevent force decay. However, the same authors, found no statistically significant differences in neither the amount of tooth displacement nor the amount of root resorption when the applied force ranged from 50 to 100 cN. It was also noted that the amount of root resorption was greater after 7 weeks with 50 cN than with 100 cN. Similarly, in a more recent study, no relationship was found between magnitude of orthodontic force, amount of tooth movement, and severity of root resorption (39). In the present study, instead of reactivating the archwire weekly, we chose a force level of 100 cN to give a greater force decay tolerance margin. When the amount of force was measured after 4 weeks, the force level did not drop below 50 cN for any patient. Recently, the application of molecular biology methods, have supported the hypothesis that apart from mechanical factors, susceptibility or resistance to root resorption is a genetically influenced trait (40,41).

In conclusion, in the present study, large variation on the amount of cervical root resorption was identified between individuals. A part of this variation was attributed to the location of the teeth in the mandible or maxilla. At the individual level, the amount of root resorption was correlated within the same subject. The amount of root resorption was correlated to the amount of cervical root resorption \( (r = 0.822) \) as evaluated by cephalometric or panoramic X-rays (29).

\( Y = 0.001 + b_1 \) displacement + \( b_2 \) location
Conflict of Interest
None to declare.

References


