CLINICAL RESEARCH

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Incidence and severity of root resorption in orthodontically moved premolars in dogs

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Structured Abstract

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Objectives – To study treatment-related factors for external root resorption during orthodontic tooth movement.

Design – An experimental animal study.

Setting and Sample Population – Department of Orthodontics and Oral Biology, University Medical Centre Nijmegen, The Netherlands. Twenty-four young adult beagle dogs.

Experimental Variable – Mandibular premolars were bodily moved with continuous or intermittent controlled orthodontic forces of 10, 25, 50, 100, or 200 cN according to standardized protocols. At different points in time histomorphometry was performed to determine the severity of root resorption.

Outcome Measure – Prevalence of root resorptions, defined as microscopically visible resorption lacunae in the dentin. Severity of resorption was defined by the length, relative length, depth, and surface area of each resorption area.

Results – The incidence of root resorption increased with the duration of force application. After 14–17 weeks of force application root resorption was found at 94% of the root surfaces at pressure sides. The effect of force magnitude on the severity of root resorption was not statistically significant. The severity of root resorption was highly related to the force regimen. Continuous forces caused significantly more severe root resorption than intermittent forces. A strong correlation ($0.60 < r < 0.68$) was found between the amount of tooth movement and the severity of root resorption.

Conclusions – Root resorption increases with the duration of force application. The more teeth are displaced, the more root resorption will occur. Intermittent forces cause less severe root resorption than continuous forces, and force magnitude is probably not decisive for root resorption.

Key words: dogs; force magnitude; force regimen; root resorption; tooth movement

Introduction

In most orthodontically treated patients root resorption is small and of no clinical importance (1). A recent systematic literature review, however, indicated that 5% of all orthodontic patients experience more than 5 mm of root shortening (2). Root resorption starts with the resorption of cementum. This initial phase is reversible as the resorption area can heal completely by deposition of new cementum when the forces are withdrawn (3, 4). Resorption of cementum alone is therefore not a risk for the dentition. But the resorption of the root dentin is irreversible and resorption areas can only be repaired by cementum deposition (5).

Root resorption can be detected histologically or radiographically. The detection of severe apical resorption is very well possible using radiographs (6–9). However, mild apical resorption and resorption at the mesial or distal root surfaces are hardly visible on radiographs, and are difficult to detect in the clinical situation. Histological techniques are more sensitive in this respect, and show the real extent of resorption (10). Although root resorption is a common side-effect of orthodontic treatment, its causes remain essentially unknown (11, 12). Patient-related factors are supposed to be the most important (10, 12–14). Tooth anatomy is generally accepted as a factor related to root resorption (7, 12, 14–16), although the mechanism behind it is still not clear (17–19). Treatment-related factors have also been reported manifold. Root resorption might be related to force magnitude, although others could not confirm such a relation (10, 20). Root resorption probably is induced by periodontal ligament compression and concomitant hyalinization (11, 21–24). It seems that these findings are in favor of the classical suggestion by Reitan (3) to aim at bodily tooth movement with light continuous forces. Others, however, suggested that tipping movement leads to less root resorption than bodily movement (25). Prevention of hyalinization or promoting its removal by the use of intermittent forces or by allowing force dissipation might also reduce root resorption (26–28).

The distance over which the tooth is moved and the treatment duration may be other factors related to the incidence of root resorption (8, 16, 11, 19), although the latter association could not be established by others (9, 15). Intrusion (6, 9, 15) and torque (29) are reported to be risk-bearing, especially if the roots are in close contact with the cortical bone (6, 30).

The present study was performed to improve the knowledge on putative treatment-related factors such as force magnitude, duration of force application, force regimen, and amount of tooth movement. Their effect on the incidence and the severity of root resorption was quantified during standardized bodily orthodontic tooth movement in beagle dogs.

Material and methods

Twenty-four young adult beagle dogs, including three pairs of twin brothers were used. After pre-medication with 1.5 mL Thalamonal® (fentanyl 0.05 mg/mL and droperidol 2.5 mg/mL; Janssen pharmaceutica, Beerse, Belgium) the dogs were anesthetized with Nesdonal® 15 mg/kg (thiopental sodium 50 mg/mL; Rhone Poulenc Pharma, Amstelveen, the Netherlands) and the mandibular third molars were extracted. Sixteen weeks later orthodontic appliances were placed at the left and right sides of the mandible in each dog. The canine, fourth premolar and first molar were connected with a lingual bar to serve as an anchorage unit. The mandibular second premolars were bodily distalized along a sliding bar using pre-stretched elastics or Sentalloy® closed coil springs (GAC, New York, NY, USA). The left and right sides of each dog were randomly assigned to one of seven experimental treatments, applying continuous forces of 10, 25, 50, 100, or 200 cN and intermittent forces (16 h a day) of 10 or 25 cN. At the left and right side of each dog different forces were used. The tooth position was measured intra-orally twice a week using a digital caliper. The forces were applied for 4, 7, 11, and 14 days (short duration) and for 14–17 weeks (long duration). The distribution of the treatments is shown in Table 1. A detailed description of the interventions can be found elsewhere (31, 32). Ethical permission for the study was obtained according to the guidelines for animal experiments of the University of Nijmegen.

At the end of the experimental period the animals were anesthetized with Narcovet® (Sodium pentobarbital

Table 1. **Number of experimental sides assigned to the different experimental conditions [force magnitude in cN, force regimen = continuous (Cont) or intermittent (Intermit), and duration = 0–2 weeks or 14–17 weeks]**

	Force regimen							
	10 cN		25 cN		50 cN	100 cN	200 cN	
Duration in weeks	Intermit	Cont	Intermit	Cont	Cont	Cont	Cont	Total
1–2	4	3	4	3	2	2	4	22
14–17	6	4	5	3	4	2	2	26
Total	10	7	9	6	6	4	6	48

60 mg/mL; Apharmo Arnhem, the Netherlands). Then 0.5 mg/kg heparin (Thromboliquine®, Organon, Boxtel, the Netherlands) was given, followed by a lethal dose of Narcovet® intravenously after some minutes. The thorax was opened and the vascular system was perfused by the aortic arch with physiological saline, followed by 4% neutral formaldehyde for fixation. Both sides of the mandible were dissected and immersed in a 4% neutral formaldehyde solution for 2 weeks. Serial mesio-distal sections of 7 μm were cut containing tooth and surrounding alveolar bone and every twenty-fifth section was HE-stained. Of each tooth five undamaged sections showing the largest root surface were selected for histomorphometric analysis. These sections were projected by a projection microscope (Bausch and Lomb, Rochester, NY, USA). The outline of the root dentin and cementum and the resorption areas were traced (Fig. 1) and digitized. Root resorption was defined as microscopically visible resorption lacunae in the dentin.

The incidence of root resorption for each root surface at the pressure sides was scored. For each resorption area the largest length (Fig. 1: L1, L2, L3) and depth (Fig. 1: D1, D2) were quantified. To determine these parameters, the original outline of the dentin-cementum border was estimated by tracing the most likely root contour (Fig. 1). Root length of each root was defined as the axial distance from the line through furcation and the enamel-cementum border to the apex of the root (Fig. 1: A, B). The relative resorption length (in percent) was calculated by (L1/A) × 100. When two or more resorption areas were present at one root surface, the relative resorption length was calculated by [(L2 + L3)/B] × 100 (Fig. 1). The surface area of the resorptions was calculated, and in case more than one resorption area was present at one side, their surface areas were added.

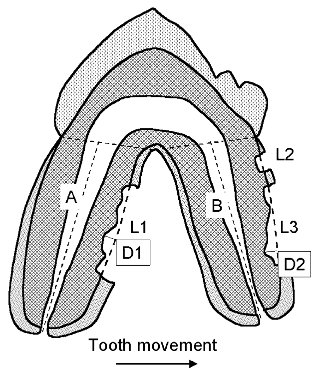

Fig. 1. Schematic drawing of a parasagittal section through a mandibular second premolar indicating the measurements on the resorption areas.

In order to estimate the intra- and interobserver measurement agreement, the histologic sections of 20 randomly chosen teeth were retraced and remeasured by two independent observers.

Statistics

Systematic differences between observers were tested by paired *t*-test after log-transformation. The relative random measurement error (e) was calculated according to Dahlberg's equation: $e = \sqrt{\Sigma \mathrm{di}^2/2n}$, in which di is the difference between two duplo measurements and n is the number of duplo measurements. The reliability of the measurement is expressed as the measurement-remeasurement correlation after log-transformation.

The influence of the treatment variables on the amount of root resorption was calculated for resorption areas at the pressure sides. The histologic sections of both pressure sides of each tooth were considered to be dependent. Therefore, the maximum resorption values for length, depth, relative length and area, for each tooth were taken for further analysis. A square root transformation was applied on the data of the area in order to obtain normality. The values of the depths of the resorptions were log-transformed. ANOVA was used for evaluation of the dog-influence. The influence of force magnitude and force regimen on the amount of root resorptions was evaluated by multiple regression analysis. The influence of the amount of tooth movement was tested by Pearson's correlation coefficient.

Results

Measurement error

The intra- and interobserver agreement on the prevalence of root resorption was 100%. Therefore, this judgement can be considered as reproducible.

The quantitative data revealed no statistical significant differences between the two observers ($p > 0.05$). For the resorption length, depth, and area, the relative intra-observer measurement error was 21, 17, and 20% respectively, and for the same parameters, the relative interobserver measurement error was 23, 20, and 35% respectively. The intra-observer measurement-remeasurement correlation for the resorption parameters ranged from 0.85 to 0.91, and the interobserver correlation ranged from 0.89 to 0.92. This means that the reliability of the quantitative assessment of root resorption under the circumstances of this experiment was high.

Incidence of root resorption

As early as 7 days after force application, small resorption areas were found at some root surfaces at the pressure side. After the first 2 weeks of force application, 16% of the root surfaces (n = 44) of the combined groups showed root resorption. Root resorption was not encountered within 2 weeks in any of the teeth to which forces of 10 or 25 cN had been applied, while it was apparent in 44% of the roots in the 50, 100, or 200 cN groups.

After long term distalization (14–17 weeks), root resorption was observed at 94% of all root surfaces (n = 52) at the pressure sides. Resorption areas were observed at all roots that had experienced continuous forces and at 86% of those that had experienced intermittent forces.

All resorption areas were located at the middle part of the roots and no apical resorptions were detected. In 88% of the teeth studied after long term distalization (n = 26), root resorption was found at the pressure sides of both the mesial and the distal root of a tooth. In the other 12% root resorption was only present at the pressure side of the mesial root.

Severity of root resorption

As the incidence of root resorption in the group with short term force application was rather low, the effect of the treatment variables on the severity of the root resorption was only analyzed in the group with long term force application. The dog influence on any of the quantitative parameters measuring the severity of the root resorption was not statistically significant (ANOVA; $p > 0.2$). Force magnitude did not have a statistically significant influence on the severity of root resorption ($p > 0.4$). For the analysis of the effect of force regimens, pooling of the sides with the same regimen but with different force magnitudes (10 or 25 cN) was therefore allowed. Multiple regression analysis on the continuous and intermittent force groups showed that the former caused more severe root resorption than the latter. For the resorption parameters length, depth, area, and relative length, the differences were significant ($p < 0.02$).

Because of their skewness, the data are presented in Box and Whisker plots, showing the medians and the 5, 25, 75, and 95 percentiles (Fig. 2). The median length, depth, and surface area in the continuous force groups were 4.6 mm, 340 μm, and 0.64 mm^2, and in the intermittent force groups 2.2 mm, 210 μm, and 0.21 mm^2, respectively. In the continuous force groups the median relative resorption length was 59% (range 42–77%), and in the intermittent force groups 30% (range 6–69%). Pearson correlation analysis revealed a significant correlation between the severity of root resorption and the amount of tooth movement for all resorption parameters ($0.60 < r < 0.68$; $p < 0.001$).

Discussion

In some patients orthodontic treatment leads to substantial root resorption while in others it does not. Variables associated with root resorption are amongst

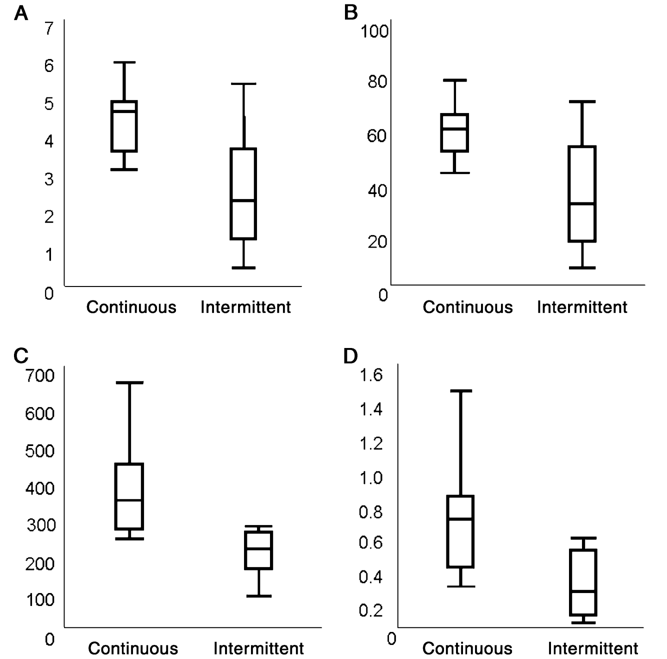

Fig. 2. Box-and-Whisker-plots of the results of the measurements for continuous and intermittent force regimes, indicating the medians, and the 5, 25, 75, and 95 percentiles. (A) Length of the resorption in millimeter. (B) Relative length of the resorption in percent. (C) Depth of the resorption in micrometer. (D) Surface area of the resorption in square millimeter.

others the duration of force application (8, 16), force magnitude (10, 20), force regimen (33), and the amount of tooth movement (15). The aim of this controlled study was to investigate the effect of these variables on the incidence and severity of root resorption during bodily tooth movement in a dog model.

In this study only root resorption extending into dentin was considered. Root resorption in cementum is difficult to quantify as the outer border of the cementum is not stable (3–5). It appeared to be quite easy to determine the incidence of root resorption in dentin in a histological section. In the quantitative part, good measurement-remeasurement correlation showed that the measurements were reliable. For the surface area and the depth of the resorption area, the original outline of the dentin-cementum border had to be estimated, which appeared to be difficult for some large resorption areas. However, the results were quite reproducible, implicating that they are reliable. It should be realized that root resorption is a three-dimensional phenomenon. This means that two-dimensional measurements only can give an indication of the extent of resorptions, and by definition lead to under-estimation of their real extent.

In this study root resorption during bodily tooth movement was studied and only the pressure sides were considered. Root resorption appeared almost exclusively in the middle part of the roots and not in the apical part. This can be explained by the sand-glass shape of the periodontal space, which is thinnest in the middle part of the root (34). Therefore, hypoxia and subsequent hyalinization will be most prominent in that area, and a close relation between hyalinization and root resorption has been suggested by several authors (21–24, 27, 35). Also the observation that root resorption is mainly found in the cervical and apical region during tipping movements (25, 36) points into that direction.

After 7 days of force application root resorption was already present at some root surfaces and after 2 weeks 16% of all root surfaces at the pressure sides showed root resorption. This is in agreement with other studies (31, 37) stating that in humans and in dogs it takes about 7 days for cells to proliferate and differentiate into osteoclasts. Other authors have shown that in rats this process is faster (26, 38). In the present study, root resorption was clearly progressing in time, and after 14–17 weeks of tooth movement, the incidence had increased to 94% of the root surfaces at the pressure sides. Root resorption was quite extensive as the length of the resorption areas ranged from 6 to 77% of the root length, and their depth ranged from 90 to 670 μm in the dentin. In the most severe case only about 60% of the dentin remained.

Force regimen turned out to be a very important factor for the severity of root resorption. Intermittent forces resulted in 40–70% less root resorption than continuous forces. The same phenomenon has been described for rats in which a daily inactivation of 4–9 h led to significant less root resorption than continuous activation (27). Intermittent forces probably prevent the formation of hyalinized areas or they allow reorganization of the hyalinized periodontal tissues and restoration of the blood flow during the time that forces are not active (27). Also in clinical situations cell proliferation in the periodontal ligament might be favored and repair or recovery is stimulated during inactive periods (5, 39, 40).

It is known from *in vitro* studies that within 1 h after mechanical stimulation, cells express adhesion molecules such as integrins, which regulate a variety of biological processes like cell differentiation, cell proliferation, and wound healing (41, 42). During inactivation, the expression of integrins might be responsible for activating the repair mechanism, but also morphogens such as growth factors, pro-inflammatory factors, and hormones may play a role. Continuous forces leave no time for repair of damaged blood vessels and other periodontal tissues, which might lead to more extensive resorption. It is therefore interesting to speculate on the length and the frequency of the inactive periods needed to achieve the most efficient tooth movement with the least negative side-effects.

In the present study in dogs, an inactivation of 8 h/day was sufficient to decrease the damage to the supporting tissues. In rats, daily inactivation for 4–9 h showed similar results (27). Another rat study, in which forces were allowed to decline for 16 days, and then were reactivated showed that tooth movement accelerated again, but root resorption did not aggravate (26).

In clinical orthodontics most forces are continuous, but declining between two activations. The duration of this clinical pause has hardly been specified in literature, but can be estimated to be approximately 1 or 2 weeks. Clinical experimental studies in which premolars were tipped through the buccal cortex (28, 33), revealed that intermittent forces were associated with reduced root resorption compared to constant continuous forces. Another clinical study showed that an interval of 3 months without force resulted in a significant lower absolute amount of root resorption (39). This might be due to the fact that the repaired cementum is more resistant to resorption.

Another factor that should be considered is that intermittent forces result in less tooth movement than continuous forces during the same time period (28, 32, 33). In dogs, distalization of premolars using intermittent forces for 3 months was less efficient than with continuous forces (32). In a clinical experimental study, tipping tooth displacement initiated by intermittent forces was 65% reduced as compared with continuous forces after 7 weeks (33). The fact that teeth in the intermittent force group moved over a shorter distance might also be an explanation for the less severe root resorption. It is therefore interesting to evaluate in future studies whether teeth moved over the same distance using continuous or intermittent forces are resorbed to the same extent.

In our study, force magnitude did not appear to be decisive for the incidence and severity of root resorption. This means that light forces can cause extensive root resorption too. In humans, the absence of a relation between force magnitude and the amount of root resorption at forces of 50, 100, and 200 cN was reported earlier (10, 20). Independent of force magnitude and force regimen large individual variations in root resorption were found. A source of variation is probably the individual metabolic response to mechanical stimuli (10, 20). The release of growth factors and prostaglandins, which are involved in bone and root resorption is probably individually determined and age related (43, 44). This means that the cause of root resorption is multifactorial and that some individuals are predisposed for root resorption. At the moment it is still not possible to identify these patients at risk before the start of treatment. Further studies are needed to get more insight into the individual factors that determine the process of root resorption.

Conclusions

From this study is can be concluded that root resorption increases with the period of force application. The severity of root resorption is highly influenced by the amount of tooth movement and the force regimen. The more teeth are displaced, the more root resorption will occur. Intermittent forces cause less severe root resorption, and force magnitude is probably not decisive in the process of root resorption.

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