The effect of endodontic procedures on apical crack initiation and propagation ex vivo

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Abstract

Aim To evaluate the potential effects of endodontic procedures (instrumentation and filling) on crack initiation and propagation in apical dentine.

Methodology Forty extracted single-rooted premolars with two canals were selected, 1.5 mm of the apex was ground perpendicular to the long axis of the tooth and the surface polished. The specimens were divided into 4 groups. The buccal canals of groups A, B and C were enlarged to size 40 with manual K-files. Group A was filled with gutta-percha using lateral condensation and vertical compaction without sealer. Group B was filled with the same method as group A except only lateral condensation was used. Group C was left unfilled, while group D was left unprepared and unfilled. Images of the resected surface were taken after resection (baseline), after canal preparation, after filling and after 4-week storage. The images were then inspected for cracks originating from the canal.

Results A significant effect of preparation on crack initiation (P < 0.05) and no significant effect of filling (P > 0.05) or 4-week storage on crack initiation (P > 0.05) was found (logistic regression). Fisher’s exact test revealed a significant effect of filling on crack propagation (P < 0.05) and no effect of 4-week storage on crack propagation (P > 0.05).

Conclusions Root canal procedures can potentially initiate and propagate cracks from within the root canal in the apical region.

Keywords: apical root cracks, crack initiation, crack propagation, dentinal cracks, vertical root fracture.

Introduction
A vertical root fracture is defined as a complete or incomplete fracture initiated from the root at any level, usually directed facio-lingually (Kahler 2008). The stresses generated from inside the root canal are transmitted through the root to the surface where they might overcome the bonds holding the dentine together (Wilcox et al. 1997). Fracture occurs when the tensile stress in the canal wall exceeds the ultimate tensile strength of dentine (Lam et al. 2005). However, since there have been very few reports of root fracture during root canal treatment, vertical root fracture is the end result of the propagation of a crack. In a spreader load study (Soros et al. 2008), a sudden drop of the curve was observed in the load penetration graph just before vertical root fracture occurred. The authors speculated that such drops might be correlated to crack initiation or propagation of pre-existing cracks.

The strength of a root filled tooth is directly related to amount of remaining sound tooth structure (Zandiligari et al. 2006). Canal preparation, which involves removal of dentine and may compromise the
fracture strength of the root (Sathorn et al. 2005), was found to have a significant effect on the incidence of incomplete apical cracks and dentinal defects (Adorno et al. 2009, Bier et al. 2009). Moreover, except in very weak roots, root canal filling (RCF) should not be regarded as a major cause of vertical root fracture because the load generated during lateral compaction is generally less than that required to fracture the roots (Saw & Messer 1995). However, RCF does have a significant effect on the incidence of incomplete root cracks and dentinal defects as reported previously (Onnink et al. 1994, Shemesh et al. 2010).

Therefore, the purpose of this laboratory study was to evaluate the effects of endodontic procedures, namely canal preparation and RCF (lateral compaction and/or vertical compaction), on crack initiation and horizontal propagation in the apical dentine. The null hypothesis was that root canal procedures have no effect on crack initiation and propagation.

**Materials and methods**

Forty extracted human maxillary single-rooted premolars with 2 canals each were randomly selected. No information was available regarding the reason for extraction or the age of the patients. A digital radiograph was used to confirm the presence of 2 canals in the root. The root surfaces of each tooth were checked under a digital microscope (VH-8000, Keyence, Osaka, Japan) for the absence of fracture lines, as well as open apices or anatomical irregularities. The teeth were stored in distilled water throughout the study.

An apical portion of 1.5 mm of the teeth was ground perpendicular to the tooth axis with waterproof 320-grit silicon carbide abrasive paper. The apical surface was polished with waterproof 1000-, 1200- and 1500-grit silicon carbide abrasive paper to reduce the fine scratches and to obtain a clear highly magnified image. Fine polishing was then performed with a short synthetic polishing cloth (Struers, Ballerup, Denmark) with diamond paste of particle sizes 0.6 and 0.3 µm. The crowns were then removed at the proximal cement/enamel junction with a water-cooled low-speed saw (Isomet, Buehler, Lake Bluff, IL, USA), perpendicularly to the tooth axis. The resulting coronal surface provided a reference plane that was parallel to the apical polished surface. The coronal and middle thirds of the buccal canal were preflared with Gates-Glidden drills (sizes 1–4. Dentsply Maillefer, Ballaigues, Switzerland) and irrigated with a 6% sodium hypochlorite (NaOCl) solution. The apical surface was then stained with 1% methylene blue dye, rinsed with water, and dried with absorbent paper. A halogen fibre optic light (SurgiTel®, General Scientific Corporation, Ann Arbor, MI, USA) was also used as an aid for identifying cracks by transillumination, with the light beam aimed perpendicularly to the long axis of the teeth. Each tooth was placed under a digital microscope (VH-8000, Keyence) with the apical surface perpendicular to the line of sight, and a baseline image was recorded.

The buccal canals were manually prepared with a size 10 stainless steel K-file (25 mm, Zipperer, Munich, Germany) using the balanced force technique (Roane et al. 1985) until the file tip was observed at the apical plane. This procedure was repeated using sizes 15, 20, 25, 30, 35, and 40 K-files. Irrigation with 1 mL of 6% NaOCl between files and final irrigation with 3 mL of 6% NaOCl was performed. The lingual canal was left unprepared. The teeth were divided into 2 experimental groups (groups A and B) and 2 control groups (groups C and D) of 10 specimens each.

**Group A:** The buccal canals were filled using gutta-percha points (GC, Tokyo, Japan) with no sealer, using the lateral compaction method. Room for 3 accessory cones was consecutively created using a nickel-titanium spreader (Naviflex NT D11T, Brasseler USA, Savannah, GA, USA). Finally, a System B unit (Analytic Endodontics, USA) was set to full power measurement of 200 °C, inserted into the canal to the binding point, and held there for 10 s. A 1 s touch of heat (200 °C) was applied and after waiting a further 1 s, the plugger was removed. The coronal portion was backpacked using an Obtura II (Obtura Spartan, Fenton, MO, USA) with a 23-gauge applicator needle at a setting of 200 °C. Vertical compaction was performed with a cold manual plugger.

**Group B:** The buccal canals were prepared following the same procedures as for group A and filled using only the lateral compaction method without using sealer.

**Group C** was left unfilled and Group D was left unprepared and unfilled.

Images were taken after preparation and immediately after filling. The specimens were stored in normal saline at room temperature for 4 weeks and a final image was taken. A total of 4 images were recorded for each specimen (baseline, after preparation,
immediately after filling, and 4 weeks after filling/storage. A crack, considered as having been produced by forces originating from within the canal (preparation and filling), was defined as a discontinuity visible on the resected surface and originating from the root canal wall (Adorno et al. 2009, 2010). The images were compared to the baseline image and the presence of a new crack (preparation, immediately after filling and 4 weeks after filling/storage) or propagation of a crack caused during preparation (immediately and 4 weeks after filling/storage images) were noted. Logistic regression was used to analyze statistically the incidence of crack initiation by instrumentation and filling (immediately and 4 weeks after), and Fisher’s exact test was used to analyze crack incidence between the groups and to analyze propagation of cracks caused by filling (immediately and 4 weeks after).

**Results**

Table 1 indicates the crack initiation and propagation incidence for each group. No cracks were found in the baseline images, and Group D showed no cracks after 4 weeks storage. Five specimens of Groups B and 4 of Group A and C had cracks after instrumentation (Figs 1b and 2b). Logistic regression analysis revealed a significant effect ($P < 0.05$) of instrumentation on crack initiation, but there was no statistical difference between the groups (Fisher’s exact test). Group A had crack propagation in 4 of the 5 specimens immediately after filling and in 1 of 5 after 4 weeks of filling/storage (Fig. 1) and Group B presented crack propagation in 4 of 4 specimens immediately after filling and no propagation after 4 weeks of filling/storage (Fig. 2). No specimen exhibited a complete fracture from canal wall to root surface. Although RCF had no significant effect on crack initiation, it had a significant effect ($P < 0.05$, Fisher’s exact test) on crack propagation. No significant difference was found between the two canal filling techniques ($P > 0.05$, Fisher’s exact test) regarding crack propagation. Only one specimen experienced crack propagation after 4-week storage (Fig. 1). However, 4-week storage had no significant effect on either initiation ($P > 0.05$, logistic regression) or propagation ($P > 0.05$, Fisher’s exact test).

**Discussion**

The grinding of the apical 1.5 mm might have had a deleterious effect on the dentine. However, very light pressure was used and, after grinding and polishing, the baseline image showed absence of cracks on the surface. Crack propagation was studied at 1.5 mm from the apex to allow a crack caused by instrumentation or filling to be monitored throughout the different procedures. Nonetheless, because of this limitation, a new crack at the resected level might have been an extension of an existing crack at a different level (Onnink et al. 1994). For the present study, a crack not present in a previous image was considered a new crack, while a crack visibly longer was considered propagation.

High concentration NaOCl solutions such as the one used in the present study can significantly affect the elastic modulus and flexural strength of dentine (Sim et al. 2001, Marending et al. 2007). However, specimens used in the former studies (dentine bars) were immersed in NaOCl solution for 1 or 2 h and had a higher contact surface per volume ratio and for a longer period of time than the specimens used in the present one. However, the large apical foramen allowed some extrusion of the irrigant to the resected surface especially during final irrigation but whether or not this might have influenced the results is not known.

Methylene blue and transillumination were used because these provide the best discrimination between cracked and non-cracked resected roots (Wright et al. 1991).

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th>Filling</th>
<th>4 week storage</th>
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<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Initiation*</td>
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<td>Group A</td>
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<td>Group B</td>
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<td>Group D</td>
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*aInstrumentation had a significant effect ($P < 0.05$) on crack initiation.
*bFilling had a significant effect ($P < 0.05$) on crack propagation.
Staining alone may not necessarily enhance the detection of cracks because the dye cannot flow into craze lines unless there is a break in the surface (Von Arx et al. 2010).

Sealer was not used in the present study because in a pilot study the methylene blue stained the sealer, obscuring the inspected area even when transillumination was used. Conflicting results have arisen from previous studies investigating the fracture load of root canals filled with different core and sealer materials (Hammad et al. 2007, Sagsen et al. 2007, Ulusoy et al. 2007). In addition to the limitations of the methodology used, it would be difficult to infer the contribution to resistance, or lack thereof, of root canal sealers, and this area warrants further investigation. However, root canal sealers that contain eugenol might produce a volumetric expansion to gutta-percha (Michaud et al. 2008), although the extent of the forces that could be produced by this expansion has not been studied before, and it is unknown if it could be sufficient to contribute to crack incidence or propagation.

Although 2 separate canals were confirmed radiographically, the distance between both canals varied slightly between the specimens. The amount of dentine between both canals might have influenced the distribution of forces if both canals were instrumented and filled. Therefore, since a small sample size was used, only the buccal canals were instrumented and filled.

The presence of craze lines and incomplete cracks after instrumentation has been reported previously (Bier et al. 2009, Shemesh et al. 2009, Adorno et al. 2011). These defects in dentine may become high stress concentration areas from where the crack may gradually propagate to the root canal surface when an external force (i.e. RCF) is applied (Lertchirakarn et al. 1999). In the present study crack propagation was observed immediately after RCF procedures in

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**Figure 1** Group A specimen. No crack is visible in the baseline image (a). A crack can be seen after canal preparation (b). Note that apical enlargement joined the isthmus with the canal. RCF produced a slight propagation of the crack (c). Further propagation of the crack was observed after 4 weeks in storage (d). However, this was an isolated case for this group. Scale bar = 0.5 mm.

**Figure 2** Group B specimen. No crack visible in the baseline image (a). After instrumentation a crack is observed originating from an irregularity (b), possibly the initial portion of a lateral canal. Crack propagation was observed immediately after RCF (c) and no propagation observed after 4 weeks in storage (d). Scale bar = 0.5 mm.
both groups A and B. The wedging effect of RCF might contribute to crack propagation (Saw & Messer 1995). Additionally, some irregularities of the root canal wall might have become stress concentration areas from where a crack was most likely to initiate. The specimen shown in Figure 2 depicts a crack that initiated from an irregularity, possibly the initial portion of a lateral canal, after instrumentation and propagated immediately after filling. A recent study (Shemesh et al. 2010) reported the incidence of dental defects (cracks, craze lines) after RCF procedures, finding a significant difference between preparation alone and lateral compaction filling. Although the present study found no significant effect of RCF on crack initiation, this finding could be due to the small sample size and methodology. The roots in the former study were sectioned at 3, 6 and 9 mm from the apex after all procedures were completed whilst in the present study the resection at 1.5 mm from the apex was performed before the procedures. Cracks caused by instrumentation were previously reported at the resection plane 2 mm from the apical foramen and no cracks were present at 1 mm distance in the same specimens (Adorno et al. 2010). However, the resection was made after the root canal preparation, unlike the present study. If the teeth had been sectioned at a different plane, it could be speculated that cracks might be present because a fracture contained within the dentine at a certain level could communicate with the canal at a different level (Altshul et al. 1997). Although removing the apical portion of the root does not faithfully represent the clinical situation, it could partially explain why there is a higher incidence of cracks in root filled teeth compared to only instrumented teeth because a crack will grow in both the horizontal and vertical plane.

The filling technique influences root strains (Saw & Messer 1995). However, no significant difference between lateral compaction and vertical compaction on the incidence of dental defects was found in a recent study (Shemesh et al. 2010). A similar finding is reported in the present study, which used a combination of lateral compaction and warm vertical compaction as a root filling technique for group A and only lateral compaction for group B. No significant difference was found between the experimental groups. However, this may be because only the apical region was observed and higher apical strain values are associated to lateral compaction in contrast to higher coronal strain values associated to warm vertical compaction (Saw & Messer 1995).

After 4 weeks in storage, no difference was observed when compared to images taken immediately after filling, and no significant difference was found between groups A and B. Crack growth requires cyclic stressing, whereas at constant or no stress, the cracks in the dentine become blunted and require higher stresses to advance (Kružić et al. 2003). Cyclic loading will allow the crack to sharpen and blunt alternatively, allowing the crack to advance. The sharpness of the crack tip will determine the stress concentration, which will focus strain energy on the next susceptible bond during crack propagation (Kishen et al. 2004).

Further studies are warranted to assess the short and long term impact of occlusal load on crack initiation and propagation. The results of this ex vivo study should be interpreted with caution because of the lack of a periodontal ligament to distribute a force applied to a tooth along itself (Choy et al. 2000).

Conclusion

The null hypothesis was rejected. Root canal procedures generate stresses that can potentially initiate and propagate cracks from within the root canal. No complete fractures were observed in the present study.

References


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