Vertical Root Fractures and Dentin Defects: Effects of Root Canal Preparation, Filling, and Mechanical Cycling

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Abstract

Introduction: The aim of this study was to evaluate the *ex vivo* effects of root canal preparation, filling techniques, and mechanical cycling (MC) on the incidence of dentin defects and vertical root fractures (VRFs). **Methods:** Seventy extracted single-rooted teeth were divided into 6 groups. The first 2 groups were the unprepared and unprepared/MC groups. The other groups were prepared by using Gates Glidden drills and ProTaper Universal files up to F3 and were grouped according to the following: prepared teeth and the absence of root canal filling, passive technique, lateral compaction, and Tagger's hybrid technique. All of the groups except the unprepared group were subjected to MC (1,000,000 cycles, 90 N, 4 Hz, 37°C). The roots were then sectioned horizontally at 3, 6, and 9 mm from the apex and observed under a ×10 stereomicroscope. The defects were categorized as no defect, vertical root fracture, and other defects. The differences between the groups were analyzed by using the Fisher exact and χ^2 tests. **Results:** MC by itself did not influence the incidence of dentinal defects ($P > .05$, between the unprepared and unprepared/MC groups). The filled groups presented a similar incidence of other defects ($P > .05$), although VRFs were observed only when the MC was associated with pressure filling techniques (the lateral compaction and Tagger's hybrid groups). **Conclusions:** MC by itself did not induce VRF. When associated with apical pressure filling techniques, however, VRF occurred in 13.3% (lateral compaction) and 33.3% (Tagger's hybrid) of the cases. *(J Endod 2012;38:1135–1139)*

Key Words

Dentin, mechanical cycling, preparation, root canal filling, vertical root fracture

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Vertical root fractures (VRFs) are a particularly significant clinical problem because they are associated with a poor prognosis for the affected tooth (1) and often lead to tooth extraction (2, 3). Root fractures may originate from preexisting dentinal defects (eg, craze lines or incomplete cracks). Diagnosing and locating crack lines are difficult in clinical trials (4), even though cone-beam computed tomography has improved VRF diagnosis (5–8). Thus, a cautious and rigorous clinical approach to the diagnosis and follow-up of suspected VRFs should be performed (9).

Removing dental tissue during canal instrumentation (10), preparing the intraradicular post space (11), using intracanal medication for more than 30 days (12), and using excessive pressure during root canal filling (12, 13) can induce VRF and other dentinal defects. Lateral compaction is commonly used to fill the root canal system. Its use may be associated with increased VRF risk (2, 13) from the spreader design and forces applied during the lateral compaction procedure (14–18). To decrease such damage, certain filling techniques use no compaction force while creating apical sealing similar to that of lateral compaction (19, 20).

Mechanical cycling (MC) is a fatigue test that can simulate masticatory function and may lead to structural fractures after repeated loads. Fractures may be explained as the result of the spread of microscopic cracks from areas of force concentration (21). MC is the best method for predicting the clinical performance of different materials and restorative techniques. Studies have examined the influence of MC on the bond strength of certain intraradicular posts when they are adhesively bonded to dentin (22). The fatigue produced by such a mechanical test may lead to structural defects or microfractures, although whether such microfractures can eventually become macrofractures that compromise clinical tooth maintenance is not clear. Moreover, no reported studies have analyzed the effects of the intermittent loads associated with endodontic procedures on dentinal damage or VRF formation.

The goal of this *ex vivo* study was to evaluate the effects of root canal preparation, filling techniques, and MC on the incidence of dentinal defects and VRFs.

Materials and Methods

Tooth Selection

This study was submitted to and approved by the Ethical Committee of the Federal University of Santa Maria. Seventy extracted human single-rooted teeth with similar dimensions were selected and stored in a 0.9% saline solution at 4°C until use. Proximal radiographs were performed to confirm the presence of only 1 root canal. Teeth that were approximately 22 mm in length were included in this study. All of the roots were observed at ×8 magnification with a stereomicroscope (Zeiss Stemi SV6; Carl Zeiss, Jena, Germany) to exclude those with external cracks.

Because of the inclusion of upper central incisors, upper lateral incisors, and canines, a stratified random selection was performed. The teeth were divided into the following 6 experimental groups: unprepared teeth, unprepared teeth/MC, prepared teeth and absence of root canal filling, prepared teeth filled by using the passive technique, prepared teeth filled by using lateral compaction, and prepared teeth filled by using Tagger's hybrid technique. All of the groups except the unprepared group were subjected to MC.

Cleaning and Shaping

Cavity access was achieved by using 1014 diamond burs (KG Sorensen, Cotia, SP, Brazil) and under water cooling in all of the groups except for the unprepared and unprepared/MC groups.

In the prepared, passive technique, lateral compaction, and Tagger's hybrid groups, canal patency was established with a size 15 K-file (Dentsply Maillefer, Ballaigues, Switzerland). The canal opening was enlarged with a Gates Glidden (Dentsply Maillefer) #2 drill to a depth of 4 mm from the coronal orifice. The root canals were prepared by using the ProTaper Universal System (Dentsply Maillefer). Initially, the cervical and middle portions of the roots were prepared by using S1, SX, and S2 instruments. Later, S1, S2, F1, F2, and F3 files were sequentially used for all of the working lengths. Each canal was irrigated with 3 mL of a freshly prepared 2% solution of sodium hypochlorite (NaOCl) between each instrument change. To ensure that the apical diameter was uniform after each preparation, a size 30 K-file was inserted into all of the working lengths. The canals were irrigated with 2 mL of 17% ethylenediaminetetraacetic acid for 3 minutes and subsequently rinsed with 2 mL of distilled water. Next, they were dried by using size 30 paper points (Dentsply Maillefer). To prevent dehydration, all of the teeth were kept moist in purified filtered water throughout the experimental procedures. After preparation, specimens from the prepared group were etched with 37% phosphoric acid for 15 seconds, rinsed for 30 seconds, and gently air-dried. The Single Bond (3M ESPE, St Paul, MN) adhesive system was applied following the manufacturer's instructions. Finally, the Filtek Z350 (3M ESPE) composite resin was adapted into the coronal openings. The composite was light-cured from the palatal aspect for 30 seconds.

Root Canal Filling

AH Plus (Dentsply Maillefer) was mixed according to the manufacturer's instructions and placed in the canal to 1 mm short of the working length by using a 400-rpm lentulo spiral (Dentsply Maillefer) for 5 seconds (23). In the passive technique group, main gutta-percha cones of size 30 and taper 0.02 (Henry Schein, Mexico City, Mexico) were coated with sealer and placed into the root canal to the working length. Additional FM gutta-percha cones (Dentsply Maillefer) were placed without using a spreader to the depth at which resistance was met (24). In the lateral compaction group, the teeth were filled by using a size C spreader (D1 diameter 0.3 mm, 0.04 taper) (Dentsply Maillefer) and FM gutta-percha cones (24). The compaction load was controlled by a digital scale and kept at a maximum of 2 kg. Finally, in the Tagger's hybrid group, the apical third of the canal was filled with a main gutta-percha cone and 2 FM accessory cones by using lateral compaction; the cervical and medium thirds were filled with a size 60 Gutta Condenser (Dentsply Maillefer) rotating at 15,000 rpm (25). The excess gutta-percha in the coronal portion was removed with a flame-heated plugger, and the access cavity was sealed as was described previously for the prepared group. The roots were stored for 1 week at 37°C and 100% humidity to allow the sealers to set.

MC

The teeth were immersed in melted wax (Horus; Herpo Produtos Dentários, Petrópolis, RJ, Brazil) up to the cementoenamel junction for periodontal ligament simulation (26). A 0.2-mm to 0.3-mm thick wax layer was obtained after cooling.

Specimens from all of the groups except for the unprepared group were embedded in a polyvinyl chloride cylinder filled with a chemically cured acrylic resin (Dencrilay, Dencril, SP, Brazil) by using the following steps: (1) the specimen was fixed on a parallelometer, with the long axes of the teeth and cylinder parallel to each other and perpendicular to the ground, and (2) the acrylic resin was prepared and poured inside the cylinder up to the cementoenamel junction.

After resin polymerization, the wax was removed from the root surface and the resin cylinder "sockets" by using warm water for 2 seconds. The resin cylinders were filled with a polyether impression material (Impregum Soft; 3M ESPE) by using a molding syringe. The teeth were reinserted into their respective cylinder sockets, and any excess impression material was removed with a #12 scalpel blade.

The specimens from all experimental groups except for unprepared group were then positioned in an MC machine (ERIOS, São Paulo, SP, Brazil). A load was applied to the palatal aspect of the specimens at 135° along the long axes of the teeth in a wet environment (1,000,000 cycles, 90 N, 4 Hz, 37°C) (22).

Examination of Roots

All of the roots were horizontally sectioned at 3, 6, and 9 mm from the apex by using a low-speed saw and underwater cooling (Labcut 1010; Extec Corp, Enfield, CT). The slices were then viewed through a $\times 10$ stereomicroscope using a cold light source. The pictures were saved in .tiff format and analyzed by a single blinded examiner who had previously been calibrated to the measurement procedure. The same observer read the stereomicroscope images twice, with a 1-week interval between readings. The dentin was inspected, and the specimens were classified as follows: (A) no defect, root dentin devoid of any lines or cracks, with no defects on the external root surface or the internal root canal wall; (B) fracture, a line extending from the root canal space to the outer surface of the root (13); and (C) other defects, all other observable lines that did not extend from the root canal to the outer root surface (24). A tooth was considered to be fractured whenever a fracture line was observed, regardless of the slice.

Statistical Analysis

The kappa test was used to analyze the agreement between the readings of the examiner at different times. Descriptive analysis was performed through the distribution of frequencies associated with the presence of VRFs and other defects in all of the groups. Comparisons of other defects between the unprepared and unprepared/MC groups and VRF comparisons between the lateral compaction and Tagger's hybrid groups were performed by using Fisher exact test. Comparisons of other defects among the prepared, passive technique, lateral compaction, and Tagger's hybrid groups were performed by using the χ^2 test. The significance level was set at $\alpha = 0.05$. The statistical analyses were performed by using the PASW Statistics 18 software package (SPSS Inc, Chicago, IL).

Results

The kappa value was 0.83. The results are summarized in Table 1. The incidence of other defects did not differ significantly between the unprepared and unprepared/MC groups ($P > .05$). Other defects were observed in 40% and 20% of the specimens from the unprepared and unprepared/MC groups, respectively. VRFs were not observed in these 2 groups. In the test groups, 51.66% of the specimens presented other defects, although no significant differences were observed among them ($P > .05$). No VRFs occurred when the roots were not filled (prepared group) or were filled by using passive technique. By contrast, VRFs occurred after the techniques that used apical pressure. The lateral compaction and Tagger's hybrid groups presented VRFs in

TABLE 1. Number of Teeth with Root Fractures or Other Defects

		MC				
			Root canal preparation with NiTi instruments			
	Unprepared (n = 5)	Unprepared/MC (n = 5)	Prepared (n = 15)	Passive technique (n = 15)	Lateral compaction (n = 15)	Tagger's hybrid technique (n = 15)
Other defects	2 (40%)	1 (20%)	8 (53.3%)	9 (60%)	7 (46.6%)	7 (46.6%)
Root fracture	0	0	0	0	2 (13.3%)	5 (33.3%)

Other defects, lines that did not extend from the root canal to the outer root surface.

13.3% and 33.3% of the specimens, respectively; the difference between these groups was not significant ($P > .05$). Figure 1 shows the root dentin images.

Discussion

This study used 1,000,000 cycles of a mechanical fatigue test to simulate approximately 5 years of clinical function (22). The results showed that cyclic loads alone do not increase the incidence of dentinal defects. However, VRFs occurred only when the MC was associated with lateral compaction or Tagger's hybrid technique.

Other studies have reproduced the periodontal ligament during root canal filling to mimic bony sockets that may change the force distributions around the tooth when external forces such as lateral compaction are used (27, 28). However, Soros et al (28) claimed that elastomeric materials are incapable of responding to compaction forces in the same manner as natural ligament, which collapses under pressure. In the current experiment, the roots were surrounded with a polyether impression material after filling and before starting the MC. This process attempted to reproduce the periodontal ligament, which provides better stress distribution during fatigue loading (26, 29).

MC alone was not capable of inducing dentinal defects or VRFs under the experimental conditions (unprepared and unprepared/MC groups). The findings for the unprepared group differed from those of Shemesh et al (24), who did not observe other defects in unprepared teeth. However, the defects observed in our study may be explained by excessive loads caused by occlusal dysfunction before extraction, by previous trauma, and by excessive loads during the extraction or even the cutting procedures. Notably, these teeth did not show any external defects when analyzed at ×8 magnification under a stereomicroscope (ie, for initial inclusion in the study).

Dentinal defects such as craze lines (surface fractures that can only be seen via transillumination, do not appear to extend into the root canals, and do not produce discontinuities that are detectable with an explorer) or partial cracks (lines starting in the canal lumen that do not reach the external surface) may propagate and develop into fractures after the endodontic treatment (13). Additional stresses to the dentin from retreatment, post-space preparation (13), and loads propagated to the root during masticatory function and occlusal loading may also induce VRFs (30). Mechanical root canal instrumentation can also produce craze lines in the root canal walls (13), which then serve as localized sites of increased stress and act in accordance with the theory of stress concentration (27). The ProTaper Universal System was selected for this study because of its widespread use and because a previous study (10) reported a higher incidence of dentinal defects when using these nickel-titanium (NiTi) rotary files than when using other systems.

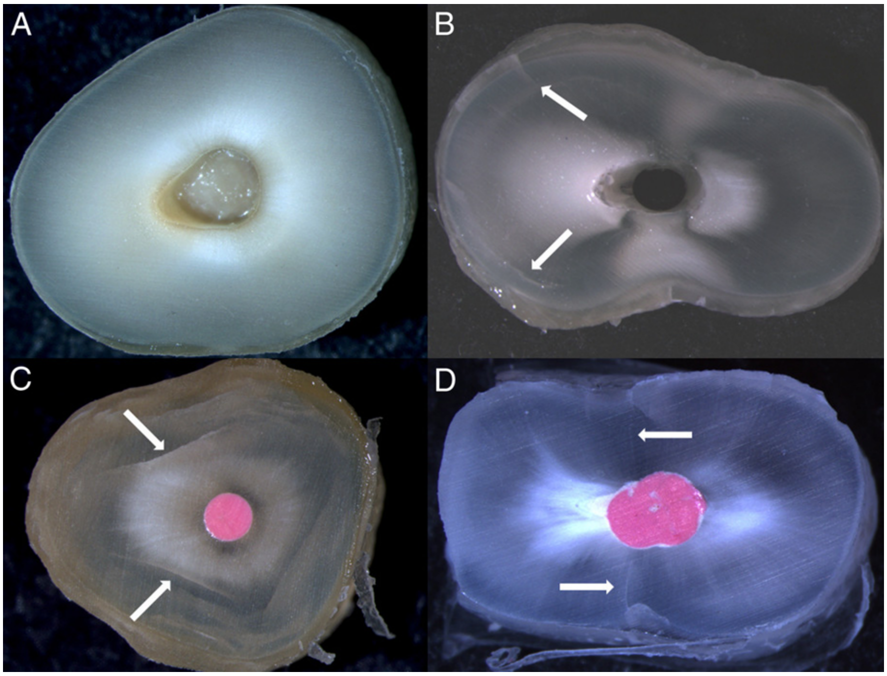

Figure 1. Classification of the different dentinal defects. (*A*) No defects. (*B* and *C*) Other defects (*arrows* indicate craze lines). (*D*) *Arrows* indicate VRF.

The prepared and passive technique groups did not differ with respect to other defects ($P > .05$). Specifically, the prepared group had 8 teeth with other defects, and the passive technique group had 9. VRFs were not found in either of these groups. On the basis of these results, MC seems to be capable of inducing a measurable amount of dentinal root defects when combined with canal preparation and a no-apical-pressure filling technique, even though it did not induce VRFs. Bier et al (10) reported that rotary NiTi instruments induced significantly more craze lines and dentinal defects than did hand file instruments. The authors attributed this disadvantage to the high number of rotations associated with rotary systems and their cutting section designs. During canal preparation, the canal is shaped via contact between the instrument and the dentinal walls, creating a momentary stress concentration in the dentin. This stress concentration may lead to dentinal defects in which VRFs can begin to form (10). Kim et al (31) used finite element analysis to compare the apical stresses generated by 3 types of NiTi rotary instruments and reported that the ProTaper generated the highest tensile and compressive stresses in the dentin, which could lead to the subsequent formation of root dentinal defects.

The lateral compaction and Tagger's hybrid groups did not show statistically significant differences regarding other defects and did not differ significantly from the prepared and passive technique groups ($P > .05$). These findings agree with those of Shemesh et al (32), who compared the lateral compaction and continuous wave filling techniques. The authors found a lower incidence of root dentinal defects, with no significant differences between the 2 techniques. The most interesting finding from the lateral compaction and Tagger's hybrid groups were the 2 and 5 VRFs, respectively, that occurred. VRFs did not occur in any other group. These findings should be highlighted because of the extreme clinical importance of VRFs and their effects on tooth survival. These values represent 13.3% and 33.3% of the VRFs that occurred when the lateral compaction and Tagger's hybrid techniques, respectively, were performed. These VRF rates are high, particularly those for the Tagger's hybrid technique; however, no significant differences were found between the 2 groups ($P > .05$). Apical pressure techniques associated with MC may possibly explain the presence of the VRFs. VRFs did not occur in the prepared group, which only received canal preparation, or in the passive technique group, which did not receive any apical pressure during canal filling. Moreover, the heat generated when using the Gutta Condenser in the Tagger's hybrid group may have generated dentinal defects, thereby inducing VRF formation (32).

Previous studies have reported that the load required to induce a VRF ranges between 7 and 17 kg (14, 27, 33). These studies have shown that the force needed to fracture a root is much higher than that formed during lateral compaction. However, VRFs result from a gradual diminution of root structures that develops from preexisting defects and should not be considered an instantaneous phenomenon (28). Shemesh et al (24) observed a higher VRF incidence in teeth prepared with NiTi rotary files and filled with lateral compaction than in teeth that were only prepared or were prepared and filled by using no-pressure techniques. No statistically significant differences were found, however. These findings agree with the results of the present study.

Lertchirakarn et al (27) assumed that VRFs are most commonly attributable to stresses generated within the canal during filling or post placement in the canal. They also found that decreasing the applied force during endodontic or restorative procedures significantly reduced the risk of fractures. These studies highlight the significance of crack initiation and propagation, rather than the actual presence of VRFs resulting from specific stress applications, when evaluating VRF formation. In the current study, the number of defects and VRFs increased when the clinical procedures combined load and MC.

Only MC failed to induce dentinal defects under the conditions of this *ex vivo* study. The incidence of dentinal defects increased when MC was associated with NiTi rotary instruments for root canal cleaning and shaping, although no VRFs were observed. Moreover, VRFs occurred in 13.3% (lateral compaction) and 33.3% (Tagger's hybrid technique) of the teeth that were subjected to apical pressure associated with cyclic loads.

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The authors deny any conflicts of interest related to this study.

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