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Influence of root dentin treatment on the push-out bond strength of fibre-reinforced posts

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Abstract: This study evaluates the influence of root dentin treatment with NaOCl alone and combined with EDTA, with and without ultrasound activation, on the push-out bond strength (BS) of fiber-reinforced posts in weakened roots, cemented with RelyX or Panavia. The root canals of 42 maxillary canines were instrumented with Reciproc and 2.5% NaOCl. In the coronal 12mm of all canals, experimental weakening of the roots was produced by reducing dentin thickness with 2.44mm diameter diamond burs. The roots were assigned to 3 groups (n = 14) according to root dentin treatment: 2.5% NaOCl; 2.5% NaOCl + 17% EDTA; and 2.5% NaOCl + 17% EDTA, with solutions agitated using passive ultrasonic irrigation. After cementation of the fiber-reinforced posts the roots were divided in thirds. The first slice of each third was used for the push-out BS test, the second slice for confocal laser scanning microscopy and dentin microhardness (Knoop) analysis. Data were analysed by a two-way ANOVA and Tukey test ($\alpha = 0.05$). NaOCl + EDTA provided highest BS values than NaOCl ($p < 0.0001$). Specimens cemented with Panavia presented significantly higher BS than those with RelyX in the three root thirds ($p < 0.0001$). The highest BS values occurred in the cervical third ($p < 0.001$). Ultrasound-activated NaOCl + EDTA promoted the greatest reduction in dentin microhardness, followed by NaOCl/EDTA and NaOCl. Ultrasonic activation of NaOCl and EDTA reduced root dentin microhardness, but did not improve the push-out BS of resin-based cements. Panavia presented higher BS than RelyX. RelyX was not influenced by the root dentin treatment protocols.

Keywords: Microscopy; Confocal; Dental Bonding; Endodontics.

Introduction

The rehabilitation of endodontically treated teeth is directly related to the amount of remaining tooth structure.[1] The absence of sufficient coronal remnant combined with the destruction of cervical root dentin results in very thin walls, allowing a higher root fracture rate when these teeth receive conventional restorations.[2] In this situation, the combined use of intracanal retainers and resin composite is recommended to reinforce the dental structure.[3] The increase of the fracture strength of endodontically treated teeth reinforced with prosthetic posts has been demonstrated clinically.[4,5] Glass-fiber posts feature advantages over other intracanal retainers such as adhesion to restorative resinous materials, elastic modulus close to that of dentin, rapid and easy technique, uniform stress distribution and good corrosion resistance.[6,7]

The cementation of an intracanal retainer has a direct influence on the stability and longevity of restorations in endodontically treated teeth.[8] Adhesiveness of the luting agent is influenced by moisture inside the canal, gutta-percha solvents and polymerization shrinkage.[9,10,11] Self-adhesive resin cements have lower contraction stress than conventional resin cements.[12]

The use of resin-based luting cements is recommended[13] to promote mechanical adhesion between the monomers of the material and the collagen fibers of dentin, with consequent formation of the hybrid layer.[14] In this sense, removal of the smear layer with consequent opening of dentinal tubules enhances the intertubular penetration of adhesive system and increases bond strength (BS).[15] Removal of the organic and inorganic components of the smear layer is achieved with irrigation with sodium hypochlorite (NaOCl) and EDTA solutions, respectively.[16] NaOCl acts as an organic tissue solvent[17] and has a bactericidal action. The chelating effect of EDTA promotes decalcification of the inorganic components exposing the dentin collagen network, which increases the adhesion of the luting agent. However, at the same time that it promotes an efficient cleaning of the root canal walls, EDTA reduces dentin microhardness, as a consequence of its decalcifying effects.[18,19]

The adhesion of resin composites used for reinforcement of weakened roots can also be influenced by the presence of root canal sealer in the dentinal tubules and along the canal walls.[20] Residual root canal sealer could reduce the intertubular penetration of the adhesive system as well as have a chemical interaction with the resin.

In this perspective, the objective of this study was to investigate the influence of different root dentin treatment protocols, with the use of NaOCl alone or combined with EDTA, with and without ultrasonic activation, on the push-out BS of fiber-reinforced posts cemented with Self-etch (Panavia F) and self-adhesive (RelyX U200) dual cure cements in experimentally weakened roots. The null hypothesis of this study is that none of the treatment protocols or cements influence the bond strength.

Methodology

Tooth selection and preparation

After Ethics Committee approval (Process number 482.179), 42 human permanent maxillary canines with a patent and single canal, fully formed apex, no internal calcifications/resorption and no previous endodontic treatment were selected based on clinical and radiographic examinations from a pool of extracted teeth belonging to our endodontics laboratory collection and stored in 0.1% thymol solution. Sex, ethnicity and age of the tooth donors were unknown. After washing in running water for 24 hours, the teeth had the crowns removed close to the cementoenamel junction to obtain roots with a standardized length of 17 mm.

The working length was visually established as 1 mm shorter than the canal length. All teeth were prepared using the Reciproc system (#50.05) in an electric motor (VDW GmbH, Munich, Germany) adjusted for reciprocating motion according to the manufacturer's instructions. During preparation, the canals were irrigated with 2 mL of 2.5% NaOCl; this was repeated each time the instrument was removed.

Experimental Root Weakening

Experimental root weakening was performed to simulate widely flared and clinically weakened roots. For the weakening protocol, the roots were inserted in a silicone cylinder, with the cervical and middle thirds remaining exposed. The cylinder was fixed to the base of a delineator and parallel to the low-rotation motor fixed to the device rod. The burs #4137 and #720G (KG Sorensen, São Paulo, SP, Brazil) were used with air/water spray coolant. At the end of the procedure, a 12-mm-long wear was obtained along the root canal.

Root Canal Filling

After final irrigation, the experimentally weakened roots had the canals dried with absorbent paper points and filled with an R50 gutta-percha cone (VDW GmbH, Munich, Germany) and an epoxy-resin sealer (AH Plus; DeTrey Dentsply GmbH, Konstanz, Germany) mixed with 0.1% Rhodamine B dye. Radiographs were taken to confirm the absence of voids in the fillings and the canal access was restored with a temporary restorative material. The roots were stored in an incubator at 37 °C and 100% humidity for a period corresponding to three times the setting time of the sealer recommended by the manufacturer. To simulate the thermal changes occurring in the mouth, the specimens were subjected to a thermal cycling regimen of 3,600 cycles in water baths at 5 °C and 55 °C with a dwell time of 5 s between baths.

Post Space Preparation

After thermal cycling, gutta-percha was removed with heated endodontic pluggers, maintaining at least 5 mm of filling material in the apical third. The post spaces were prepared to a depth of 12 mm measured from the sectioned surfaces using the drills supplied with the fiber post system. In each specimen, a White Post DC® #2 glass-fiber post (FGM, Joinville, Brazil; 1.8 mm cervical diameter, 1.05 mm apical diameter and 20 mm length) was tested to fit the canal space.

For the relining procedure, the canal space was filled with a micro-hybrid light-cure resin composite (Filtek Z-250; 3M/ESPE, St. Paul, USA) (Table 1) inserted incrementally, from apical to cervical, and compacted apically with a hand compactor. In each canal, a post coated with a thin layer of petroleum jelly was inserted centrally into the resin mass along the whole post space extension. Photoactivation was performed using a LED curing unit with output intensity of 30 mW/cm^2, as measured by a curing radiometer (Optilux 501, SDS/Kerr, Orange, USA). The light-curing tip was placed over the post, activated for 5 seconds and then photoactivaton was carried out for 20 seconds on each face. After resin composite polymerization, the post was clamped with needle-nose pliers and removed from the canal.

Distribution of Experimental Groups

The roots were randomly divided into 3 groups (n = 14) according to the root dentin treatment protocols. A volume of 5 mL was used for all irrigation solutions: NaOCl: 2.5% NaOCl for 1 min; NaOCl + EDTA: 2.5% NaOCl for 20 s, 17% EDTA for 20 and 2.5% NaOCl for 20s; and NaOCl + EDTA+US: three 20-s irrigation cycles with 2.5% NaOCl followed by 17% EDTA and 2.5% NaOCl for 20 s each. The solutions in this group were agitated using passive ultrasonic irrigation with a size 20, .01 taper E1- Irrissonic file (HELSE Capelli e Fabris Ind., Santa Rosa do Viterbo, Brazil) attached to a Jet Sonic ultrasonic device with power setting at 10% and 30 KHz of frequency (Gnatus, Ribeirão Preto, Brazil). For all groups, final irrigation was performed with distilled water for 30s. In each group, half of posts were cemented with RelyX U200 (3M ESPE, St. Paul, MN, USA) and the other half with Panavia F (Kuraray Noritake, Tokyo, Japan). Prior to the cementation, 0.1% fluorescein was added to both luting cements[21].

Preparation of Root Dentin Slices

The restored roots were individually taken to a precision cutting machine with a water-cooled

Table 1. Partial and total mean values over the standard deviation total (MPa) of BS as the root reinforcement treatment protocol for each sealer and root third of the post.

Root dentin treatment	Panavia F			RelyX U200		
	Root third			Root third		
	Cervical	Middle	Apical	Cervical	Middle	Apical
NaOCl	2.7 ± 0.6Ab	2.4 ± 0.5Ab	2.2 ± 0.4Aa	2.7 ± 0.5Ab	2.3 ± 0.6Aa	1.9 ± 0.3Aa
NaOCl+EDTA	9.3 ± 1.7Aa*	7.6 ± 1.1Ba*	3.5 ± 1.0Ca	3.9 ± 1.0Aab*	2.9 ± 0.9Ba*	2.3 ± 0.4Ba
NaOCL+EDTA+US	7.9 ± 1.2Aa*	6.2 ± 0.8Ba*	3.3 ± 0.9Ca*	4.3 ± 0.7Ab*	2.9 ± 0.5Ba*	1.9 ± 0.3Ba*

Different uppercase letters in rows are designed to compare root third for each irrigant protocol, lowercase letters in columns are designed to compare irrigant protocol for each root third indicate significant differences.*Significant difference for pairwise comparison between Panavia F and RelyX U200 for each group ($p < 0.05$)

diamond disc (Isomet 1000; Buehler, Lake Buff, USA) and serially sectioned perpendicular to the long axis of the post. Two 1.5-mm-thick (±0.1 mm) slices were obtained from the coronal, middle and apical root thirds. The first slice from each root third was used for the push-out BS test and the second slice for confocal laser scanning microscopy (CLSM) and dentin microhardness analysis.

Push-out Test

After confirming thickness with a digital calliper, each slice was taken to an Instron machine (model 2519-106; Instron Corporation, Norwood, USA) with its coronal side facing the metallic base and the resin/cement/post section area coinciding with the 2.5-mm-diameter hole in the base. The posts were pushed out with cylindrical plungers of different diameters (2.5 mm, 2.0 mm, 1.5 mm, 1.0 mm) elected according to the size of the resin/cement/post section area. The plunger tip was positioned in such a way to touch only the post, avoiding any contact with the materials and dentin. The load was applied on the apical side of the root slice in an apical-coronal direction at a 0.5 mm/min crosshead speed, until bond failure occurred. The post was pushed toward the larger portion of the root slice to avoid limitation to its dislodgment due to canal taper. Care was also taken to ensure that the contact between plunger tip and the post section occurred over the most extended possible area to avoid notching effects on post surface, which would interfere with BS results. Bond failure was recorded by the extrusion of the post section from the root slice. In order to express the BS in MPa, the load at failure recorded in N was divided by the area of the bonded interface, which was calculated using the following equation: a ¼ 2pr h where p is the constant 3.14, r is the post radius, and h is the thickness of the slice in mm.

The failure type was evaluated by means of fractographic analysis, using a stereomicroscope (Leica M165C, Leica Microsystems GmbH., Wetzlar, Germany) at 50´ magnification. Failures observed after debonding were determined on a percentage basis and classified in four types: adhesive (between the relining material and dentin), cohesive in the relining material, cohesive in dentin and mixed (combination of adhesive and cohesive in the relining material).

CLSM analysis

The second slices of each root third were evaluated qualitatively to assess the penetration of the materials throughout the dentinal tubules using a confocal inverted microscope (Leica TCS-SPE Leica, Mannheim, Germany) and a method of epifluorescence with wavelengths of absorption and emission to rhodamine B of 543/560 nm and to fluorescein of 488/500 nm. The histotomographic images revealed the areas of dentinal tubules filled with AH Plus sealer mixed with rhodamine B (red), and Panavia F or RelyX U200 cements mixed with fluorescein (green), as well as tubules in which sealer and cement were found (yellow). The specimens were analyzed 10 μm below the surface with 10× magnification, 5x5mm field of vision with 512×512 pixel resolution.

Dentin Microhardness Analysis

The specimens were ground wet with 400-, 500-, and 600-grit silicon carbide papers, polished with felt disks embedded in aluminum oxide paste at low speed, washed in running water for 4 h, dried with gauze, and examined at 40× magnification to confirm smoothness. Measurement of microhardness is only possible on smooth dentin surfaces because the indentations are not visible on nonpolished surfaces[22]. Dentin microhardness was measured with a Knoop indenter (Shimadzu HMV-2000; Shimadzu Corporation, Kyoto, Japan) under 10-g load and 15-second dwell time. For each slice, three indentations were performed, starting from the root canal lumen towards the cement, located 200 μm apart from each other.

Statistical analysis

The data were examined for normal distribution (Shapiro-Wilk test, $p > 0.05$) and homogeneity of variance (Levene test, $p > 0.05$). BS and microhardness data were analyzed by two-way ANOVA in a split-plot arrangement with the plot represented by root dentin treatment protocol and cement, and the subplot represented by the root thirds. All pairwise multiple-comparison procedures were made using the Tukey's test. All tests were performed using InStat version 3 software (GraphPad Software Inc., San Diego, USA).

Results

Push-out Test

A two-way ANOVA in a split-plot arrangement revealed that BS was significantly affected by the root dentin treatment ($p < 0.0001$), cement ($p = 0.0001$), root third ($p < 0.0001$) and their interaction ($p < 0.0001$). For the root dentin treatments, specimens treated with NaOCl + EDTA (4.9 ± 2.8) and NaOCl + EDTA + US (4.4 ± 2.2) showed higher BS than NaOCl alone (2.3 ± 0.6). For the cements, significantly higher BS was obtained with Panavia F (5.0 ± 2.7) than RelyX U200 (2.8 ± 0.9). Comparing the root thirds, higher BS was observed in the coronal third (5.1 ± 2.7) compared with the middle (4.0 ± 2.1) and apical (2.5 ± 0.8) thirds.

For Panavia F, dentin treatment with NaOCl+EDTA and NaOCl + EDTA + US increased the BS in coronal and middle thirds compared with NaOCl ($p < 0.05$). For RelyX U200, dentin treatment with NaOCl + EDTA + US increased the BS compared with NaOCl in the coronal third, but no significant increase in BS was observed in the other thirds. When root dentin was treated with NaOCl + EDTA and NaOCl + EDTA + US, Panavia F cement presented higher BS than RelyX U200, but no different was observed between the cements when root dentin was treated with NaOCl alone (Table 1).

The failure pattern data are presented in Table 2. All cohesive failures occurred in the relining material. Panavia F showed a predominance of cohesive and mixed failures in the coronal and middle thirds for NaOCl and NaOCl + EDTA dentin surface treatments, When NaOCl + EDTA + US was used, there was a predominance of mixed failures in the coronal and apical thirds and mixed and cohesive failures in the middle third. For RelyX U200, the majority of failures were mixed in the coronal third and cohesive and mixed in the middle third, regardless of the dentin surface treatment. In the apical third, there was a predominance of adhesive and cohesive failures for NaOCl and NaOCl + EDTA + US and cohesive failures for NaOCl+EDTA dentin surface treatments.

CLSM Analysis

Figure 1 is a composite figure with images of 6 slices, each slice representing one of the three root dentin treatments and one of the two cements. In specimens treated with NaOCl alone, there was a predominance of AH Plus sealer in practically the entire root canal circumference, with very little or no evidence of penetration of Panavia (Figure 1A) or RelyX U200 (Figure 1B) cements throughout the dentinal tubules. In specimens treated with NaOCl + EDTA, most dentinal tubules were filled with AH Plus sealer and discreet penetration of Panavia F (Figure 1C) and RelyX U200 (Figure 1D) could be observed. In the group with solutions agitated using passive ultrasonic irrigation, although most tubules revealed the presence of AH Plus, several regions of dentin exhibited yellowish areas, resulting from the interaction between AH Plus sealer and Panavia F (Figure 1D) and RelyX U200 (Figure 1F) luting cements.

Table 2. Failure pattern distribution.

Resin cement	Root dentin treatment	Root third											
		Coronal				Middle				Apical			
		A	CR	M	CD	A	CR	M	CD	A	CR	M	CD
Panavia F	NaOCl	0.0	71.4	14.3	14.3	28.6	42.9	28.6	0.0	28.6	42.9	28.6	0.0
	NaOCl + EDTA	0.0	57.1	28.6	14.3	14.3	28.6	57.1	0.0	42.9	28.6	14.3	14.3
	NaOCL + EDTA + US	0.0	0.0	85.7	14.3	0.0	57.1	42.9	0.0	0.0	28.6	71.4	0.0
RelyX U200	NaOCl	0.0	28.6	51.7	14.3	14.3	42.9	42.9	0.0	42.9	42.9	14.3	0.0
	NaOCl + EDTA	0.0	28.6	57.1	14.3	14.3	57.1	28.6	0.0	0.0	71.4	28.6	0.0
	NaOCL + EDTA + US	28.6	0.0	57.1	14.3	14.3	42.9	42.9	0.0	57.1	28.6	14.3	0.0

A: adhesive failure (between the relining material and dentin); CR: cohesive failure in the relining material; M: mixed failure (combination of adhesive and cohesive in the relining material); CD: cohesive failure in dentin.

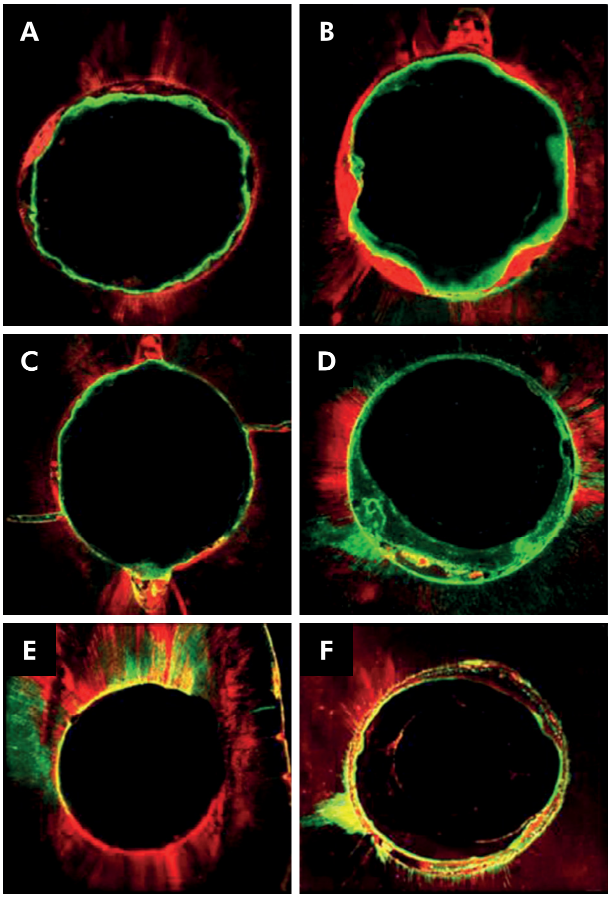

Figure 1. Histotomographic images representing the slices according to each root dentin treatment. A) NaOCl/Panavia F: presence of AH Plus (red) in the dentinal tubules, without evidence of penetration of Panavia F(green); B) NaOCl/RelyX U200: predominance of AH Plus in the dentinal tubules with very few coloured tubules with traces of cementing agent (green); C) NaOCl + EDTA/Panavia F: tubules filled with AH Plus (red) and discreet penetration of Panavia F (green); D) NaOCl + EDTA/RelyX: several tubules filled with root canal sealer (red) and some tubules filled with RelyX U200 cement (green); NaOCl + EDTA + US: several yellow-coloured dentinal tubules resulting from the interaction between the filling material and Panavia F (E) and RelyX U200 (F).

Dentin microhardness

The analysis of variance indicated that there was difference only among the solutions ($p < 0.001$), without significant difference among the thirds ($p = 0.511$) and nor in the solution/third interaction ($p = 0.153$). NaOCl (50.45 ± 5.9 KHN) promoted the greatest reduction in dentin microhardness followed by NaOCl+EDTA (56.70±6.6 KHN) and NaOCl + EDTA + US (64.13 ± 4.7 KHN). Table 3 presents the Knoop microhardness mean values for each canal third according to the dentin treatment and cement used.

Discussion

The dentin treatment protocols as well as the luting cements influenced the bond strength fiber-reinforced post in weakened roots, thus rejecting the null hypothesis.

The use of glass fiber posts for the restoration of endodontically treated teeth is a common procedure.[23,24] The clinical success of the restorative treatment depends mainly on the BS between the post and the root dentin[25] and therefore, the occurrence of failures at the post-adhesive cement-dentin interface is critical. Treatments of dentin surface with different solutions have been proposed to increase the retention of the post/cement/dentin set, including EDTA, NaOCl, chlorhexidine, ethanol and ethylene acetate.[26,27,28]

Three root dentin treatments were evaluated in the present study: NaOCl alone, NaOCl and EDTA, NaOCl and EDTA with passive ultrasound activation. The purpose of root dentin treatment is basically the removal of smear layer, opening of dentinal tubules and exposure of collagen fibers to permit an adequate infiltration of the adhesive system and

Tabela 3. Mean values of dentin microhardness for each root canal third according to the cement and dentin treatment.

Variable	NaOCl			NaOCl + EDTA			NaOCl + EDTA + US		
	C	M	A	C	M	A	C	M	A
RelyX	62.6 ± 2.8	66.0 ± 2.8	67.6 ± 4.4	57.0 ± 2.2	51.3 ± 5.7	51.6 ± 3.9	50.3 ± 4.1	53.6 ± 4.3	54.1 ± 8.4
Panavia	65.8 ± 5.0	60.7 ± 6.9	62.1 ± 2.4	62.2 ± 8.3	56.1 ± 2.9	61.9 ± 7.0	49.3 ± 6.1	50.3 ± 6.0	44.9 ± 2.5
$\dot{x}$ ± SD		64.1 ± 4.7			56.7 ± 6.6			50.4 ± 5.9	

$\dot{X}$ ± SD = Mean ± standard desviation; C: coronal third; M: middle third; A: apical third.

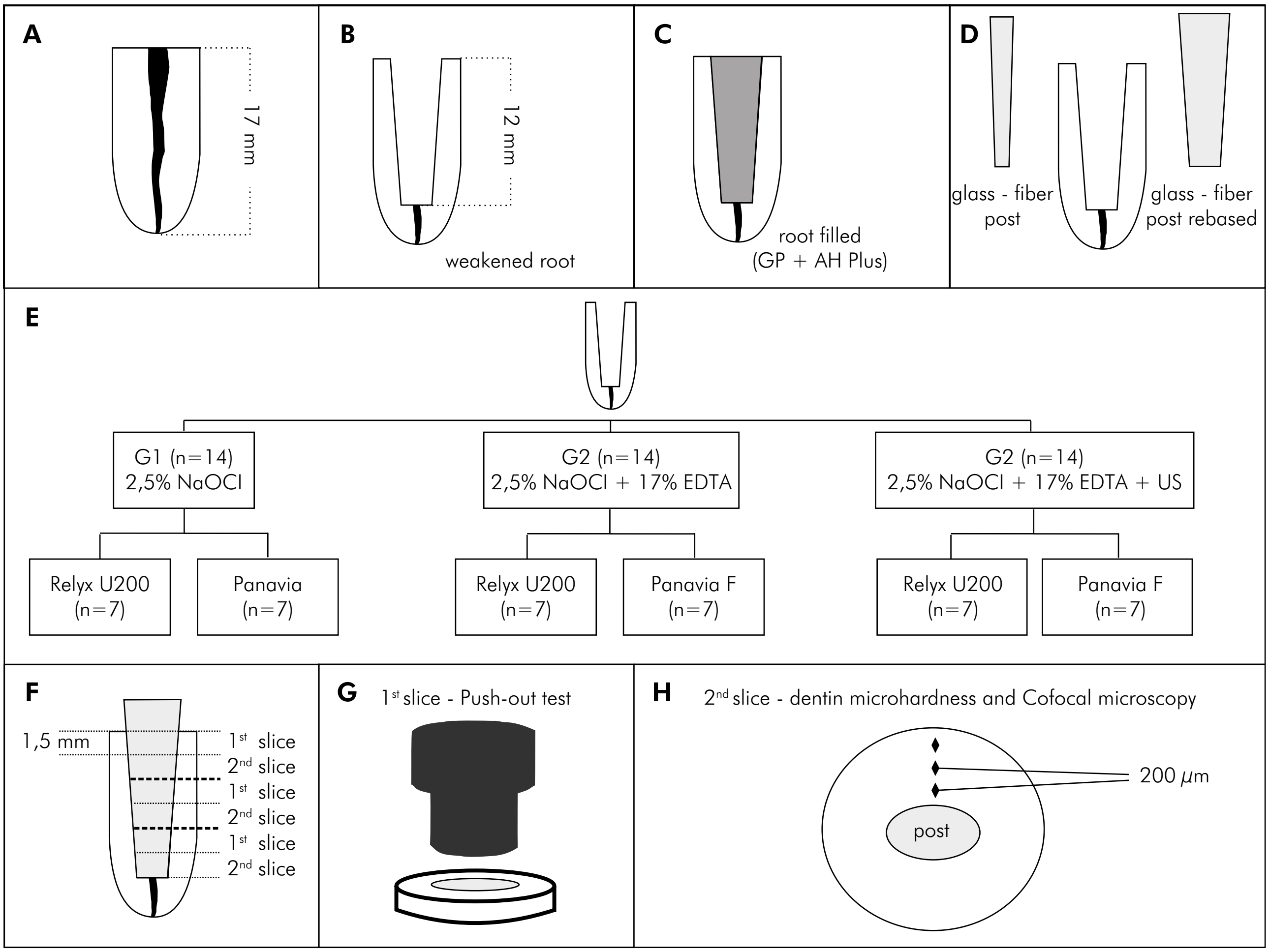

Figure 2. Schematic picture illustrating the study methodology.

formation of an hybrid layer, producing a high BS.[15] The combination of NaOCl and EDTA has benefits[7] while the halogenated solution promotes dissolution of organic tissues, the chelating agent acts on the inorganic portion of the smear layer.[17,29,30] In addition, ultrasonic activation enhances the actions of the irrigants[31] and increases the removal of residual sealer of the dentinal tubules.[32]

Self-etch (Panavia F) and self-adhesive (RelyX U200) dual cure cements were used due to their wide clinical use.[33]

The combination of push-out test and CLSM allowed a better understanding and visualization of the relationship between the endodontic sealer, resin-based luting cements and root dentin at the tooth/material interface. In the histotomographic images, the red-colored dentinal tubules were interpreted as those filled with AH Plus sealer at the time of root canal filling. The green-colored dentinal tubules were filled with luting cement (Panavia or RelyX) with no penetration of AH Plus sealer during root canal filling. This could be attributed to different factors such as insufficient amount of sealer, air bubbles inside the canal, filling technique, and sealer flow capacity. The interaction between red and green colors resulted in yellow-colored dentinal tubules, interpreted as the interaction between the materials, that is, partial removal of the endodontic sealer and penetration of the luting cement in the tubules. Removal of part of the sealer from the tubules is most likely due to the use of ultrasound,[32] since there are no reports suggesting that the use of NaOCl or EDTA could be effective for such procedure. On the other hand, there is information that passive ultrasound action displaces debris and induces turbulence of the irrigating fluid with consequent fluctuations in hydrostatic pressure. This turbulence can form bubbles resulting from physical cavitation phenomenon, which implode and produce increased temperature and pressure, resulting in impact waves against the canal walls and ultimately removing debris.[34] The process of debris removal is also assisted by the continuous flow of the irrigating solution, promoting a better cleaning of canals.[35]

The results of this study showed that the root dentin treatments interfered with the BS of the tested materials. In general, specimens that had the dentin surface treated with NaOCl alone presented the lowest BS. These findings are consistent with those of other studies,[36,37] which revealed that pre-treatment of dentin with EDTA increased the BS of self-etch adhesive systems. In fact, NaOCl alone does not remove the smear layer,[38] maintaining the dentinal tubules closed and impeding penetration of the luting cement, and so the combination of NaOCl and EDTA is the main indication to remove remaining organic and inorganic matter.[16] The resulting pH of this combination favors the selectivity of the chelating agent for calcium ions, increasing its action. In addition, EDTA has the capacity of removing non-collagen and hydroxyapatite proteins selectively, avoiding major changes in the structure of collagen fibers.[39] It contributes to preserve the intrafibrilar minerals, increasing the resistance to dehydration[39] and consequently improving the infiltration of resinous materials.[37]

Other authors have found different results from ours, showing that the use of NaOCl alone increased the BS of adhesive systems.[26] These differences could be attributed to particular features of the dentin substrate or even to the incomplete removal of demineralized collagen zone due to low concentration of the solution and or insufficient application time.[36]

In the present study, EDTA was applied for 20s, based on Calt & Serper,[40] who showed that the application of the chelating agent over 1 min promotes erosion of peritubular dentin. A 2.5% NaOCl solution was applied for 1 min and probably this concentration was not sufficient to remove the demineralized collagen zone. Studies reporting an increase in BS to root dentin used a 5.25% NaOCl solution.[26]

No significant difference was between the protocols combining NaOCl and EDTA with and without ultrasonic activation. However, although the use of ultrasound did not increase BS, the qualitative analysis CLSM suggested removal of the root canal sealer and penetration of the cements into the tubules. This finding can be a very positive aspect for the future degradation of the resin cement.

Previous studies have shown that self-etch (Panavia F) and self-adhesive (RelyX Unicem) cements have statistically similar BS.[41] However, in those studies, dentin surface was not treated after reduction of filling material and post space preparation. In the present study, the root dentin treatments interfered directly on the adhesion of the cements, since the BS of the self-adhesive cement (RelyX U200) and self-etch cement (Panavia F) decreased and increased, respectively. Panavia F presented significantly higher BS than RelyX U200. The results lead to the interpretation that the application of adhesive agents on the pretreated dentin is beneficial to the BS of self-adhesive cements, which do not require acid etching or use of an adhesive system. Particularly for Panavia F, the bonding agent presents in its composition a monomer that adheres chemically to the calcium of the hydroxyapatite remaining in the hybrid layer,[42] resulting in a compound with low solubility and stable hydrolytic bond[2]. The adhesion of RelyX U200 seems to be associated with the presence of smear layer on dentin surface since better results are found compared with smear-free dentin surfaces. In this study, root dentin treatment with NaOCl and EDTA, hypothetically removed the smear layer, exposing the collagen network and allowing the penetration of the adhesive system, which is a more favorable condition to the adhesion of Panavia F compared with RelyX U200.

CLSM analysis of the specimens treated with NaOCl and EDTA without ultrasonic showed penetration of Panavia F into the dentinal tubules, probably deep enough to promote adhesion. However, although intertubular penetration was observed, RelyX U200 had lower BS than Panavia F. When ultrasonic activation was used, both materials interacted with the root canal sealer (AH Plus), as demonstrated by the presence of yellow-colored tubules in the histomicrographs. Nevertheless, this interaction did not affect the BS of the luting cements.

There are reports stating that, even if used alone, NaOCl has the capacity of removing the smear layer.[39] CLSM analysis confirmed the partial removal of the smear layer, showing discrete presence of RelyX U200 inside the tubules.

In the region of root reinforcement with resin composite, there was a decrease in BS from coronal to apical, as observed in other works.[43] This result could be attributed to the more difficult access to the apical region with consequent limitation of cement flow to that area as well as reduced light transmission to this region. Another factor is related to the distribution and density of dentinal tubules in the different regions of the root. There are reports that tubule density in the coronal region is greater than in the apical region and that the tubule diameter decreases in the apical direction.[35]

The failures observed after the push-out test were predominantly adhesive followed by mixed and cohesive in the relining material. These results are consistent with those of studies that investigated BS and failure mode after the displacement of different self-etch and self-adhesive resin cements from root dentin.[36]

Regarding dentin microhardness, the three treatment protocols differed significantly from each other. The use of NaOCl+EDTA with ultrasonic activation followed this combination without activation produced a greater decrease of dentin microhardness than the use of NaOCl alone, which is explained by the excellent chelating action of EDTA. This agent is capable of reducing dentin hardness from the first minute of contact with the mineralized tissue,[44] which can be avoided by using EDTA for less than 1 minute.[40]

Conclusion

Within the limitations of this study, it may be concluded that ultrasonic activation of NaOCl and EDTA reduced root dentin microhardness, but it did not improve the push-out BS of resin-based luting cements. Panavia F presented higher BS in the three root thirds. RelyX U200 was not influenced by the root dentin treatment protocols. Failures after the push-out test were predominantly adhesive followed by mixed and cohesive in the relining material. In view of these findings, dentin treatment with NaOCl + EDTA and cementation with Panavia F was the protocol that promoted the highest bond strength of fiber-reinforced posts in experimentally weakened roots.

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