International Journal of Adhesion and Adhesives 88 (2019) 26–33

Contents lists available at ScienceDirect

International Journal of Adhesion and Adhesives

journal homepage: www.elsevier.com/locate/ijadhadh

The influence of endodontic sealer dentine penetration on fibreglass post retention

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ARTICLE INFO

Keywords:
Confocal microscopy
Dentine
Push-out bond strength

ABSTRACT

This study aimed to evaluate the influence of endodontic sealer inside dentinal tubules on the retention of fibreglass posts. One hundred eighty extracted teeth were instrumented with rotary instruments and divided into two groups (n = 90) according to their filling technique: (LC) lateral condensation and (CT) controlled technique, and subdivided into three subgroups according to the endodontic sealer used: (A) epoxy resin sealer, (B) zinc-oxide and eugenol sealer, and (C) bioceramic endodontic sealer. After root preparation, each subgroup received a fibreglass posts cemented with (1) adhesive resin cement, (2) self-adhesive resin cement, and (3) glass ionomer cement. After stored for 15 days at 37 °C and 100% humidity, the teeth were sectioned transversely into 1-mm thick slices and subjected to laser confocal scanning microscopy and push-out test. The failure mode was analyzed by stereo microscope, and scanning electron microscopy images of representative fractures were made. Although there were no significant differences in the dislocation resistance among the filling techniques ($p > 0.05$), the type of sealer used affected bond strengths on the cervical and middle thirds. Fibreglass posts cemented with glass ionomer cement presented higher values for the push-out test than those cemented with resin cements ($p < 0.05$). Mix failure modes were predominant and occurred in all experimental groups. The use of bioceramic endodontic sealer was able to reduce the bond strength, mainly when the fibreglass posts was cemented by resin cement.

1. Introduction

Restoration of the endodontically treated teeth is a challenge because of the small amount of coronal structure. Excessive loss of coronal tooth structure in anterior teeth requires the use of the root canal to support the permanent filling or crown. It is often necessary to place some type of retainer in order to retain the coronary reconstruction [1,2].

Fibreglass posts are widely used because the insertion technique is simple [3], and they can be prepared and molded in a single session. Moreover, combined with the adhesive system and resin sealer, they have similar elastic modulus as the dentin [3,4] and favor stress distribution of occlusal load on the radicular tooth structure.

Root canal reinforcement by using fibreglass posts cemented with resin adhesive materials [5,6] depends on the effective bonding between the adhesive components and the substrate [7]. However, the chemical nature of sealers can influence the bond strength of fibreglass posts to root dentin [8,9]. The zinc oxide and eugenol-based sealers negatively affect the bond strength between root dentin and fibreglass posts, especially at the apical region of the post [8]. Moreover, several studies have investigated the penetration capability of various sealers within the dentinal tubules [10–13] and its importance once the micromechanical retention to the filling mass has been provided [14]. Furthermore, such penetration is capable of enclosing and eliminating microorganisms and keeping them distant from the nutrition source. However, it is unclear whether these sealers affect the bond strength of fiber posts to root dentin.

That said, it is difficult to establish the actual impact of the presence of endodontic sealers inside dentinal tubules upon the bond strength of fibreglass posts. To elucidate this question, the aim of this study was to

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https://doi.org/10.1016/j.ijadhadh.2018.10.014
Accepted 17 October 2018
Available online 01 November 2018
0143-7496/

Table 1
Push-out bond strengths (MPa) in the cervical-apical third.

Experimental groups			n (cervical/apical)	Median (cervical/apical)	P25 – P75 (cervical/apical)
CL	AH Plus	ARC	9/9	3.14^{a} / 1.07	1.35 – 5.95 / 0.35 – 1.97
		U200	10/9	2.33^{a} / 2.29	1.41 – 3.13 / 1.06 – 4.25
		GIC	10/10	3.45^{a} / 2.82	2.44 – 4.42 / 1.71 – 4.53
	Endofill	ARC	10/9	0.68 / 0.90^{a}	0.26 – 4.91 / 0.30 – 1.99
		U200	10/10	2.32 / 0.83	1.01 – 3.65 / 0.33 – 1.74
		GIC	10/10	4.21^{a} / 2.01	2.4 – 4.81 / 0.99 – 4.85
	MTA	ARC	10/10	2.91^{a} / 2.08	1.18 – 6.68 / 0.93 – 2.05
		U200	10/10	1.26 / 1.14	0.39 – 2.29 / 0.93 – 2.05
		GIC	10/9	1.68 / 1.85	0.96 – 3.01 / 1.85 – 4.54
TC	AH Plus	ARC	10/9	2.91^{a} / 1.01	2.33 – 3.42 / 0.37 – 1.89
		U200	10/10	2.68 / 3.07	0.36 – 4.30 / 1.26 – 6.72
		GIC	10/9	1.97 / 4.50^{b}	1.23 – 3.04 / 2.56 – 6.52
	Endofill	ARC	10/10	2.13 / 1.22	1.50 – 3.31 / 0.58 – 2.63
		U200	10/10	1.92 / 2.19	1.64 – 2.42 / 0.85 – 3.33
		GIC	10/10	3.46^{a} / 2.53	1.83 – 5.06 / 2.07 – 3.93
	MTA	ARC	9/9	2.36 / 1.29	1.72 – 4.49 / 0.54 – 2.57
		U200	9/9	0.59^{b} / 1.27	0.12 – 1.02 / 0.46 – 2.38
		GIC	10/10	1.83 / 2.55	0.62 – 2.36 / 1.54 – 4.46

Within each column, values with different lowercase superscript letters are significantly different at $p < 0.05$ (Dunn's test).

compare diferent endodontic sealers and their effects using different luting agents (glass-ionomer, adhesive and self-adhesive resin) on the bond strength of fiber posts. The null hypotheses tested were: the endodontic sealer would not significantly affect the bond strength of fiber posts; the type of endodontic sealer (resin-based or zinc oxide-eugenol-based) does not affect the bond strength of fiber posts; the type of luting agent (glass ionomer, adhesive and self-adhesive) does not affect the bond strength of fiber posts.

2. Material and methods

This study was approved by the Research Ethics Committee. The study was conducted using a total of 180 extracted human single-rooted mandibular first premolars (n = 90), thoroughly cleaned and decoronated at the cemento- enamel junction using a water-cooled diamond saw. The roots were then radiographed at two angulations to confirm the presence of a single canal. To be included in the experiment, teeth should have complete root formation, no root laceration, endodontic treatment, internal or external root resorption, and absence of root fractures or cracks.

The coronal portion was sectioned at the cementoenamel junction level, perpendicularly to the tooth long axis to obtain a standardized root length of 15 mm. The root canals were instrumented using #15 K-file (Dentsply-Maillefer, Ballaigues, Switzerland) until the tip of the file became visible at the apical foramen. This measure was noted and the working length was set 1 mm short of this measure. The chemical-mechanical preparation was performed with Waveone 40.08 reciprocating system (Dentsply Maillefer, Ballaigues, Switzerland) driven by an electric motor (VDW Silver; VDW Company, Munich, Germany) using the "WaveOne all" software as stipulated by the manufacturer.

During the instrumentation phase, root canals were irrigated with 5 ml saline solution. After completion of the chemical-mechanical preparation, the canals were irrigated with 3 ml of 17% EDTA for 3 min and subsequently with 2 ml of saline solution. All irrigation procedures were performed using a 5 ml syringe (Ultradent Prod. Inc., UT, USA) and fine needle (Endo easy Tip; Ultradent Prod. Inc., UT, USA).

Root canals were dried with absorbent paper cones in the same size as the final apical diameter. The master cone was introduced into the root canal until the working length was reached.

The teeth were randomly divided into 2 groups (n = 90) according to the filling techniques. The aim was to impregnate the root dentin with sealer in one group and avoid in the other: (1) Lateral condensation (LC) - the root canals were filled with main cone, sealer (across the root canal) and accessory cones (FM; Dentsply-Maillefer, Ballagues, Switzerland) by using a digital spacer until penetrating into the cervical portion of the root canal only; (2) Controlled technique (CT) – only the apical portion (5 mm) of the cone was covered with endodontic sealer, in order to prevent the penetration of endodontic sealer into the root dentin. Then, a few accessory cones were placed just to complete the filling of the apical portion.

Each group was divided into three subgroups (n = 30) according to the endodontic sealer used: AH Plus (Dentsply-Maillefer, Ballagues, Switzerland), Endofill (Dentsply-Maillefer, Petrópolis, Brazil), and MTA Fillapex (Angelus Soluções Odontológicas, Londrina, PR, Brazil).

These sealers were handled according to the manufacturer's guidelines. However, 0.1% Rodhamina B dye was added to provide sufficient fluorescence for visualizing the sealer inside the dentinal tubules during confocal laser scanning microscopy. Excess gutta-percha was sheared off with a hot instrument and the canals were sealed with a temporary filling material (Cavit, 3 M do Brasil, São Paulo, Brazil). All teeth were stored for 15 days at 37°C and 100% humidity.

The partial filling removal was initially performed with a heated Rhein probe (Golgran, São Caetano do Sul, SP, Brazil). Then, the preparation was carried out with large #4 drill (diameter 1.3 mm, depth 10 mm). Each subgroup was further divided into three sub-subgroups (Table 1) according to the agent luting used: adhesive resin cement (RelyX ARC, 3 M ESPE, Sumaré, SP, Brazil), self-adhesive resin cement (RelyX U200, 3 M ESPE, Sumaré, SP, Brazil) and glass ionomer cement (Gold Label Cement Lining, GC, Tokyo, Japan).

Prior to cementation with resin cement RelyX ARC (ARC), the posts were cleaned with 70% ethanol and silanized with silane (Prosil, FGM Produtos Odontológicos, Joinville, SC, Brazil). The coronary and radicular dentin was washed with distilled water and dried with absorbent paper points. Then, the samples were etched for 30 s with 37% phosphoric acid, rinsed with distilled water for 60 s and dried out. The etch & rinse adhesive system (Scotchbond Multipurpose, 3M ESPE, Sumaré, SP, Brazil) was applied to the coronary and radicular dentin according to the manufacturer's recommendations. The ARC resin cement was manipulated and inserted into the canal by using a Lentulo drill, and a fibreglass post (Reforpost #2, Angelus, Londrina, PR, Brazil) was immediately placed in the root canal. Next, the excess was removed with a disposable microbrush and light polymerization was performed for 40 s.

Prior to cementation with self-adhesve resin cement RelyX U200 (U200) and glass ionomer cement (GIC), the fiber posts were cleaned with 70% ethanol and only those cemented with U200 were silanized. The coronary and radicular dentin was washed with distilled water and dried with absorbent paper points. U200 and GIC cements were handled and inserted into the canal using a Lentulo drill, and a fibreglass post (Reforpost #2, Angelus, Londrina, PR, Brazil) was immediately placed in the root canal. The excess cement was removed with a microbrush. Fibreglass posts cemented with U200 were light-cured for 40 s, whereas it took 10 min to complete the polymerization of the posts cemented with GIC.

All teeth were stored for 15 days at 37 °C and 100% humidity. After preparation of the specimens, they were classified into 18 experimental groups, as shown in Fig. 1.

The specimens were cross-sectioned into 1-mm thick slices using a cutting machine (Extec Labcut 1010, Enfield, CT, USA) under water cooling.

The first slice was discarded in order to avoid any misinterpretations arising from the sealing material used. The slices were labeled in the apical-coronal direction (Fig. 2).

Subsequently, a sample of each group had its surfaces polished with Arotec paste in a polishing machine (Arotec, Cotia, SP, Brazil) under water cooling, to remove sharp edges left from the cutting process. Samples were examined by using Olympus Fluoview 1000 confocal laser scanning microscope (Olympus Corporation, Tokyo, Japan), with excitation wavelength of 559 nm. Images were recorded in fluorescence mode at 10X with numerical apertures of 0.3 and 1.3 mm, respectively.

The tooth slices were marked in green, blue and red with a marker pen on the apical surface, so that the root depths were properly identified as cervical, middle and apical.

The push-out test or shear extrusion was used to assess bond strength between fiber posts and root dentin.

Each slice was placed on a metallic device with a central opening (Ø = 3 mm) larger than the root canal diameter in a universal testing machine (INSTRON 3369, Barueri, SP, Brazil). The coronal portion of the slice was placed in contact with the metal device. The metallic cylinder (Ø = 0.8 mm) induced a load on the fiber post in the apical-cervical direction without applying any pressure to the sealer layer or the dentin.

The push-out test was performed at a speed of 0.5 mm/min. Bond strengths in MPa were obtained by using the following formula: $\sigma = F/A$, where F = load required for specimen rupture (N) and A = adhesive area (mm^2). To determine the adhesive interface area, a formula for calculating the lateral area of a circular cone with parallel bases was used. The formula is defined as: $A = 2\pi g\ (R1 + R2)$, where $\pi = 3.14$, g = generatrix, R1 = radius of the smaller base, R2 = radius of the larger base. The generatrix is determined by the following formula: g2 = (h2 + [R2- R1]2), where h = height of the sectioned area, R1 and R2 were obtained by measuring the internal diameters of the smaller and larger base, respectively, which correspond to the internal diameter of the root canal walls. These measures were obtained by using a digital caliper.

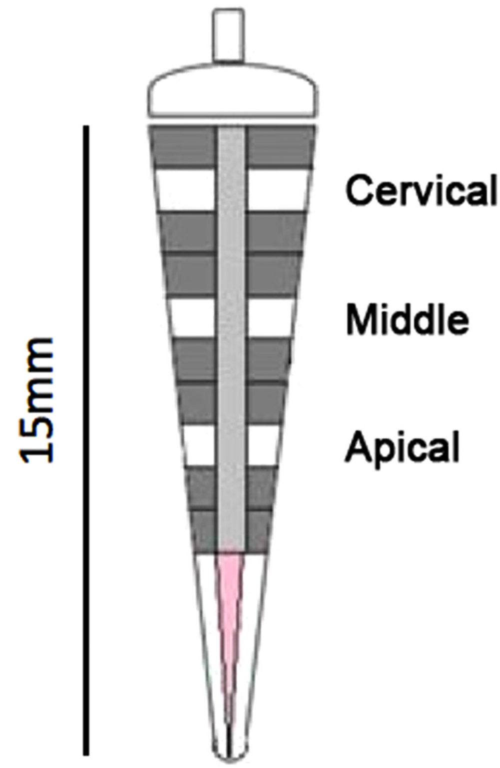

Fig. 2. Schematic representation of the specimen sectioned into 1-mm thick slices for the push-out test.

The specimens showing cohesive failures of the fiber post or dentin were excluded from the study, as they did not actually represent the bond strengths between the post and sealer, or between the sealer and dentin.

Two examiners crosschecked the specimens under a stereomicroscope (EMZ-TR, MEIJI Techno CO., Ltd., Tokyo, Japan) to examine the failure area. Failure modes were classified as: adhesive failure between dentin and the luting agent, adhesive failure between the luting agent and the post, and cohesive failure or mixed failure.

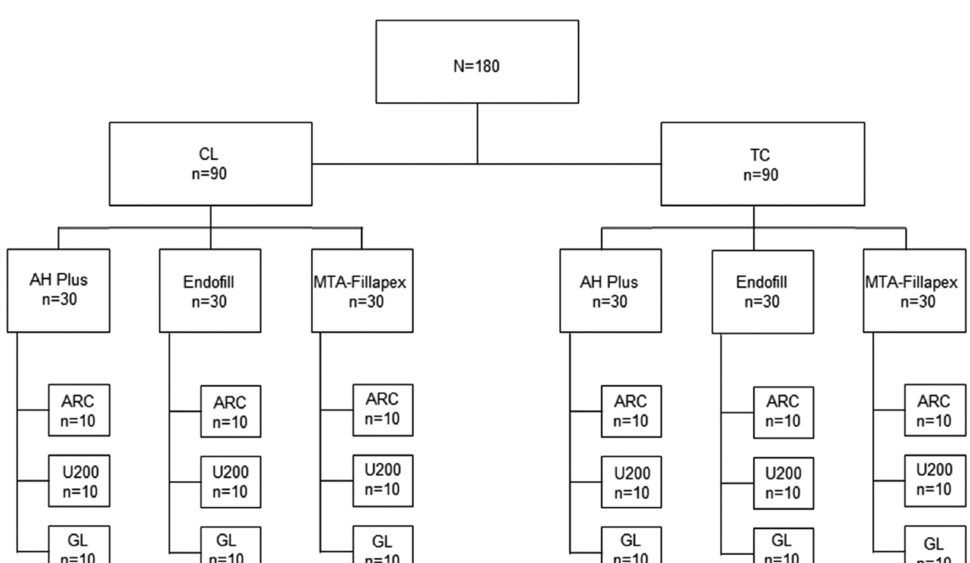

Fig. 1. Representation of the experimental groups according to the filling technique, endodontic sealer and luting agent.

Table 2
Bond strengths (MPa) according to the filling technique.

Experimental groups	N	Median	P25-P75
CL	247	1.85^{A} (2.36/1.67)	0.91–3.14
TC	252	1.93^{A} (2.15/2.04)	1.03–3.00

Values with different uppercase superscript letters are not statistically significant different at $p < 0.05$ (Mann Whitney test).

Table 3
Bond strengths (MPa) according to the endodontic sealer used.

Experimental groups	N	Total Median (cervical-apical)	P25 – P75
AH Plus	156 (59/53)	2.14^{A} (2.66^{a}/1.95^{a})	1.15–3.5
Endofill	185 (60/59)	$1.93^{A,B}$(2.43^{a}/1.71^{a})	0.91–3.22
MTA-Fillapex	170 (58/57)	1.81^{B} (1.57^{b}/1.89^{a})	0.88–2.62

Values with different superscript letters within the column are significantly different at $p < 0.05$ in the cervical third (Dunn's test).

Representative images of each failure mode were analyzed under scanning electron microscopy. For that purpose, some specimens were mounted on specific stubs for JEOL 6060 microscope (JEOL, Tokyo, Japan) and metalized in gold-palladium alloy (Med 010, Balzers Union, Balzers, Liechtenstein, Germany).

The results were analyzed using the GraphPad Prism software (GraphPad Software, Inc., CA). Shapiro-Wilk test was used to test for normality of data. Mann-Whitney test was used for comparison of bond strengths in MPa, considering only two filling techniques used. Comparison of the dislocation resistance (MPa) of the experimental groups was performed by using Kruskal–Wallis test with Dunn's post hoc test at $p < 0.05$ level of significance.

3. Results

The push-out test results were examined by observing the different parameters tested. There were significant differences ($p < 0.05$) between the medians of the experimental groups. The TC-MTA-U200 group had significantly lower bond strengths ($p < 0.05$) as compared to the other experimental groups (Table 1). There were no differences in the dislocation resistance between the different filling techniques used (Table 2).

Table 3 depicts the bond strengths according to the endodontic sealer used. The specimens filled with MTA-Fillapex had significantly lower bond strengths as compared to AH Plus ($p > 0.05$). There was no significant difference between Endofill and other sealers ($p < 0.05$). Analysis of only the cervical third revealed that MTA-Fillapex presented lower resistance values than AH Plus and Endofill ($p < 0.05$). In the apical third, there was no significant difference between the endodontic sealers ($p > 0.05$).

Median bond strengths for each luting agent used in this study are described in Table 4. The groups using GIC for cementation of fiber posts exhibited higher values for the push-out test than resin cements ($p < 0.05$). There was no significant difference between the ARC and U200 cement ($p > 0.05$). When analyzed by thirds, U200 cement presented significantly lower values than ARC and GIC cements in the cervical third ($p < 0.05$). In the apical third, GIC had significantly higher values than ARC and U200 cements ($p < 0.05$).

Table 4
Bond strengths (MPa) for each luting agent.

Experimental groups	N	Total Median (cervical-apical)	P25 – P75
ARC	167 (58/56)	1.64^{A} (2.57^{a}/1.18^{a})	0.79–2.73
U200	164 (59/55)	1.45^{A} (1.79^{b}/1.35^{a})	0.75–2.54
GIC	168 (60/58)	2.53^{B} (2.45^{a}/2.60^{b})	1.65–4.06

Different letters in the column represent median values with statistically significant differences between them, as compared by using Dunn's test ($p < 0.05$).

A specimen from each experimental group was analyzed by using confocal laser scanning microscopy in order to perform a qualitative assessment of endodontic sealer penetration into the dentinal tubules (Fig. 3A-F). The specimens filled by lateral condensation technique presented sealer-impregnated dentin. Those specimens in which the sealer was applied only in the apical portion of the gutta-percha cone, did not present sealer-impregnated dentin in the areas corresponding to the gutta-percha cone without sealer.

Among the endodontic sealers used in the lateral condensation technique, AH Plus sealer showed extensive sealer penetration into the surrounding dentine. The specimens cemented with ATM-Fillapex sealer showed small areas of sealer penetration into the dentinal tubules, whereas the specimens cemented with Endofill sealer had a low rate of sealer penetration, only impregnating the root canal perimeter.

Table 5 presents the failure mode distribution, which varied according to the luting agent used. Mixed failures were observed in 41% of the specimens.

ARC resin cement showed predominantly adhesive failures between dentin and cement (63.69%), except when Endofill endodontic sealer was used. Mix failures were predominant in the lateral condensation technique.

The U200 cement exhibited higher numbers of mixed failures (53.93%), regardless of the type of endodontic sealer when the lateral condensation technique was used. However, when the controlled technique was associated with a zinc oxide-eugenol-based endodontic sealer, there was a higher number of adhesive failures.

In the groups in which the posts were cemented with GIC, the failures ranged from adhesive failures between post and cement (51.63%) to mixed failures (37.25%), depending on the filling technique and the endodontic sealer used.

Images of the specimens were taken using scanning electron microscopy (SEM) before and after push-out tests, exhibiting different failure modes (Fig. 4A-F).

Fig. 5 shows failure modes in SEM images at the highest magnifications. Image (a) exhibits the adhesive interface between glass ionomer cement and dentin with no failure (*). The large arrow indicates failure between the fiber post and GIC. The small arrows indicate the presence of spherical bodies. Image (b) shows the displacement of the fiber post from the ARC resin cement and exposure of dentinal tubules in the root canal. Image (c) exhibits a mixed failure mode, in which part of the GIC has maintained the adhesive interface and part of the material has dislocated together with the fiber post. In image (d), part of the endodontic sealer remained in the root canal after preparation and cementation of fiber posts.

4. Discussion

As depth increases, there is an increase in the dentin moisture, which is often a barrier to good adhesion. Increased moisture in the root canal may cause a reduction in bond strength resistance [4]. In this study, there was a concern to create conditions similar to that of the oral cavity through metallic devices [15], simulating an environment in which there was the presence of moisture throughout the sealing process, which permits checking in vitro behaviors closer to clinical situations.

In this study, there was no significant difference between the groups filled with the lateral condensation technique and those in which dentin remained without endodontic sealer, unlike the results of Menezes et al. [8] who observed a decrease in the bond strength in all three thirds of the root canals filled with Endofill sealer as compared to the control. Demiryürek et al. [16] founded significantly higher bond strengths in the control group without dentin sealer. The authors attributed the

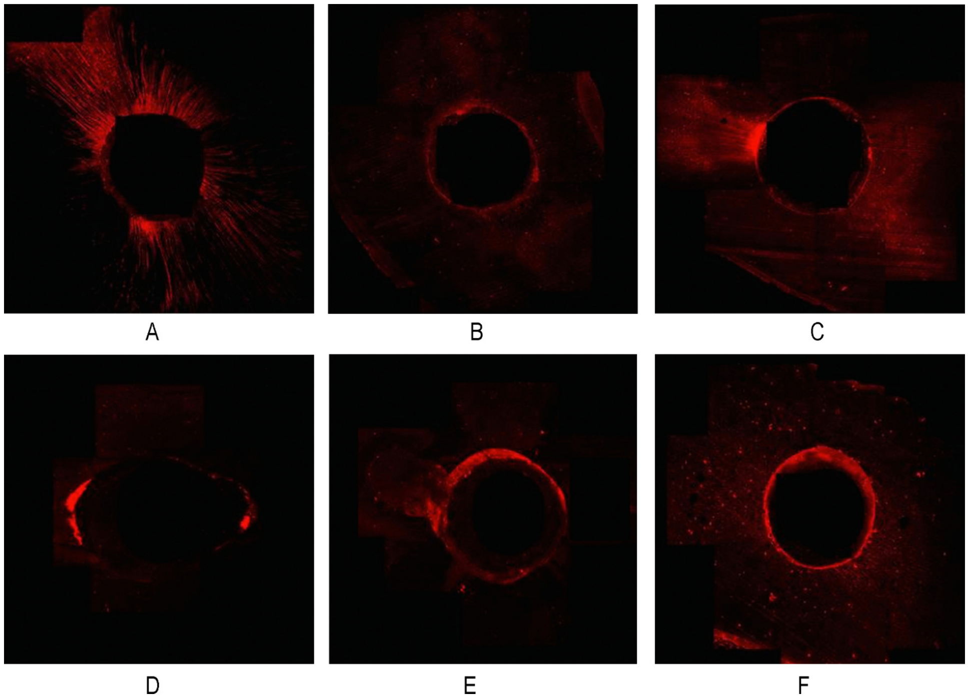

Fig. 3. Confocal laser microscopy images of the sealer penetration into the dentinal tubules. Lateral condensation: AH Plus (A), Endofill (B), MTA-Fillapex (C); controlled technique: AH Plus (D), Endofill (E), MTA-Fillapex (F).

Table 5
Distribution of failure modes among the experimental groups.

Groups			Adesive sealer/dentin	Post/ adhesive sealer	Cohesive Sealer	Mix
	AH Plus	ARC	14(60.86%)	2(8.69%)		7(30.43%)
		U200	8(32%)	5(20%)		12(48%)
		GIC		13(65%)		7(35%)
CL	Endofill	ARC	11(36.66%)	4(13.33%)		15(50%)
		U200	8(28.57%)	6(21.42%)	1(3.57%)	13(46.42%)
		GIC		10(35.71%)	4(14.28%)	14(50%)
	MTA	ARC	22(75.86%)			7(24.13%)
		U200	3(10%)	2(6.66%)	3(10%)	22(73.33%)
		GIC		20(68.96%)	2(6.89%)	7(24.13%)
	AH Plus	ARC	25(83.33%)			5(16.66%)
		U200	8(30.76%)	1(3.84%)	1(3.84%)	16(61.53%)
		GIC	6(23.07%)	8(30.76%)		12(46.15%)
TC	Endofill	ARC	18(60%)			12(40%)
		U200	19(73.07%)			7(26.92%)
		GIC	1(3.70%)	10(37.03%)	4(14.81%)	12(44.44%)
	MTA	ARC	17(65.38%)			9(34.61%)
		U200	1(3.33%)	7(23.33%)	3(10%)	19(63.33%)
		GIC		18(66.66%)	4(14.81%)	5(18.51%)
Total			161(32.85%)	106(21.63%)	22(4.48%)	201(41.02%)

better results to the dentinal tubules, which remained open, allowing maximum penetration of the resin sealer, whereas the penetration of endodontic sealer in the dentinal tubules adversely affected bond strength.

As a result of canals instrumentation for cementing posts performed after filling, the dentin impregnated with endodontic sealer may have been removed, thus exposing the open dentin tubules. The order of the steps in preparing root canals after dental filling significantly increased the bond strength of fiber posts, regardless of the sealer used [2]. During preparation for post cementation, most of the remaining root canal sealer can be removed, and the amount of debris and free eugenol that are capable of inhibiting polymerization of resin sealers of zinc oxide, and eugenol-based sealers are removed as well [9]. This process shows that the mechanical removal of the sealer-impregnated dentin from root canals is a critical step to achieve better retention of fiber posts.

The results suggest that the chemical composition of endodontic sealers interferes with the bond strength of fiber posts. The results support previous studies that have observed variations in bonding strength of fiber posts depending on different filling materials used [8,9,16]. These variations have been associated with eugenol-containing sealers, which negatively affect the bond strength of fiber posts [8,11]. Eugenol remnants in the root canal adversely affect the formation of the hybrid layer [16] between the resin cement and dentin, and may slow polymerization of resin materials. However, there is no consensus on the effect of eugenol on the bond strength of fiber posts; in addition, some studies have found no influence of the chemical composition of the sealers [17]. In this experiment, eugenol-containing sealers did not affect the bond strength when compared to other types of sealers. This fact has been associated with the time interval between root canal filling and cementing of fiber posts [18].

Significantly lower bond strengths were associated with the use of MTA-Fillapex sealer. Currently, there are few studies about this salicylate-based resin and its bond strength. The results of this study are in agreement with Rosa et al. [9] who evaluated whether this sealer affected the bond strength of fiber posts, and found that salicylate-based resin had significantly lower bond strengths as compared to AH Plus sealer, and similar values as compared to Endofill. MTA Fillapex has short working and setting times and low viscosity that benefit its application; however, it can cause extrusion into the periapical tissues. Its physical properties favor the penetration of the sealer into the dentinal tubules, ramifications and irregularities of the root canals [19] and may be associated with maintaining the material after the preparation of the canals for fiber posts, thereby generating lower levels of bond strength. The absence of significant difference between the AH Plus and Endofill shown in this study are consistent with other studies that found no significant differences between eugenol-based sealers and resin sealers [2,16].

The second null hypothesis formulated, which stated that the type of luting agent did not affect the bond strength of fiber posts, was rejected because bond strengths were significantly higher for the GIC groups as

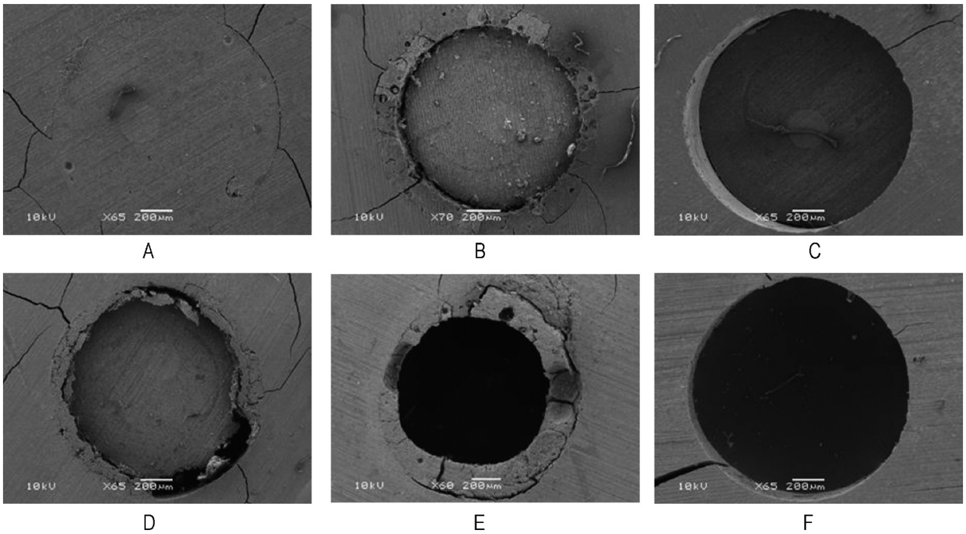

Fig. 4. SEM images of the cement-dentin interface. A – a specimen before the push-out test (CL – AH Plus/U200); B – adhesive failure at the cement-post interface (TC – MTA/GIC); C – adhesive failure at the cement-dentin interface (TC – MTA/ARC); D – Mixed failure (TC – MTA/ARC); E – adhesive failure at the cement-post interface (CL – AH Plus/GIC); F – adhesive failure at the cement-dentin interface (TC – AH Plus/ARC).

compared to resin cements ($p < 0.05$). These results are consistent with those found in previous studies [20]. The authors of those studies have attributed the results to the intimate contact of the material with the root canal walls provided by hygroscopic expansion that contributed to improving bond strength by increasing the friction between root dentin and fiber post, thus reducing failures at the resin cement-post interface [21]. The hygroscopic expansion of the glass-ionomer cement is associated with two distinct phases of glass-ionomer setting reaction. Initially, the material absorbs moisture originally present in the sealer, and then absorbs water available in the surrounding dentin surface or from the external environment [22]. This aspect is favorable, since complete drying of the dentin is impossible [21], making it a plus point for the use of glass-ionomer cements. Previous studies about the cementing of the posts in wet environment have found higher bond strengths for the glass-ionomer cement because of the method used, which favored the hygroscopic expansion due to the moisture available in the medium [15,21]. The disadvantage of glass ionomer cement is that there is a lot of brands, the clinician must pay attention on the best ones [21].

SEM images (Fig. 5) showed the formation of spherical bodies in specimens cemented with GIC. Yiu et al. [22] have also identified the presence of these spherical bodies at the resin cement-dentin interface, suggesting that their formation is associated with slow penetration of water from the dentin surface to the glass ionomer matrix. Absorption of water is favored by the moisture available in material, possibly increasing the formation of spherical bodies and contributing to the second reaction phase. The ionic interaction of carboxyl groups and polyalkenoic acid with calcium ions present in the hydroxyapatite

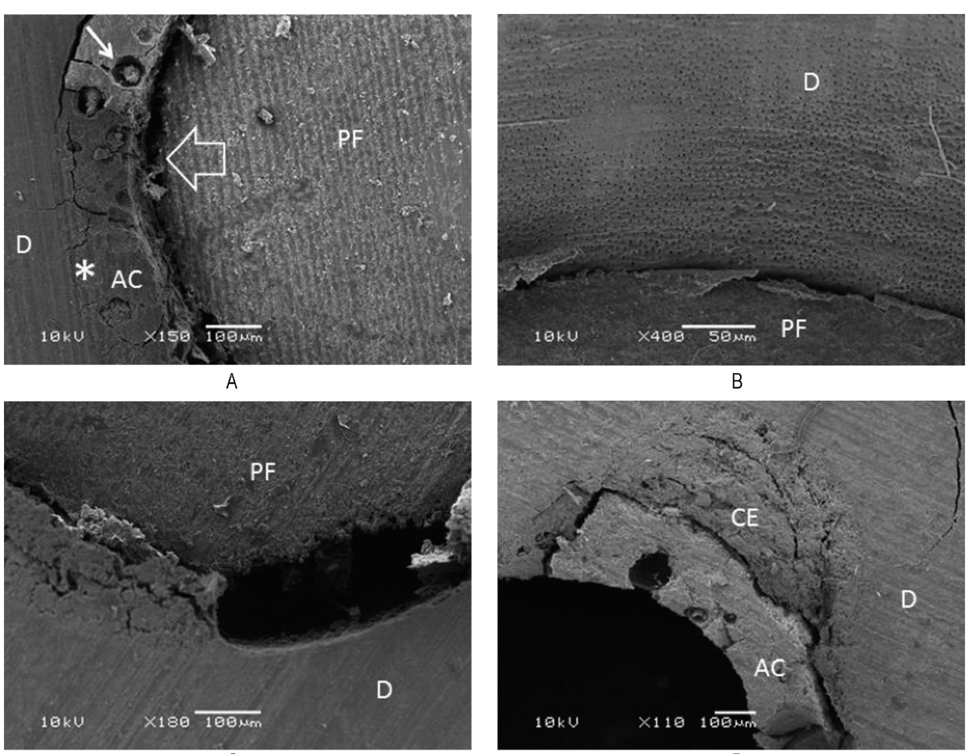

Fig. 5. SEM images of failure modes, at the highest magnification, in 3 experimental groups: a – (TC-MTA/GIC); b – (TC-MTA/ARC); c – (TC-MTA/GIC); d – (CL-AH Plus/GIC). (D) dentin; (PF) fiber post; (AC) luting agent; (CE) sealer.

provides chemical adhesion to glass-ionomer cements. Cook [23] has suggested that the transfer of zinc and calcium ions continues for at least 5 weeks, after which its tensile strength and modulus increase. This reaction would probably not cease, as he noted a continuous increase of tensile strength for more than one year. Furthermore, it has been postulated that there is always a continuous and slow diffusion of cations by the cement, especially aluminum cluster anions [24].

The properties of glass-ionomer cements appear to be even more favorable in the apical third of the root canal. This cement are not dependent on light-curing, and its use becomes favorable in these conditions. Furthermore, the dentin tends to be more sclerotic in the apical portion of the canal [25], thus reducing the density of dentinal tubules. On the other hand, this calcification increases the availability of hydroxyapatite crystals [26], and promotes chemical bonding of the glass-ionomer cement by the presence of a greater amount of calcium ions.

Among the resin cements tested, there was only a significant difference between the materials in the cervical third ($p < 0.05$). The highest bond strengths for the dual ARC sealer may be associated with the partial removal of the smear layer by using conditioners, thus contributing to the increase in dentin permeability, as well as the ability of the three-step self-etching adhesive system to create a suitable dentin hybridization, which provides high bond strengths [27].

When the results obtained in the apical third were examined, there was no significant difference between the resin cements ($p > 0.05$). Access to light cure for polymerization affects the bond strength of glass fiber posts to root canal, providing a superior bonding performance than self-polymerization [28]. The dual-cured cements are dependent on light-curing for converting monomers into a polymer, which could impair bonding to root dentin at the deepest root thirds of the canal where the light does not reach. Furthermore, these cements require the application of a multiple-step adhesive system, making it more technique-sensitive than others, and may affect bonding quality [29].

The use of self-adhesive cements has become a good alternative to lute fiber posts, as they provide greater ease of use, making them less technique-sensitive and more predictable than other types of cements [28]. However, findings of this study revealed lower bond strengths associated with the use of U200. Vaz et al. [27] found that the acidic monomers incorporated by the self-adhesive cements are not strong enough to etch through the smear layer when compared to the “traditional” hybrid layer, resulting in lack of deep penetration of the resin tags into the exposed dentinal tubules. Self-adhesive cements have turned the bonding process poor in relation to micromechanical retention [29], but more dependent on chemical interactions between the acidic monomer and hydroxyapatite. In order to overcome this deficiency, Baldea et al. [30] have used EDTA for canal irrigation prior to cementation. This fact may be related to a better performance of the self-adhesive cement in that study. In the present study, pretreatment of the substrate was not performed, and lower bond strengths were related to this material. If the adhesive cementation of the fiber posts showed no advantage over bond strength, the use of expensive materials could be questioned.

The use of materials of different elasticity modulus in the rehabilitation of endodontically treated teeth generates different stresses for each material. In case of fiber post cementation, the greatest differences are in stiffness between the post and the resin cement, so that probably the failure will occur at the weakest sealer-dentin interface [4]. This type of failure was predominant with RelyX ARC, except when using Endofill, in which mixed failures were predominant, probably because of the interference with the cement polymerization. Rosa et al. [9] has associated the largest number of adhesive failures between dentin and cement to the difficulty in controlling moisture in the root canal, the high C-factor of the cavity, and its dependence on photoactivation, damaging the bond strength in the deepest thirds of the canal where there is decreased light transmission [22]. A fragile adhesive bonding of the hybrid layer formed by the dual-cured cement was observed. In the displacement of fiber post, the exposure of dentinal tubules could be observed (Fig. 5B).

Although the present study found no statistically significant differences in bond strength between endodontic sealer-impregnated dentin and clean dentin, the mechanical preparation of the canal system was not able to completely remove the sealer-impregnated dentin from root canals as it could be seen from confocal laser microscopy images. This technique allows the acquisition of images from several sections of the same specimen, which are then reconstructed [16], allowing to assess the penetration of the sealer into the root canal without the need for the preparation of samples, thus reducing the risk of artifacts during the analysis. To perform this, Rodhamine B was used because its fluorescence allows visualizing the distribution of endodontic sealer inside the dentinal tubules [31,32]. The images obtained allowed us to visualize the penetration of the resin sealer (AH-Plus and MTA-Fillapex) into the tubules, even after site preparation with drills. Previous SEM studies have shown that it is difficult to obtain clean and adequate dentin for applying a resin sealer in endodontically treated teeth after preparation for post [16,33]. Large areas of the root canal remain covered with smear layer, gutta-percha and sealer, especially in areas with anatomical irregularities [33], which was also observed in this study (Fig. 5D).

Furthermore, some long-term investigations and clinical studies should be conducted to monitor the stability of materials.

5. Conclusions

Based on the results and experimental conditions of this study, it may be concluded that the chemical composition of endodontic sealers interferes with the bond strength of fiber posts. The substrate adaptation to the luting agent appears to be a key factor for the successful rehabilitation of endodontically treated teeth. Furthermore, the highest bond strengths were observed when the fiber posts were cemented with the GIC.

References

[1] Morgano SM, Brackett SE. Foundation restorations in fixed prosthodontics: current knowledge and future needs. J Prosthet Dent 1999;82:643–57.
[2] Boone KJ, Murchison DF, Schindler WG, Wlaker WA. Post retention: the effect of sequence of post-space preparation, cementation time, and different sealers. J Endod 2001;27:768–71.
[3] Ferrari M, Vichi A, Mannocci F, Mason PN. Retrospective study of the clinical performance of fiber posts. Am J Dent 2000;13:9–13.
[4] Bitter K, Meyer-Lueckel H, Priehn K, Kanjuparambil JP, Neumann K, Kielbassa AM. Effects of luting agent and thermocycling on bond strengths to root canal dentine. Int Endod J 2006;39:809–18.
[5] Malferrari S, Monaco C, Scotti R. Clinical evaluation of teeth restored with quartz fiber-reinforced epoxy resin posts. Int J Prosthodont 2003;16:39–44.
[6] Grandini S, Sapio S, Goracci C, Monticelli F, Ferrari M. A one step procedure for luting glass fibre posts: an SEM evaluation. Int Endod J 2004;37:679–86.
[7] Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: a review of the current literature. J Prosthet Dent 1998;80:280–301.
[8] Menezes MA, Queiroz EC, Campos RE, Martins LR, Soares CJ. Influence of endodontic sealer cement on fibreglass post bond strength to root dentine. Int Endod J 2008;41:476–84.
[9] Rosa RA, Barreto MS, Moraes RA, Broch J, Bier CA, Só MV, et al. Influence of endodontic sealer composition and time of fiber post cementation on sealer adhesiveness to bovine root dentin. Braz Dent J 2013;24:241–6.
[10] Ordinola-Zapata R, Bramante CM, Graeff MS, del Carpio Perochena A, Vivan RR, Camargo EJ, et al. Depth and percentage of penetration of endodontic sealers into dentinal tubules after root canal obturation using a lateral compaction technique: a confocal laser scanning microscopy study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:450–7.
[11] Cavenago BC, Duarte MA, Ordinola-Zapata R, Marciano MA, Carpio-Perochena AE, Bramante CM. Interfacial adaptation of an epoxy-resin sealer and a self-etch sealer to root canal dentin using the System B or the single cone technique. Braz Dent J 2012;23:205–11.
[12] De Deus G, Brandão MC, Leal F, Reis C, Souza EM, Luna AS, et al. Lack of correlation between sealer penetration into dentinal tubules and sealability in nonbonded root fillings. Int Endod J 2012;45:642–51.
[13] Kok D, Duarte MAH, Rosa RA, Wagner MH, Pereira JR, Só MV. Evaluation of epoxy resin sealer after three root canal filling techniques by confocal laser scanning microscopy. Microsc Res Tech 2012;75:1277–80.

[14] White RR, Goldman M, Lin OS. The influence of the smeared layer upon dentinal tubule penetration by plastic filling materials. J Endod 1984;10:558–62.
[15] Pereira JR, Oliveira MT, Neto EMR, Valle AL, Ghizoni JS, Honório HM, et al. Evaluation of shear bond strength (push-out) of glass fiber posts cemented with different resin cements in humid ambient. Pilot study RFO 2011;16:287–93.
[16] Demiryürek EO, Külünk S, Yüksel G, Saraç D, Bulucu B. Effects of three canal sealers on bond strength of a fiber post. J Endod 2010;36:497–501.
[17] Hagge MS, Wong RDM, Lindemuth JS. Effect of three root canal sealers on the retentive strength of endodontic posts luted with a resin cement. Int Endod J 2002;35:372–8.
[18] Davis ST, O´Connell BB. The effect of two root canal sealers on the retentive strength of glass fibre endodontic posts. J Oral Rehab 2007;34:468–73.
[19] Silva EJ, Rosa TP, Herrera DR, Jacinto RC, Gomes BP, Zaia AA. Evaluation of cytotoxicity and physicochemical properties of calcium silicate-based endodontic sealer MTA Fillapex. J Endod 2013;39:274–7.
[20] Pereira JR, Valle AL, Guizoni JS, Só MV, Ramos MB, Lorenzoni FC. Evaluation of push-out bond strength of four luting agents and SEM observation of the dentine/fibreglass bond interface. Int Endod J 2013;46:982–92.
[21] Pereira JR, Rosa RA, Só MVR, Afonso D, Kuga MC, Honório HM. Push-out bond strength of fiber posts to root dentin using glass ionomer and resin modified glass ionomer cements. J Appl Oral Sci 2014;22:390–6.
[22] Yiu CK, Tay FR, King NM, Pashley DH, Sidhu SK, Neo JC. Interaction of glass-ionomer cements with moist dentin. J Dent Res 2004;83:283–9.
[23] Cook WD. Dental polyelectrolyte cements. I. Chemistry of the early stages of the setting reaction. Biomaterials 1982;3:232–6.
[24] Fricker J, Hirota K, Tamiya Y. The effects of temperature on the setting of glass ionomer (polyalkenoate) cements. Aust Dent J 1991;36:240–2.
[25] Paqué F, Luder H, Sener B, Zehnder M. Tubular sclerosis rather than the smear layer impedes dye penetration into the dentine of endodontically instrumented root canals. Int Endod J 2006;39:18–25.
[26] Mesquita GC, Veríssimo C, Raposo LHA, Santos-Filho PC, Mota AS, Soares CJ. Can the cure time of endodontic sealers affect bond strength to root dentin? Braz Dent J 2013;24:340–3.
[27] Vaz RR, Hipólito VD, D´Alpino PH, Goes MF. Bond strength and interfacial micromorphology of etch-and-rinse and self-adhesive resin cements to dentin. J Prosthodont 2012;21:101–11.
[28] Radovic I, Monticelli F, Goracci C, Vulicevic ZR, Ferrari M. Self-adhesive resin cements: a literature review. J Adhes Dent 2008;10:251–8.
[29] De Munck J, Van Meerbeek B, Yoshida Y, Inoue S, Suzuki K, Lambrechts P. Four-year water degradation of a glass-ionomer adhesive bonded to dentin. Eur J Oral Sci 2004;112:73–83.
[30] Baldea B, Furtos G, Antal M, Nagy K, Popescu D, Nica L. Push-out bond strength and SEM analysis of two self-adhesive resin cements: an in vitro study. J Dent Res 2013;8:296–305.
[31] Sabadin N, Böttcher DE, Hoppe CB, dos Santos RB, Grecca FS. Resin-based sealer penetration into dentinal tubules after the use of 2% chlorhexidine gel and 17% EDTA: in vitro study. Braz J Oral Sci 2014;13:308–13.
[32] Baldissera R, Rosa R, Santini M, Nascimento A, Kuga M, Pereira JR, et al. CLSM assessment of tubule penetration and bacterial leakage evaluation of two resin-based sealer. J Res Dent 2014;2:388–97.
[33] Serafino C, Gallina G, Ferrari M. Surface debris of canal walls after post space preparation in endodontically treated teeth: a scanning electron microscopic study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004;97:381–7.