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ORIGINAL RESEARCH

The Effect of Viscosity and Application Mode of Phosphoric Acid on Bond Strength of GlassFiber Post

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Background: When a phosphoric acid is used, before applying an adhesive system, it is known that obtaining an effective adhesion to the root canal walls is a challenge. The aim of the present study was to evaluate the influence of phosphoric acid viscosity and application mode on the push-out bond strength (BS) values of fiberglass post to root dentin. The conditioning pattern on the root dentin was also evaluated.

Materials and Methods: The roots of 44 endodontically treated premolars were divided into 4 groups, of eleven teeth each, according to the combination of the main factors: phosphoric acid viscosity (liquid or gel) and application mode (passive or sonic). After application of the two-step etch-and-rinse adhesive system, the fiberglass posts were cemented with a dual-cure resin-cement. Roots were sectioned transversely into six 1-mm slices for push-out BS test at 0.5 mm/min. Some roots of each group were selected for evaluation of the conditioning pattern by scanning electron microscopy. BS results (three-way ANOVA and Tukey's test) and the conditioning pattern (Kruskal–Wallis test and Mann–Whitney test) were statistically evaluated ($\alpha = 0.05$).

Results: The highest BS value was observed with a liquid phosphoric acid under sonic application mode ($p < 0.05$), being all other groups similar to one another ($p < 0.05$). Also, the highest BS value was observed in the cervical third, followed by the medium and the apical thirds ($p < 0.05$). The sonic application produced better smear layer removal and opening of dentinal tubules for both viscosities ($p = 0.015$).

Conclusion: A better bonding of fiberglass posts to root canals can be achieved when the post spaces are conditioned with a liquid phosphoric acid under sonic application.

Keywords: fiberglass reinforced polymer, acid etching, post and core technique

Introduction

Teeth with great loss of dental structure due to restorations, deep carious lesions or trauma may need to be treated endodontically. However, pulpless teeth are more susceptible to fracture due to tissue loss and it was indicated to restore with an intra-radicular retainer to increase the retention.[1] Fiberglass post has been universally accepted as a better option to achieve this goal, mainly because they are esthetically favorable. The advantage of the fiberglass posts in relation to other types of posts is that they have a modulus of elasticity close to the dentin.[2,3] However, obtaining an effective adhesion to the root canal walls is a challenge, considering the unfavorable geometry of the root canal and inherent limitations of the cementation materials.[2,3] The limited access to the root canal, the limited cure

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of cementation system at the apical region,[4,5] the difficulties in the pre-treatment of the root dentine,[6] difficulty in achieving an adequate dentin moist control could lead to clinical failures.[2,3]

Regarding the current adhesive strategies for luting glassfiber posts into root canal, traditionally, this could be achieved by etching the dentin (with phosphoric acid or self-etch primers) following the application of a primer and/or an adhesive, associated to a conventional dual-cured resin cement.[3] Taking into consideration that two more important mechanisms to contribute to the resin-to-dentin bond strength are the formation of resin tag penetration and resin penetration into the dentin tubules.[2] Resin tag penetration seems to be the most important mechanism in terms of root canal.[2,7] Phosphoric acid has been widely used as it is required before application of etch-and-rinse adhesive systems. The ability of phosphoric acid to etch the root dentin depends on a good contact with the substrate to be etched or in other words on its ability to completely infiltrate the irregularities of the root dentin.[8,9]

One cannot deny that the viscosity of the phosphoric acid gel and its passive application may impair good conditioning of the root dentin.[8,9] Better control is obtained when applying phosphoric acid gels, but liquid etchants have deeper penetration action, improving conditioning due to their lower viscosity, higher wettability and lower surface energy compared to the gel. A recent study[8] showed that a liquid phosphoric acid yielded better endodontic smear layer removal and higher bond strength values in the apical third.

Another way to improve the wettability of the phosphoric acid is by through active application. Sonic and ultrasonic instruments have been used in different phases of the endodontic treatment.[10,11] However, there are few studies in the literature using these devices in root canal adhesion to optimize the action of dentin conditioning.[10,11] Therefore, the aim of the present study was to evaluate the influence of the phosphoric acid viscosity (liquid or gel) and the application mode (passive or sonic) on the push-out bond strength values of fiberglass post to different root dentin and the conditioning pattern on the root dentin before cementation. The following null hypotheses were evaluated: 1) the phosphoric acid viscosity (liquid or gel) does not affect the push-out bond strength values, as well as, the conditioning pattern; 2) the application mode (passive or sonic) does not affect the push-out bond strength values, as well as, the conditioning pattern and; 3) the different thirds root (cervical, medium or apical) does not affect the push-out bond strength values, as well as, the conditioning pattern.

Materials and Methods

This research project and consent form were approved under the protocol number 010.164.439–60 from the Research Ethics Committee of the School of Dentistry, State University of Ponta Grossa, Paraná, Brazil. The local Ethics Committee on Involving Human Subjects reviewed and approved the protocol and consent form for this study (protocol 1.752.848). Written informed consent was obtained from all participants prior to starting the treatment.

Sample Size and Inclusion Criteria

For this research, 44 extracted human lower unirradicular premolars were selected. The sample size was calculated using www.sealedenvelope.com. The bond strengths in the apical third for adhesive associated with the dual-cure resin cement were considered for sample size calculation. According to the literature, the bond strength mean and standard deviation was 3.0 MPa.[6,8] In order to detect a difference of 3 MPa among the test groups, using a significance level of 5%, a power of 80% and a two-sided test, the minimum sample size was 11 teeth per group. The selected teeth presented the following eligibility criteria: root length of 14 mm, measured from the cement-enamel junction (CEJ), absence of caries and root cracks, absence of prior endodontic treatments and incomplete root end. The teeth were disinfected in 1% thymol, stored in distilled water, and used within 6 months of extraction.

Specimen Preparation

All teeth were cross-sectioned immediately below the CEJ using a low-speed diamond saw (IsoMet 1000, Buehler, Lake Bluff, Illinois, USA). The endodontic instrumentation was performed with ProTaper Next (Dentsply Malleifer, Ballaigus, Switzerland) with a low torque motor at a contact speed of 300 rpm. Composite resin was used to fix rubber stopper to control instrumentation length. When instrumentation length was 1 mm from the apical foramen, apical patency was performed after each file by inserting #15 K-file until it appeared at the apical foramen. Each canal was irrigated by using a syringe and a 27-gauge needle with 2 mL of freshly prepared 2% NaOCl solution between the uses of each instrumentation. ProTaper Next (Dentsply Malleifer) was used in full instrumentation lengths in the following sequence X1, X2, and X3.[5,6,10,11]

The roots were dried with paper points (Dentsply Maillefer), and only the 4 mm apical was filled with calcium-hydroxide-based canal sealer (Sealer 26, Dentsply Maillefer) and gutta-percha points (Tanari, Manacapuru, Amazonas, Brazil) using the Schilder technique. Then, the root access was temporarily filled with conventional glass ionomer cement (Vitro Fil, DFL, Rio de Janeiro, RJ, Brazil).

After one week of storage in 100% relative humidity (Eppendorf tubes, supported by gauze soaked in distilled water) at 37 ± 1°C, the root canals were prepared with the corresponding tungsten carbide bur of the post Whitepost DC # 2 (cylindrical with tapered end with 1.8 mm cervical diameter; 1.05 mm apical diameter; FGM, Joinville, SC, Brazil). One bur was used for every six preparations. The root canals were then irrigated with 10 mL of distilled water, and then dried for 5 s with an air stream and one paper point # 80 (Dentsply Maillefer). The working length of the post space was 10 mm for all teeth, to maintain the apical 4-mm apical filling.[5,6,10,11]

Experimental Groups

The roots were randomly divided into 4 groups by block randomization (n = 11 per group), according to the combination of the following factors: Etchant viscosity – liquid or gel and; Application mode – passive or sonic. Thirty-two out of these 44 roots were used for push-out bond strength test and twelve roots were used for evaluation of the conditioning pattern of the root dentin under scanning electron microscopy. Only one operator performed all restorative procedures.

Before cementation, fiberglass posts were horizontally sectioned at the coronal region with a water-cooled diamond-cutting instrument to reduce the post length to 13 mm. While 10 mm were cemented inside the root canal the coronal 3 mm served as a guide to standardize the distance of the light-curing device from the cervical root area. All the posts were cleaned with a gauze immersed in 70% alcohol for 5 s.

The post cementation procedure was performed according to the different experimental groups, following the recommendations of each manufacturer (Table 1). The root canal walls were either etched with 37% phosphoric acid gel (Condicionador Alpha Acid gel, Nova DFL, Rio de Janeiro, RJ, Brazil) or with 37% phosphoric acid liquid (Condicionador Alpha Acid líquido, Nova DFL). The gel etchant was taken with the syringe provided by the manufacturer, while the liquid etchant was provided in a bottle. To standardize the process, both phosphoric acid were firstly dropped in a millimeter syringe to ensure that the same amount of gel and liquid was used. Then, each phosphoric acid was dispensed in a microbrush (Cavibrush Longo, FGM, Joinville, SC, Brazil) and inserted into the whole length of the root canal.

In the passive application mode, both the gel and the liquid were left undisturbed for 15 s into the root canal and then the etchant was washed with tap water for 30 s. In the active application mode, a microbrush (Cavibrush Longo, FGM, Joinville, SC, Brazil) was attached to the tip of a prototype sonic applicator, which will be released on the dental market by FGM as Smart (FGM). The prototype produces an oscillating vibration of 10,200 rpm or 170 Hz measured by the Blackman-Harris sound method.[10,11] The sonic device has 5 different oscillating frequencies (144.5, 150, 167.5, 170 and 223.5 Hz). The middle frequency (170 Hz) of the device[10,11] was used. It is important to report that the microbrush attached to the sonic device vibrates at the same oscillating frequency (170 Hz) of the device when in a non-contact condition. The device was kept inside the root canal for 15 s in contact with the acid gel or acid liquid. After this period, the etchant was washed out for 30 s with abundant water rinsing.

The root canals were dried with compressed air for 5 s at 2 cm and dried with two #40 paper points, taking care to not dehydrate the dentin surface.[6] A rigid microbrush (Cavibrush Longo, FGM) was used to apply the universal adhesive system (Single Bond Universal, 3M Oral Care, St. Paul, MN, USA, also known as ScotchBond Universal in some countries), which was used in the etch-and-rinse mode according to the manufacturer's directions. In summary, two coats of the adhesive were applied on root dentin under vigorous application, followed by solvent evaporation for 5 s after each coat. The excess of adhesive was removed with a paper point and then the adhesive was light cured for 40 s (Radii Plus, SDI Limited, VIC, Australia) set at 1,200 mW/cm^2.[5,6,10,11]

The luting cement RelyX ARC (3M Oral Care, St. Paul, MN, USA) were handled according to the manufacturer's recommendations, inserted into the root canal with a Centrix syringe (Centrix Inc., Shelton, CT, USA) and the fiberglass post (Whitepost DC # 2; 1.8 mm cervical diameter; 1.05 mm apical diameter; FGM, Joinville, SC, Brazil) positioned into the root. In all groups, the same brand of fiberglass post (cylindrical with tapered end with a crown diameter of 1.8 mm was cemented).

Then the luting cement were photo-activated for 120 s with the same light-curing unit.[5] After the luting procedures, the roots with cemented posts were covered with conventional glass ionomer cement (Vitro Fill, DLF) and

Table 1 Material/Manufacture, Application Mode, Batch Number of Cementation and Adhesive Systems

Material/ Manufacturer	Composition	Application Mode	Batch Number
Condicionador Alpha Acid gel, Nova DFL	37% Phosphoric acid, 5–7% of colloidal silica dioxide (Aerosil 200), methylene blue CI52015 and deionized water, bidistilled glycerin. The gel showed a thixotropic consistency.	Apply the gel standby for a period of 15 seconds. Wash and dry the cavity so that the dentin does not dehydrate.	14091329
Condicionador Alpha Acid líquido, Nova DFL	37% Phosphoric acid, methylene blue CI52015 and deionized water	Apply the liquid to a disposable device and wash the region to be conditioned. Wash and dry the cavity so that the dentin does not dehydrate.	14091286
Single Bond Universal, 3M Oral Care	Bisphenol A diglycidyl ether dimethacrylate, 2-hydroxyethyl methacrylate, silica-treated silica, ethyl alcohol, decamethylene, dimethacrylate, water, 1,10-decanediol. Phosphate methacrylate, acrylic and itaconic acid copolymer, camphorquinone, N, N-dimethylbenzocaine, 2-dimethylamonoethyl methacrylate, methyl ethyl ketone.	Apply the adhesive with a disposable applicator inside the canal for 20 s, dry with a slight jet of air for 5 s to evaporate the solvent, apply one absorbent paper point #40 and light cure for 10 s.	638367
RelyX ARC, 3M Oral Care	Paste A: Bisphenol A diglycidyl ether dimethacrylate, tetraethylene glycol dimethyl ether, inorganic zirconia and silica particles (68 wt.%), Photoinitiators, amine and pigments. Foliar B: Bisphenol A diglycidyl ether dimethacrylate, tetraethylene glycol dimethyl ether, benzoyl peroxide, inorganic particles of zirconia and silica (67% by weight).	Manipulate the paste in the same proportion for 10 s, apply the cement around and inside the endodontic canal by means of a specific syringe, seat the post within the post space, removing excess cement and light cure for 40 s through the remainder of the post.	1628100400

all roots were stored in high relative humidity in distilled water at 37 ± 1°C for one week.

Push-Out Bond Strength Test

A different operator that was blindly for the restorative procedure was responsible for the push-out bond strength evaluation. This methodology was described in detail in earlier publications.[5,6,10] Roots were sectioned perpendicular to the long axis into seven 1-mm thick slices using a low-speed diamond saw. The first coronal slice was discarded due to the presence of excess cement. For each root, we obtained six slices representing the coronal third (2 slices), medium third (2 slices) and apical third (2 slices).

The push-out bond strength test was performed on all slices obtained from the 8 roots of each experimental group. The slices were photographed on both sides with an optical microscope at 40X magnification (Olympus BX 51 model, Olympus, Tokyo, Japan), with the purpose of calculating their individual bonding areas with the aid of the Image Tool software (University of Texas; San Antonio; Texas, USA). To calculate the adhesive area, we used the formula of a lateral surface of a truncated cone: $LS = \pi(R + r)[(h^2 + (R - r)^2]^{1/2}$ where $\pi = 3.14$, R = coronal post radius or root canal radius (coronal post + resin cement radius), r = apical post radius or apical root canal radius (post + resin cement radius), and h = root slice thickness.[10]

Each slice was positioned with cervical side down on a metal jig of the universal testing machine (INSTRON Corp., Canton, MA, USA), with a small central opening, so that a constant compressive force (with a 50 kg load cell) at a cross-head speed of 0.5 mm/min would be exerted in the center of each post with cylindrical metal tips until debonding. The diameter of these metallic tips was compatible with the diameter of post in each root canal third, being slightly smaller to avoid touching on dentin.

The load value for post dislodgment was recorded in Newtons (N), and converted to MPa by dividing the load value (N) by the value of the adhesive area (mm2). After the push-out evaluation, each specimen was evaluated under a stereomicroscope (40X magnification) and the failure modes were classified according to the following criteria: (a) mixed failure, (b) adhesive failure between luting cement and dentin, (c) adhesive failure between luting cement and post, (d) cohesive failure within the post, (e) cohesive failure within luting cement and (f) cohesive failure within dentin. The specimens that presented the most representative fracture modes were taken to the scanning electron microscope.

Analysis of the Conditioning Pattern Under Scanning Electron Microscopy (SEM)

Three roots of each group were randomly selected for morphological evaluation of the pattern of the smear layer removal after the root dentin conditioning according to each experimental group. To facilitate root fragmentation and consequent exposure of the root dentin, two longitudinal grooves (at the buccal and at the lingual root surface) were carried out in the outer root surface with the aid of a diamond saw adapted at low speed, taking care to not reach the root canal. Then, all root canals were conditioned according to its respective experimental groups, as already described earlier in the section of the push-out bond strength test.

Two hemi-sections were obtained exposing the entire inner length of the root canal. At this step, all roots were cleaned again in an ultrasonic water bath for 8 min. Then, the samples were fixed in 2.5% glutaraldehyde for 12 h at room temperature and rinsed with distilled water for approximately 1 min. The specimens were dehydrated in ascending grades of ethanol: 25% (20 min); 50% (20 min); 75% (20 min); 95% (30 min); 100% (60 min), mounted in stubs with cyanoacrylate resin, left in a desiccator with colloidal silica for 24 h, sputter coated with gold (MED 010, Balzers Union; Balzers, Liechtenstein), and taken in SEM (SSX-550, Shimadzu; Tokyo, Japan) in a secondary electrons mode at x2000 magnification. As two hemi-roots were examined and a total of three roots were used in each experimental group, a total of 6 images were obtained for each experimental group at each root third.

Morphological Evaluation of Smear Layer

Before the start of the evaluation, two different operators that were blindly for the restorative procedure were responsible for the morphological evaluation of smear layer. The evaluators had been trained in the use of the assessment criteria in a blind manner. The examiners were instructed to apply the criteria independently without reference to each other. The number of dentinal tubule opening was scored from 0 to 2: score 0 - all dentinal tubules open, without debris; score 1 - some dentinal tubules open, with a thin smear layer; and score 2 - all dentinal tubules blocked by a thick smear layer. Also, the presence of debris and smear plugs were qualitatively evaluated. The kappa interobserver agreement (Kappa) was applied. Disagreements were solved by consensus.[12]

Statistical Analysis

The data were first analyzed using the Kolmogorov–Smirnov test to assess whether the data followed a normal distribution, as well as Barlett's test for equality of variances to determine if the assumption of equal variances was valid. After confirming the normality of the data distribution and the equality of the variances, data obtained from the push-out bond strength test were subjected to a three-way analysis of variance (etchant viscosity vs application mode vs root third) and Tukey's test ($\alpha = 5\%$). The data obtained from the conditioning pattern were evaluated by Kruskal–Wallis test and Mann–Whitney test ($\alpha = 5\%$). The fracture pattern mode was only evaluated qualitatively. The Sigma Plot 11 software (Systat Software, San Jose, CA, USA) was used for statistical analysis.

Results

Push-Out Bond Strength Test

The overall means and standard deviations for all experimental groups are described in Table 2. The three-way ANOVA detected that only the cross-product interaction etchant viscosity vs application mode ($p < 0.001$) and the main factor root third ($p < 0.001$) were statistically significant.

The highest bond strength value was observed when the conditioning of the root canal was performed with a liquid phosphoric acid under sonic application mode ($p < 0.001$; Table 3). In all other groups, the push-out bond strength values were statistically similar ($p = 0.35$; Table 3). Regarding the root third, the highest push-out bond strength value was observed in the cervical third (7.9 ± 2.9) and the

Table 2 Overall Means and Standard Deviations of the Push-Out Bond Strength Values (MPa) for All Experimental Groups

Root Third	Passive Application		Sonic Application	
	Gel	Liquid	Gel	Liquid
Cervical	8.8 ± 3.0 a,b	6.9 ± 2.5 b	7.0 ± 2.7 a,b	9.5 ± 6.0 a
Medium	4.1 ± 1.3 b,c	3.3 ± 0.9 c	4.5 ± 1.4 b,c	6.0 ± 1.5 b
Apical	2.0 ± 0.7 d	2.2 ± 0.6 d	2.1 ± 0.4 d	3.7 ± 1.2 c

Note: Averages identified with the same lowercase letters indicate means statistically similar.

Table 3 Means and Standard Deviations of the Push-Out Bond Strength Values (MPa) for the Cross-Product Interaction Mode of Application vs Etchant Viscosity (*)

Mode of Application	Etchant Viscosity	
	Gel	Liquid
Passive	4.7 ± 3.3 b	4.2 ± 2.6 b
Sonic	4.6 ± 2.7 b	6.2 ± 3.1 a

Note: Averages identified with the same lowercase letters indicate means statistically similar.

lowest value was observed in the apical third (2.6 ± 1.0). The medium third had an intermediate value (4.5 ± 1.6) between the cervical and apical thirds. The cervical third was statistically significant difference of medium and apical thirds, as well as, medium third was statistically significant difference of apical third ($p < 0.001$).

The most common fracture pattern was mixed (64.5%). Few cohesive failures in the post (4.8%) and adhesive failures between the cement and post (19.8%) or adhesive failures between cement and dentin were observed (10.9%; Figure 1). The failure pattern was not different when two etchant viscosity were compared, as well as application mode (Figure 1).

Analysis of the Conditioning Pattern Under Scanning Electron Microscopy (SEM)

The interobserver agreement was 0.89 (Kappa). The percentage of the scores attributed to the number of obliterated dentinal tubules can be seen in Figure 2. The Kruskal–Wallis test detected that only the application mode was statistically significant ($p = 0.01$). Therefore, since the statistical analysis did not detect significant difference among root thirds (Kruskal–Wallis test; $p = 0.78$), only the overall data are presented. The differences in the frequency values among the treatment groups are greater than would be expected by chance; therefore, a statistically significant difference was detected (Figure 2; Mann Whitney; $p = 0.015$).

Representative SEM images can be seen in Figure 3A–C. It was possible to see that the liquid and gel applied as passive technique shows dentinal surfaces with smear layer debris and partial opened tubules due to the presence of smear plugs in all thirds (Figure 3A–C). On the other side, the sonic application produced a better removal of the smear layer and opening of the dentinal tubules for both phosphoric acid viscosity when compared to passive application mode. No debris was observed when sonic application was performed (Figure 3A–C).

Discussion

In the etch-and-rinse strategy, phosphoric acid is always applied with the aim to remove the smear layer before resin infiltration, as well as in the previously simplified etch-and-rinse adhesives.[13,14] For such purpose, phosphoric acid gel is the most frequently used for dental purposes, as its higher viscosity allows greater control of application.[15] On the other hand, this characteristic has the disadvantage of reduced flowability, which restricts acid diffusion in constrained areas, such as the apical region of root canals.[11]

Theoretically, phosphoric acid in the liquid viscosity has a higher wettability,[15,16] which facilitates the access to these difficult areas. However, in the present study,

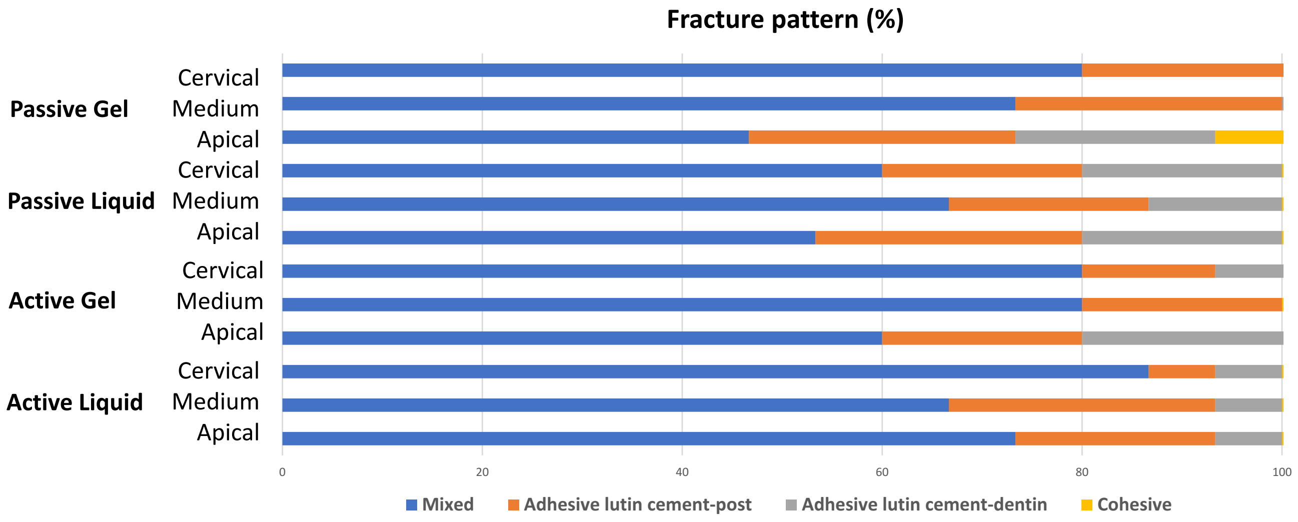

Figure 1 Number of specimens (%) according to the fracture pattern modes observed in the different experimental groups.

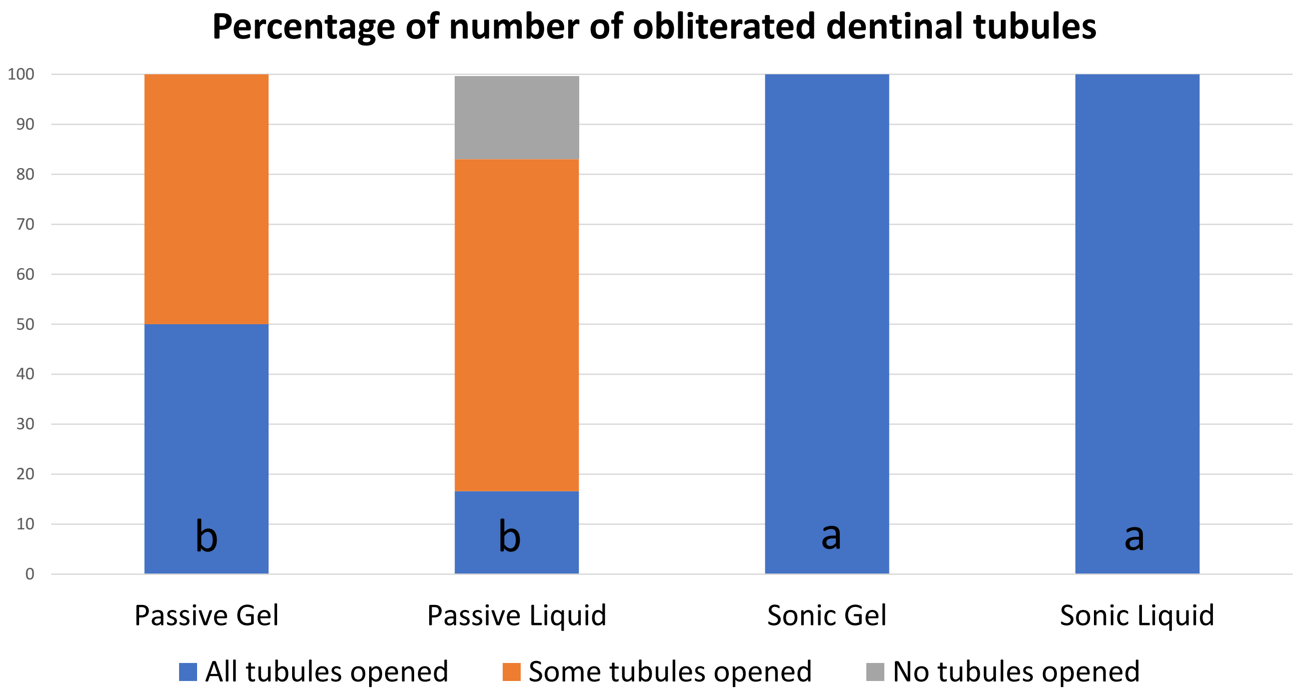

Figure 2 Number of specimens with opened dentinal tubules (%) observed in the different experimental groups. Groups identified with same lowercase letters indicate values statistically similar ($p > 0.05$).

contrary to our previous expectation and previous literature,[8] both etchants produced similar bond strength values when they were used without agitation, in the passive mode, as well as previously showed when enamel surface were evaluated.[16,17] The pattern of smear layer removal was also similar for both groups, with a presence of smear plugs inside the dentinal tubules. This leads us to partially accept the first null hypothesis.

These results are not in agreement with Salas et al[8] and Scotti et al[9] In both studies, the authors evaluated the influence of acid viscosity on the push-out bond strength of a glass fiber post. The results showed that, in general, liquid phosphoric acid had significantly higher bond strength values.[8,9] However, this depended on the endodontic sealer applied[8] or to endodontic device used to apply phosphoric acid.[9] In the present study, only one endodontic sealer was used and the phosphoric acid was applied with a microbrush. Therefore, future studies need to be done, comparing the effect of acid viscosity when different endodontic sealer and devices were used to apply phosphoric acid.

However, the most relevant results could be observed when both etchants were applied under sonic application, since higher bond strength values were observed only for the liquid etchant. This leads us to partially reject the second null hypothesis. The sonic vibration imparted energy to the liquid etchant, creating pressure waves, shear forces and microscopy bubbles[10,18] that propelled the acid against the root dentin surfaces to which it is applied. This may have increased the demineralization of the smear layer, the reason of why less smear layer debris were observed with sonic application. The increased removal of the smear layer could be indirectly responsible for the highest bond strength values observed with the liquid etchant under sonic application. These results are in agreement with the previous literature.[10,18]

Interestingly, the acid etchant gel did not benefit from sonic application. Although sonic application of the gel produced a smear layer with less debris, some differences between gel and liquid phosphoric acid could be responsible for the lack of efficacy of sonic application for the gel etchant in terms of bond strength to root dentin.

It is known that the main difference between the gel and the liquid phosphoric acid is the amount of thickening agents, as colloidal silica or polymers, added to their composition. Colloidal silica usually remains on the surface, being not completely washed away before bonding and may negatively affect bonding.[15] The sonic application may have compressed the silica against the root dentin during application. Washing of gel etchants is more difficult and it requires more time for removal of the chemical by-products of the demineralization process as there is

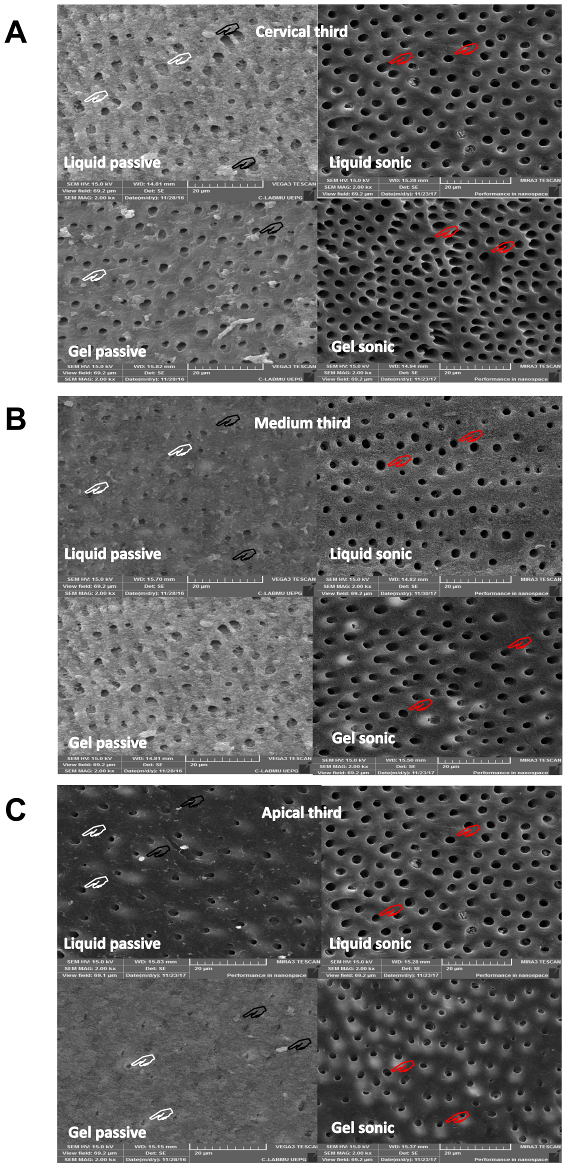

Figure 3 Representative SEM images of each third ((**A**) cervical; (**B**) medium; (**C**) apical) of the conditioning pattern observed in the experimental groups. It was observed that, in all thirds, the liquid and gel applied as passive technique shows dentinal surfaces with smear layer debris (black hands) and partially opened tubules due to the presence of smear plugs (white hands). On the other side, in the groups where the liquid and gel etchants were applied in the sonic mode, it was a more complete opening of the dentinal tubules (red hands).

reduced miscibility of the etchant with water when in the gel state.[8,9] Altogether this might have jeopardized resin infiltration, as previously shown by several authors.

In regard to root third, reduced bond strength values were observed in the apical third, lead us to reject the third null hypothesis. This is in line with what has been published for fiber posts cemented with etch-and-rinse adhesives.[2,5,6] This reduced bond strength in this area has been attributed to several factors acting together. The number of tubules and the ratio between peritubular and intertubular dentin greatly varies from the apical to the coronal third.[2,5,6] This means lower adhesive impregnation and helps to understand the lower bond strength to apical area. Additionally, handling of materials in the apical area is more difficult due to the limited endodontic space[2,3] in comparison with the cervical third.

Although the sonic application produced a better removal of the smear layer and opening of the dentinal tubules for both phosphoric acid viscosity when compared to passive application mode, an improved bonding of fiberglass posts to root canals could be achieved only when the roots were conditioned with a liquid phosphoric acid under sonic application.

It worth to mention that, a conventional luting resin cement was used in the present study, instead of a self-adhesive resin cement. Although a recent systematic review of in vitro studies showed that a self-adhesive resin cement to be less technique-sensitive to luting, these results are based on a predominance of one particular self-adhesive resin cement, indicated that these results should not be generalized for all self-adhesive resin cement. Also, the clinical studies that compared self-adhesive resin cements with conventional resin cements are still scarce.[19]

Also, in the present study, a light-curing adhesive was used instead of a dual-curing adhesive. Although a common sense that, a dual-curing adhesive is better than light-curing adhesives, in a post space, the former does not appear better than that using light-curing adhesives.[4,5,20,21] This is because there are several adverse interactions between simplified adhesive and resin cement due to a lack of light exposure.

In the absence of light, due to the longer time to chemically cured of resin cement, it occurred adversely reaction being that the use of simplified adhesives systems was found incompatible with chemically cured resin cements.[22] It occurred due to chemical interaction between unpolymerized acidic adhesive resin monomers and the basic tertiary amine catalyst in the chemically cured resin cement.[23] The second problem is that simplified adhesive systems are highly hydrophilic and act as permeable membranes, that permitting rapid water movement across the polymerized adhesive,[24] even in endodontically treated teeth.[25]

Although purportedly able to polymerize even in the complete absence of light, dual-curing resin cements develop better mechanical properties when they are exposed to curing light.[26,27] Therefore, exposure to curing light has been suggested even when dual-curing adhesive and resin cements are used.[5,21,26,27] One simple way to overcome these obstacles is to use a high-intensity light-curing unit and/or prolong the light exposure time that may improve the adhesion of the adhesive/resin cement to root canal dentin.[4,5,20,21,26,27]

When higher radiant exposure values were delivered to the adhesive/resin cement during fiber-post cementation in the root canal, it occurred an increased degree of conversion and the root-canal bond strength, as well as, a reduced nano-leakage within the hybrid layer for dual-curing and light-curing adhesives evaluated, without significant difference among them.[5] This was the reason to use a high-intensity light-curing unit associated with a prolonged light exposure time during the luting procedure in the present study.

Some limitations need to be described and one of that is only short-term results are shown. Unfortunately, the application of both acids under sonic application increases the conditioning pattern and this occur due to deeper demineralization of root dentin with more exposed dentin matrix, and consequently, increase in the endogenous enzymatic activity.[28] In fact, it has previously been demonstrated that host-derived proteases play a role in the degradation of resin–dentin interfaces.[29] Therefore, it will be expected that a decrease in the bond strength values after long-term water storage when sonic application was applied associated with phosphoric acid. However, future studies need to be done for evaluating this hypothesis. Also, further studies should still be conducted with other types of adhesives and cementation systems to detect if the results herein observed can be extrapolated to other combination of materials.

Conclusion

Although the sonic application produced a better conditioning pattern for both phosphoric acid viscosity when compared to passive application mode, it is only increasing the push-out bond strength values when a liquid phosphoric acid was used.

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Disclosure

The authors report no conflicts of interest in this work.

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