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Effect of Proanthocyanidine Pre-treatment on Bonding Durability of Three Resin Cements with Fiber Post

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Background and objectives: Establishing a strong and durable bond between cements and root canal dentin has been widely studied. Since the effectiveness of proanthocyanidin (PA) as a collagen cross-linker has been proven, the strength and durability of the bond between fiber posts and root canal dentin are expected to increase following the application of PA. Therefore, the present study aimed to assess the effect of PA pre-treatment on the bonding durability of fiber posts with three resin cements.

Materials and methods: Ninety human single-rooted teeth with similar anatomical root shape and length were collected. After decoronation and root canal therapy, the teeth were divided into nine groups: etch and rinse (ER), self-etch (SE), self-adhesive (SA), PA pre-treatment and etch and rinse (PAER), PA pre-treatment and self-etch (PASE), PA pre-treatment and self-adhesive (PASA), chlorhexidine (CHX) pre-treatment and etch and rinse (CHXER), CHX pre-treatment and self-etch (CHXSE), and CHX pre-treatment and self-adhesive (CHXSA). After microslicing the roots, push-out tests were performed immediately for half the specimens and after three months of water storage and thermocycling for the other half. Data were analyzed using two-way ANOVA and Tukey's test with $\alpha = 0.05$.

Results: Resin cement type ($P = 0.001$), dentin pre-treatment method ($P = 0.001$), water storage and thermocycling ($P = 0.001$), and the root region ($P = 0.001$) had significant effects on bond strength.

Conclusion: SA resin cement had the lowest immediate and long-term bond strength in comparison with the other two cements. For ER and SE resin cements, no pre-treatment led to higher immediate and long-term bond strength. For SE and SA resin cements, PA pre-treatment inhibited the loss of bond strength in the long-term. The bond strength in the coronal region was higher than that in other regions.

Keywords: Bond strength, Fiber post, Proanthocyanidin, Resin cement.

1. Introduction

Fiber posts reinforced with glass fibers are recommended for use in combination with composite resins for the final restoration of endodontically treated teeth (1). Some fiber posts privilages include biocompatibility, optimal mechanical properties similar to those of dentin, high corrosion resistance, and polymerization light transmission (2,3). In the cementation of fiber posts, forming a durable bond between cement and the root canal dentin is imperative to increase the fracture strength, establish a coronal seal, and enhance the retention of restorations (4-6). In this regard, resin cements are usually preferred to other cements. Characteristics such as easy manipulation, a better film thickness, extended working time, and low solubility are ideal properties in luting cement (7). Bonding to root canal dentin is accompanied by complexities in clinical practice, such as limited access and vision, difficult moisture control, decreased number of dentinal tubules in this region, and deposition of cementum and secondary dentin. In addition, such a bonding is constantly subjected to continuous degradation (8).

A hybrid layer resulting from the copolymerization of adhesive and primer-penetrated collagen fibers plays a significant role in resin bonding to dentin (9). This layer also contains residual hydroxyapatite crystals, the primer solvent, and water. The presence of the two latter factors, in particular, can impair the structural integrity of the hybrid layer. On the other hand, due to interference in resin polymerization, these factors increase the probability of the removal of unreacted monomers from the resin layer and ultimately prevents the formation of resin coating over the naked collagen fibers. The hybrid layer is subjected to degradation over time (10). Matrix metalloproteinases (MMPs) are zinc- and calcium-dependent endopeptidases trapped in dentin during tooth development and contribute to the initial formation of dentin and its regeneration. Most of these enzymes are pre-enzymes released from odontoblasts and must be activated. These enzymes can destroy the extracellular dentin matrix components and, consequently, the hybrid layer (11-13).

Methods such as inactivation of enzymes in dentin using MMP inhibitors, quaternary ammonium methacrylate, or benzalkonium chloride compounds, ethanol wet bonding, and the use of collagen cross-linkers are employed to increase the durability of the bond between resin and dentin (14-19). Chlorhexidine (CHX)can potentially inhibit a wide range of MMPs and can exclusively affect the activity of MMP-2, MMP-8, MMP-9, and cysteine cathepsins (CP) (20, 21). Materials that can chemically cross-link the collagen can be used to achieve a hybrid layer with a desirable resistance to enzymatic degradation. Using external cross-linkers can improve the mechanical properties of collagen and simultaneously decrease its enzymatic degradation. Proanthocyanidin (PA), a polyphenolic compound, is a natural collagen cross-linker extracted from plants (22). Such a cross-linker has a higher biocompatibility than synthetic compounds. PA can play the same role as MMP inhibitors and has a dual action in increasing the durability of the bond between resin and dentin (23, 24).

Some studies have shown that using PA leads to an immediate increase in the elastic modulus of the collagen matrix. More interestingly, the magnitude of this increase is maintained even after the onset of the attack of bacterial collagenase. It is worth noting that the improvement in the mechanical properties of dentin in the presence of PA is mainly due to the chemical bond between collagen and cross-linker agents. In addition, PA prevents the destruction of collagen fibers and thus enhances the immediate adhesion of resin to dentin and bonding durability (25-27). Despite the existing evidence regarding the effect of collagen cross-linkers on physical and chemical properties of collagen, their clinical use is still a matter of debate. This study aimed to investigate the effect of PA pre-treatment on the bonding durability of fiber posts with three resin cements.

2. Materials and methods

Ninety single-rooted human teeth with similar anatomical root shapes and no crack or fracture were collected. The study was approved by the ethics committee of Shahed University (IR. Shahed.REC.1396.38).

2.1. Specimen preparation

In order to prevent microbial growth, the samples were stored in 0.02% sodium azide solution at 4°C. Then, they were decoronated using a diamond saw (D&Z, Berlin, Germany) so that we eventually obtained a set of samples with an equal length of 15 mm. The root canals of the teeth were cleaned to 1 mm from the apex using K-files with a maximum number of 40. The root canals were filled with gutta-percha (Aria Dent, Asia ChemiTeb, Tehran, Iran) and AH26 sealer (Dentsply Caulk, Milford, Germany). The coronal seal was obtained using resin-modified glass ionomer (Fuji II LC; GC Corporation, Tokyo, Japan). Next, the root canal walls of all teeth were cleaned from gutta-percha and sealer such that a minimum of 4 mm of gutta-percha remained at the apical third. This length was ensured radiographically. The post space was then prepared at a depth of 10 mm using a #4peeso-reamer according to the manufacturer's instructions. Then, #2fiber posts (Reforpost-Angelus, Londrina/PR, Brazil) with 1.3 mm diameter were used. After ensuring the passive insertion of the fiber posts, their surface was cleaned with ethanol and silanized. Ethanol was selected as a solvent of grape seed extract (Santa Cruz Biotechnology, Dallas, TX, USA), and the PA solution was made with it at a 5% concentration.

The teeth were randomly divided into nine experimental groups. Based on the type of resin cement and pre-treatment groups are: 1) etch and rinse (ER), 2) self-etch (SE), 3) self-adhesive (SA), 4) PA pre-treatment and etch and rinse (PAER), 5) PA pre-treatment and self-etch (PASE), 6) PA pre-treatment and self-adhesive (PASA), 7) CHX pre-treatment and etch and rinse (CHXER), 8) CHX pre-treatment and self-etch (CHXSE), 9) CHX pre-treatment and self-adhesive (CHXSA).

For the first three groups, etch and rinse (Excite DSC/Variolink II; IvoclarVivadent), self-etch (ED Primer II/Panavia F2.0; Kuraray, Osaka, Japan), and self-adhesive (Panavia SA luting plus; Kuraray, Osaka, Japan) resin cements were used according to the manufacturer's instructions. Details in this respect are provided in Table 1.

In the PAER group, after etching the root canal dentin with 37% phosphoric acid, 5% PA solution was applied on the root canal walls for one minute, and after rinsing, the remaining steps were carried out as mentioned for group ER (Table 1). Also, 5% PA solution was used for dentin pre-treatment in group PASE, prior to using the ED Primer II, and in group PASA, pre-treatment was done before the application of resin cement. Moreover, in group CHXER, 2% CHX was applied to root canal walls for one minute after etching. CHX pre-treatment was done before using the ED Primer II in group CHXSE, and in group CHXSA, CHX was applied on the root canal walls before using the resin cement.

After applying the resin cement into the post space, the fiber posts were placed, and light-curing was performed for 40 seconds with a light intensity of 600 mW/cm^2 (Demi Plus LED Light Curing System, Kerr, USA). Finally, a coronal seal was achieved with resin-modified glass ionomer cement. The samples were stored in distilled water at 37.8°C for one week. It is worth noting that all stages of the work were carried out by one operator. Afterward, half of the samples were stored in 0.4% sodium azide at 37.8°C for three months and underwent 10,000 thermal cycles between 5-55°C with a dwell time of 30 seconds. For the other half of the samples, the bond strength test was performed immediately.

2.2. Thin-slice push-out test

For microslicing, a slow-speed cutting machine (Mecatome T201 A, Presi, Grenoble, France) was used, and each of the samples was transversely cut into seven slices with 1 mm thickness. The first coronal slice and the 3 mm apical part were excluded, and, therefore, six slices consisting of two apical, two middle, and two coronal slices were obtained. Finally, 540 samples were tested in this experiment. The thin slice push-out test was performed using a universal testing machine (Zwick, Roell, Ulm, Germany) by applying compressive load at a crosshead speed of 0.5 mm/minute. The force was applied to the center of each post along its apicocoronal direction. The bond strength was calculated in megapascals (MPa) by dividing the maximum load tolerated by each post in Newton's by the surface area of the interface between the post and the root canal in square millimeters.

2.3. Failure mode analysis

To determine the failure mode, all tested pieces were inspected under a stereomicroscope (Nikon SMZ800; Japan) atx40 magnification. There are five possible failure modes as follows: 1) cohesive failure in dentin, 2) cohesive failure in cement, 3) adhesive failure between cement and dentin, 4) adhesive failure between cement and post, and 5) mixed failure (combination of two or more failure modes) (Figure 1).
In each group, samples whose bond strength was close to the average value of their groups were selected, and after gold sputter coating, they were inspected under a scanning electron microscope (SEM; CAMSCAN, MV 2300, Czech) at x100 and x500 magnifications under vacuum conditions (Figure 2).

2.4. Statistical analysis

Data were analyzed by IBM SPSS statics for Windows (Version 22.0. Armonk, NY: IBM Corp). Considering the normal distribution of data, two-way ANOVA and Tukey's multiple comparisons test were used to study the effect of independent variables on bond strength with $\alpha = 0.05$.

3. Results

The statistical analysis of the data showed that the resin cement type (P= 0.001), dentin pre-treatment method (P= 0.001), water storage and thermocycling (P= 0.001), and root regions (P= 0.001) had significant effects on bond strength.
The immediate and long-term bond strength values of all root regions in groups without pre-treatment, with ER and SE resin cements were higher than the values in groups with PA and CHX pre-treatments (P< 0.05). For all root regions, SA resin cement with no pre-treatment provided higher or similar immediate and long-term bond strength compared to PA or CHX pre-treatment (P< 0.05). Only for the middle region with CHX pre-treatment the bond strength was higher than other pre-treatment groups (P< 0.05). For all three types of pre-treatments, SA resin cement yielded lower immediate and long-term bond strength values compared to other resin cements (P< 0.05). However, for all groups, the long-term bond strength values were lower than the immediate values (P< 0.05). For SA and SE resin cements, PA pre-treatment prevented the loss of long-term bond strength (P> 0.05). Moreover, when using SE resin cement without pre-treatment, the reduction in long-term bond strength wasn't significant (P> 0.05). In the use of ER and SA resin cements with all three types of pre-treatments, the immediate and long-term bond strength values in the coronal region were higher than those in other regions (P< 0.05). However, in the use of SE resin cement with pre-treatment (irrespective of type), both immediate and long-term bond strength values in all root regions were similar (P> 0.05) (Table 2).
Table 3 presents the frequency of failure modes. Regarding frequency, the mixed and adhesive failure between the cement and dentin ranked first and second in immediate bond strength testing, respectively. In long-term bond strength testing, in terms of frequency, the mixed and cohesive failure in dentin ranked first and second, respectively.
Figures 1 illustrate the stereomicroscopic micrographs of all failure modes at x40 magnification. Figures 2 illustrate the SEM micrographs of the failure modes at x100 and x500 magnifications.

4. Discussion

CHX is one of the most well-known MMP inhibitors, and its exclusive effect on MMP-2, MMP-8, and MMP-9 has been previously proven (20). CHX is water soluble and has a large molecular weight. Thus, it may be washed and removed from the hybrid layer over time (15). Furthermore, some studies have reported mild cytotoxicity of CHX (28).
One alternative to CHX is a natural substance called proanthocyanidin (PA), the positive effects of which, as a collagen cross-linker and MMP inhibitor, have been previouslyconfirmed (29-31). Kalra et al. showed that the use of PAcontaining grape seed extract with a concentration of 6.5% increases the resistance of demineralized root dentin to

Table 1. Summary of the characteristics and applications of different appliances.

Resin cement manufacturer (Lot No.)	Resin cement type	Application mode	Composition
Excite DSC+ Variolink II, IvoclarVivadent, Schaan, Liechtenstein (w11068)	Etch and rinse (ER)	Phosphoric acid etching for 15 s, rinsing, gently air drying, applying ExciteDSC for 10 s, removing the excess, gently drying, cementing post with mixed Variolink II, light curing for 40 s.	Excite DSC: phosphoric acidacrylate, dimethacrylates, HEMA, highly dispersed silicon dioxide, ethanol, catalysts, stabilizers, fluoride microbrush: coated withinitiators.
			Variolink II: Bis-GMA, UDMA, TEGDMA, barium glass filler, ytterbium trifluoride, Ba-Al-fluorosilicate glass, catalyst, stabilizers, pigments.
ED Primer II + Panavia F2.0; Kuraray, Osaka, Japan (A:980040, B:980039 + A:9D0170, B:940041)	Self-etch (SE)	Mixing ED primer II, applying for 30 s, gently drying, cementing with mixed Panavia F2.0, light curing for 40 s.	ED primer II: A—HEMA, MDP, chemical initiator, water, 5-NMSA. B-5-NMSA, chemical initiator, water.
			Paste A: hydrophobic aromatic andaliphaticdimethacrylate, sodium aromatic sulfonate, N, N-diethanol-p-toluidine, functionalized sodium fluoride; glass. Paste B: 10-MDP,hydrophobic aromatic andaliphaticphoto-initiator, dibenzoylperoxidedimethacrylate, hydrophilicdimethacrylate, silanized silica.
Panavia SA luting plus; Kuraray, Osaka, Japan (3B0127)	Self-adhesive (SA)	Cementing with mixed Panavia SA and light curing for 40 s.	Paste A: 10-MDP, Bis-GMA, TEGDMA, hydrophobic aromatic dimethacrylate, silanized barium glass filler, silanized colloidal silica, Dl-Camphorquinone, benzoyl peroxide, initiators. Paste B: Bis-GMA, hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, silanized barium glass filler, silanized colloidal silica, surface treated sodiumfluoride, accelerators, pigments.

Table 2. Mean bond strength (MPa) for the groups with three resin cement types and various dentin pre-treatment methods. Significant differences in each column between the pre-treatment method in each root region are shown with uppercase letters (A and B), and in each row between resin cements for immediate and long-term groups are shown with lowercase letters (a and b).

Pre-treatment	Root region	Resin cement type					
		Etch and rinse		Self-etch		Self-adhesive	
		Immediate	Long-term	Immediate	Long-term	Immediate	Long-term
No treatment	Coronal	16.56 Aa ± 7.28	8.60 Aa ± 4.55	11.86 Aa ± 6.44	10.62 Aa ± 4.74	4.03 Ab ± 2.23	2.57 Ab ± 1.30
	Middle	11.03 Aa ± 7.34	6.59 Aa ± 2.59	13.74 Aa ± 7.41	8.68 Aa ± 1.72	0.81 Ab ± 0.70	2.85 Ab ± 1.60
	Apical	7.28 Aa ± 3.40	4.41 Aa ± 2.56	10.73 Aa ± 4.61	7.61 Aa ± 4.69	0.74 Ab ± 0.56	1.56 Aab ± 0.79
PA pre-treatment	Coronal	13.04 Aa ±7.37	7.08 Aa ± 2.64	10.01 Aab ± 4.49	8.68 ABa ± 3.67	5.41 Ab ± 4.44	2.47 Ab ± 1.71
	Middle	2.30 Ba ± 1.26	4.98 Aa ± 1.81	3.89 Bb ± 1.32	6.31 ABa ± 3.26	1.80 ABa ± 1.40	0.65 Bb ± 0.40
	Apical	2.00 Ba ± 1.38	3.20 ABa ± 1.09	5.16 Bb ± 2.24	5.19 ABa ± 2.70	1.86 Aa ± 1.73	0.46 Bb ± 0.27
CHX pre-treatment	Coronal	17.05 Aa ± 5.22	10.08 Aa ± 4.87	10.53 Ab ± 4.63	4.44 Bb ± 2.88	6.61 Ab ± 3.98	3.91 Ab ±1.84
	Middle	10.28 Aa ± 6.87	2.24 Ba ± 1.49	11.92 Aa ± 5.28	4.48 Bb ± 1.87	2.50 Bb ± 1.43	0.67 Ba ± 0.53
	Apical	8.36 Aa ± 5.76	2.29 Ba ± 1.61	8.67 ABa ± 3.36	2.20 Ba ± 1.25	2.74 Ab ± 2.15	0.32 Bb ± 0.21

Table 3. Percentage of modes of failure in each experimental group.

Experimental group	Aging	Failure mode				
		1	2	3	4	5
Etch & rinse	Immediate	20.0%	4.0%	0.0%	24.0%	52.0%
	Long-term	37.9%	0.0%	6.9%	3.4%	51.7%
PA pre-treatment + etch & rinse	Immediate	6.9%	0.0%	6.9%	13.8%	72.4%
	Long-term	35.7%	7.1%	3.6%	21.4%	32.1%
CHX pre-treatment + etch & rinse	Immediate	9.1%	4.5%	4.5%	22.7%	59.1%
	Long-term	10.0%	3.3%	3.3%	16.7%	66.7%
Self-etch	Immediate	25.7%	0.0%	8.6%	8.6%	57.1%
	Long-term	20.0%	0.0%	12.0%	8.0%	60.0%
PA pre-treatment + self-etch	Immediate	16.1%	0.0%	38.7%	9.7%	35.5%
	Long-term	24.1%	3.4%	3.4%	20.7%	48.3%
CHX pre-treatment + self-etch	Immediate	34.3%	0.0%	0.0%	25.7%	40.0%
	Long-term	7.1%	0.0%	17.9%	7.1%	67.9%
Self-ahesive	Immediate	0.0%	0.0%	34.8%	0.0%	60.0%
	Long-term	0.0%	0.0%	34.8%	0.0%	44.0%
PA pre-treatment + self-adhesive	Immediate	0.0%	0.0%	34.8%	00%	65.2%
	Long-term	0.0%	0.0%	19.0%	19.0%	61.9%
CHX pre-treatment + self-adhesive	Immediate	7.4%	0.0%	22.2%	0.0%	70.4%
	Long-term	7.7%	0.0%	23.1%	0.0%	69.2%

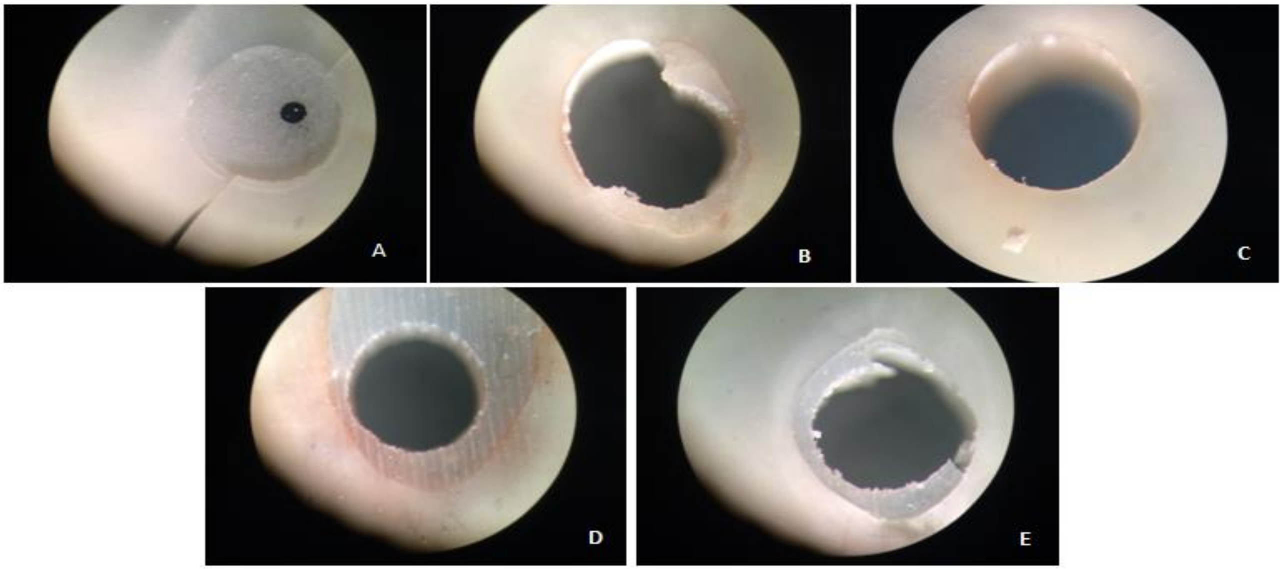

Figure 1. Failure modes: A: cohesive failure in dentin, B: cohesive failure in resin cement, C: adhesive failure between cement and dentin, D: adhesive failure between cement and fiber post, E: mixed failure (combination of two or more failure modes).

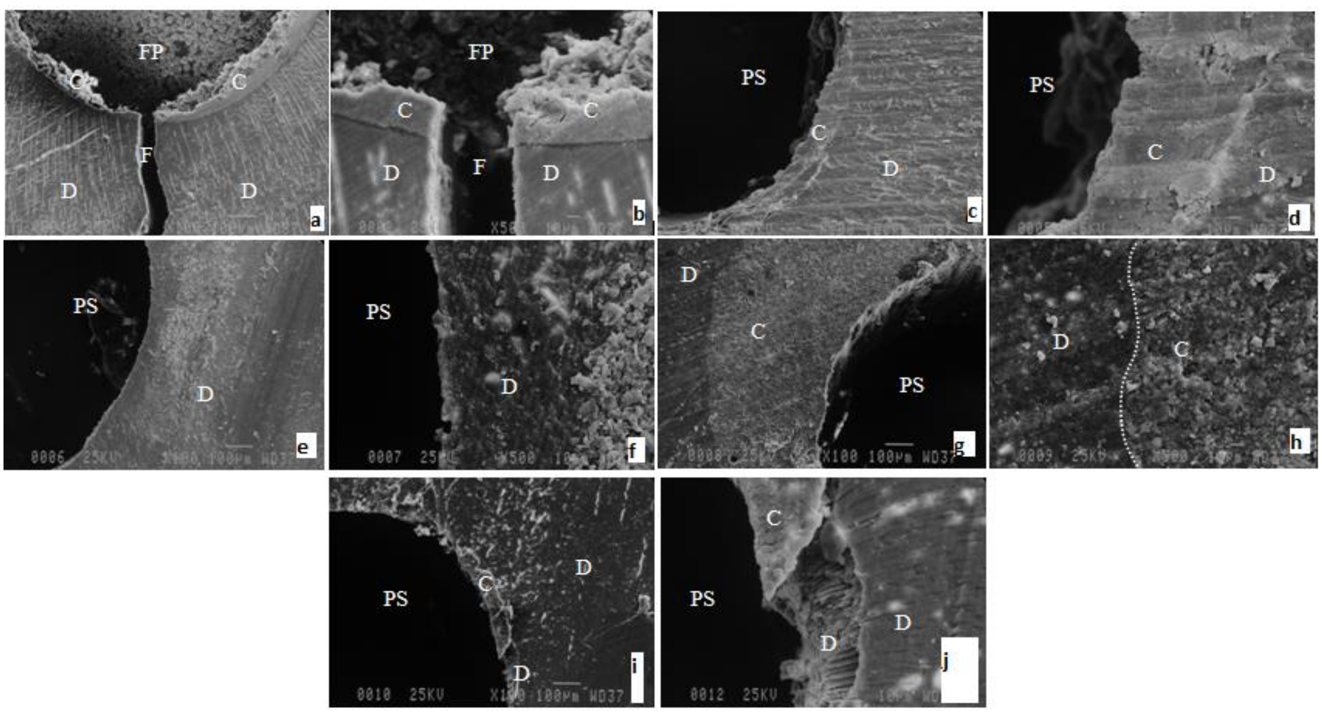

Figure 2. SEM view of fracture modes, a & b: cohesive failure in dentin x100 and x500, c & d: cohesive failure in cement x100 and x500, e & f: adhesive failure between cement and dentin x100 and x500, g & h: adhesive failure between cement and dentin at x100 and x500, i& j: mixed failure (combination of two or more failure modes) at x100 and x500 (FP: fiber post, C: cement, D:dentin, and F: failure).

enzymatic degradation, which is sometimes accompanied by an increase in the bond strength and durability of the bonding of resin-based sealers (32).

A review of the literature revealed that there are three commonly used methods for evaluation of the bond strength of fiber posts to root canal dentin, namely 1) push-out test, 2) thin-slice push-out test, and 3) microtensile test. The main advantage of the push-out test is attributed to its similarity to the clinical conditions; however, on the other hand, fiber posts under this testare loaded by concentrated forces, and as a result, stress distribution would not be uniform, leading to inaccurate estimates of the bond strength. In this regard, it should be stated that the main advantage of the thin-slice push-out test incomparison with the push-out test stems from the uniform stress distribution at the interface of the fiber post and dentin. In the microtensile test, the probability of premature fracture is very high, and the standard deviation of the results is usually high. It seems that, although the loading of fiber posts in the thin-slice push-out test is not very similar to the clinical setting, this test is more reliable for measuring fiber post-bond strength to dentin (1, 2, 33-37). For this reason, this method was employed in the present study. The results of the present study showed that independent variables such as type of resin cements, dentin pre-treatment methods, root region, and aging (immediate/long-term bondstrength) significantly affected the bond strength of fiber posts. According to Table 2, it can be concluded that the use of SA resin cement compared to the other two cements in all three dentin pre-treatment groups led to lower immediate and long-term bond strength. Assessment of the failure modes revealed that the specimens cemented with SA had a higher percentage of adhesive failure at the cement-dentin interface than the other types of cements (Table 3). This finding implies that the bond strength of SA cement to dentin was lower than that of fiber post and its cohesive strength. In simplified adhesives, in addition to collagen degradation, other factors such as water sorption and degradation of hydrophilic resin monomers can decrease the bond strength. The adhesive layer, because of its permeability, facilitates water sorption and bonding degradation (4). Several studies have shown that in SA resin cements, due to their lower level of demineralization, the penetration of monomer into dentin is limited. These studies have claimed that the high viscosity of SA resin cements and the absence of hybrid layers are the main reasons for lower bond strength (38, 39). In addition, the hydrophilic and acidic nature of SA resin cements may also activate MMP and CP enzymes (40). On the contrary, some other studies have reported higher bond strength of SA resin cements (4, 34). This could be due to differences in their composition and the type of chemical bond.

The results of this study demonstrated that in the case of using ER resin cements, no pre-treatment can result in higher immediate or long-term bond strength compared to the use of PA or CHX for pre-treatment. This finding was in accordance with that of Leitune et al.(41). They stated that the use of CHX cannot prevent the bonding degradation of fiber posts. Soares et al. obtained similar results for the effect of CHX on the bond strength of resin to coronal dentin (42). Likewise, Bitter et al. found that dentin pre-treatment with 2% CHX and ER resin cement cannot prevent the bond strength loss in the coronal root region (34). Lindblad et al. (43) and Cecchin et al. (17) showed that CHX does not interfere with the immediate bond strength of ER resin cements. On the other hand, there are several studies have suggested the use of CHX to prevent the hybrid layer degradation and increase the bonding durability (24, 44-46).

Fang et al. reported the positive effects of PA on the bond strength of ER adhesives (47). However, it is worth mentioning that their study was conducted on coronal dentin, which naturally has different characteristics from root dentin, and the duration of PA treatment on dentin in their study was far longer than that in the present study; our logic behind the one-minute application of PA was based on the advantages of clinical convenience.

According to the results of this study, it can be declared that in the case of using SE resin cements, no pre-treatment leads to higher immediate or long-term bond strength compared to the use of PA or CHX for pre-treatment. Leitune et al. showed that CHX does not have any positive effect on long-term bond strength, which can be attributed to inadequate storage time in their study (41). Moreover, there are some studies indicating that CHX pre-treatment would not interfere with the immediate bond strength of SE resin cements (16, 43, 48). Zhou et al. reported that when using SE resin cements, 1%CHX pre-treatment can increase the immediate and long-term bond strength (2). Nonetheless, they found that, despite such a positive effect of CHX, the long-term bond strength of specimens was significantly lower than their immediate bond strength. This finding implies that CHX cannot play a remarkably effective role in bonding durability and therefore, some factors other than MMPs probably play a role in bonding degradation (2). Zhou et al. added 1% CHX to the primer of SE resin cement and demonstrated that it had no detrimental effect on bond strength. Some others have shown that adding higher concentrations of CHX may have adverse effects on bond strength (2, 49). For this reason, in the present study, we used 2% CHX for pre-treatment as a separate clinical step, which may undesirably increase the possibility of practical errors.

As observed in the present study, the use of PA did not have a positive effect on bond strength. Similarly, Islam et al. indicated that dentin preparation with grape seed extract did not have a positive effect on the bond strength of resin to dentin (50). When using PA for pre-treatment, the dentinal tubules are filled with particles of the smear layer, which gives rise to a lower bond strength. The PA effect on the insolubility of smear particles can be attributed to the large size of the PA molecule, preventing the penetration of monomers.

The current study revealed that for ER and SA resin cements with any pre-treatment, the immediate and long-term bond strength values of the coronal root region were higher. This finding, which agrees with several studies (2, 3, 16, 32, 34), can be justified considering the variability of dentin structure indifferent root regions. In addition, lower light transmission, limited access, and difficult moisture control in the apical region are among other reasons for lower bond strength in this region. It is noteworthy that partial light transmission gives rise to a low degree of conversion, a high rate of liquid penetration into the hybrid layer, and consequently low level of long-term bond strength (41, 51). Another major parameter affecting the bond strength of the apical region is the high C-factor (numerically about 200).

The results of this study revealed that PA can prevent the reduction of bond strength of SE and SA resin cements in the long term. Similarly, for SE resin cement, even without any dentin preparation, the difference between the long-term and immediate bond strength was not significant. The positive effects of PA pre-treatment can be the result of its inhibitory effect on MMPs as well as its cross-linking ability.

In a study by De Munch et al., neither MMP-2 nor MMP-9 were observed when using SE adhesive (52). Therefore, it can be concluded that these enzymes are less effective in SE bond degradation, which is in agreement with the findings of the present study regarding similar immediate and long-term bond strength values.

On the contrary, some studies have reported the positive effect of CHX dentin pre-treatment on enhancing the long-term bond strength of SE and ER resin cements (44, 45). It is important to note that in the aforementioned studies, water storage was the only method of aging, while in the present study, in addition to water storage, thermocycling was also performed to more realistically simulate the intra-oral thermal alterations, which can further decrease the long-term bond strength.

One of the weak points of bonding is in the connection between the resin used to cement the fiber paste and the root canal dentin. It seems that if this bond is formed on an ivory substrate that has a high resistance to the destruction of enzymes, its durability will increase. Considering the dual role proposed for PA as a cross-linker and MMP inhibitor, it is possible that this substance is able to reduce the rate of collagen fiber destruction due to its positive effects on the mechanical properties of dentine collagen as well as the ability to inhibit the enzymes present in dentin. Following the investigations that were carried out on the existing studies, it was found that until today, no research has been done on the effect of using PA on the durability of the bond between fiber post and root canal dentin.

5. Limitations

Due to the methodology and the large number of variables, it was difficult to discuss and draw a definite conclusion. In experimental studies, the impossibility of simulating oral condition is one of limitations.

6. Conclusion

According to the conditions and limitations of this study, the following results were obtained: 1) SA resin cement had the lowest immediate and long-term bond strength compared with the other two types of cement. 2) For ER and SE resin cements, no treatment led to higher immediate or long-term bond strength. 3) For SE and SA resin cements, PA pre-treatment decreased the rate of reduction in bond strength in the long term. 4) The bond strength in the coronal region was higher than in other regions.

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Authors' contribution

Mohammad Bagher Rezvani: Conceptualization, Administration
Mahshid Mohammadi Basir: Methodology, Supervision
Fatemeh Farzaneh: Investigation, Data collection
Hanieh-Sadat Emami-Razavi: Investigation, Writing - Review & Editing

Conflict of interest

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