Dental Research Journal

Original Article

Effect of polymerization mode of two adhesive systems on push-out bond strength of fiber post to different regions of root canal dentin

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ABSTRACT

Background: A few studies have investigated the effect of the activation mode of adhesive systems on bond strength of fiber posts to root canal dentin. This study investigated the push-out bond strengths of a glass fiber post to different root canal regions with the use of two adhesives with light- and dual-cure polymerization modes.

Materials and Methods: In this *in vitro* study, 40 maxillary central incisors were decoronated at cement-enamel junction with 15 ± 1 mm root length. After root canal therapy and post space preparations, they were randomly divided into four groups. Post spaces were treated with four different adhesives: Excite, Excite Dual cure Single Component (DSC), self-etch adhesive (AdheSE), and AdheSE dual-cure. Then the fiber-reinforced composite (FRC) post, Postec Plus, was cemented with dual-cure resin cement, Variolink II. The roots were cut into three 2-mm-thick slices. Push-out tests were performed with a universal testing machine at a crosshead speed of 0.5 mm/min. The mode of failures was determined under a stereomicroscope. Data were analyzed by three-way analysis of variance (ANOVA) and Tukey test was conducted to compare post hoc with $P < 0.05$ as the level of significance.

Results: The highest bond strength was obtained for AdheSE dual-cure (15.54 ± 6.90 MPa) and the lowest was obtained for Excite light-cure (10.07 ± 7.45 MPa) and only the bond strength between these two adhesives had significant difference ($P = 0.02$). Bond strength decreased from the coronal to the apical in all groups and this was significant in Excite (group 1) and AdheSE (group 3) ($P < 0.001$). In apical regions, bond strength of dual-cure adhesives was significantly higher than light-cure adhesives ($P < 0.001$).

Conclusion: Push-out bond strength of fiber post to different regions of root canal dentin was affected by both adhesive systems and their polymerization modes.

Key Words: Adhesive, bond strength, fiber post, polymerization mode

Received: November 2012
Accepted: May 2013

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INTRODUCTION

One of the important issues in dentistry is restorative procedure of endodontically-treated teeth, which needs post for core retention in the cases of extensive tooth damage. Metal cast posts increase the possibility of root fracture due to providing intra-canal post space, corrosion, wedging effect, and high modulus of elasticity.[1] In recent years, new kinds of posts called fiber posts are introduced, which are commonly used due to their good mechanical properties, more uniform stress distribution in root canal, need to minimal tooth structure preparation, esthetics, and in some kinds, better light transmission to apical regions, which improve resin cements polymerization. One clinical study indicated 95-99% success rate in treatment with fiber posts and no root fracture during

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the study was reported.[2] Fiber posts are divided into two groups based on their light transmission capacity including translucent (light transmitted) or opaque (non-light transmitted). Translucent posts increase degree of conversion of the resin cement due to light transmission.[3] Different adhesive systems could be used in cementation of fiber posts in root canal that include light-cure, self-cure or dual-cure ones.[4] Retention of fiber posts depends on several factors such as bond strength of post-resin cement and resin cement-root canal dentin. Some studies have indicated that there are no voids in the post-cement interface and the bond strength of cement-dentin is less than the post-cement interface. In the other words, cement-dentin interfaces is the weak point in bonded fiber posts.[5] Because of various dentinal morphology in different areas of the root canal, the bonding quality is different in coronal, middle, and apical regions. On the other hand, for achieving an optimal bond in interface, adhesive and resin cement should be polymerized well. Although, it is hard to transmit light to the apical region of the root canal, dual-cure adhesives may result in a more acceptable and better bond in comparison with light-cure ones.[6]

The aim of this study was to evaluate the effect of different adhesives and their different polymerization modes (dual or light-cure) on the push-out bond strength of a translucent glass fiber post and post space dentin in different root canal regions. The null hypothesis of this study was that there are no differences in push-out bond strength among these adhesives and their different polymerization modes.

MATERIALS AND METHODS

In this *in vitro* experimental study, 40 freshly extracted human single canal central maxillary teeth with 15 ± 1 mm root length and without any defect, cracks, curvature, and previous root canal therapy were selected and kept in 0.5% chloramine-T (Fisher Chemical, Fair Lawn, NJ, USA) for 24 hours.

The crowns of the teeth were removed from cementoenamel junction (CEJ) perpendicular to the teeth long axis with a high-speed water cooled diamond disc (Buehler Ltd, Lake Bluff, IL, USA). The canals were instrumented to 1 mm shorter of the root length using step-back method with stainless steel k-files (#15-20-25-30; Dentsply, Maillefer, Ballaigues, Switzerland). At each change of the instrument, the root canals were thoroughly irrigated with 3 mL of 5.25% NaOCl and suction was performed. Then flaring was done by using Gates Glidden (#2; Dentsply, Maillefer, Ballaigues, Switzerland) and all canals were obturated with gutta-percha cones and AH26 sealer (Dentsply, Maillefer, Ballaigues, Switzerland) by lateral condensation technique. After 24 hours storage of the specimens in 37°C water, 9 mm of coronal gutta-percha was removed using Gates Glidden (#2-3; Dentsply, Maillefer, Ballaigues, Switzerland) without widening the canal. Then the post space was prepared and shaped by fiber-reinforced composite (FRC) Postec Plus low-speed post drill (#3; Ivoclar Vivadent, Schaan, Liechtenstein).

The teeth were randomly divided into four groups of 10 specimens each based on bonding type. In all groups, translucent glass fiber posts (#3; FRC Postec Plus, Ivoclar Vivadent, Schaan, Liechtenstein) were used. All materials information is presented in Table 1 and were used according to the manufacturer's instructions. The information of the groups is described below:

Group 1 (Excite Light-cure)

The canal was etched 15 seconds by 37% phosphoric acid with a syringe, rinsed by water and then gently dried. Excess moisture was removed by paper point (Dentsply, Maillefer, Ballaigues, Switzerland). One layer of Excite (Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the root canal dentin by microbrush (Microbrush X, Grafton, USA). The excess adhesive was removed by paper point and then it was cured by Quartz-Tungsten Halogen (QTH) light curing device (Optilux 501, Demetron Kerr, Orange, CA, USA) with 650-700 mW/cm^2 intensity for 20 seconds.

Group 2 (Excite Dual-cure)

The etching process of the canal was similar to group 1. Then one layer of Excite Dual cure Single Component (DCS) (Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the root canal dentin according to the manufacturer's instruction with an endo Microbrush. The excess adhesive was removed by the paper point and then cured for 20 seconds.

Group 3 (AdheSE Light-cure)

The canal was rinsed by water, it was gently air dried, and the excess water was removed by the paper point. Two layers of the self-etch adhesive (AdheSE) primer (Ivoclar Vivadent, Schaan, Liechtenstein) were applied to the root canal dentin and after removing the excess by strong air blow and paper point, AdheSE bonding

Table 1: Materials used in this study

Material	Manufacturer	Type	Composition
FRC Postec Plus	Ivoclar Vivadent, Schaan, Liechtenstein	Translucent glass fiber post	21% Triethyleneglycol dimethacrylate, Urethane dimethacrylate, Highly dispersible silicon dioxide, 9% Ytterbium fluoride, 0.5% Stabilizers and catalysts, 70% Glass fiber
Excite	Ivoclar Vivadent, Schaan, Liechtenstein	Etch and rinse adhesive	Phosphonic acid acrylate, Hydroxyethyl dimethacrylate, Methacrylate, Highly dispersible silicon dioxide, Ethanol (solvent), Catalysts and stabilizers
Excite DSC	Ivoclar Vivadent, Schaan, Liechtenstein	Etch and rinse adhesive (dual-cure)	Excite + applicator impregnated with initiators
AdheSE	Ivoclar Vivadent, Schaan, Liechtenstein	Primer	Bis acrylamide, Phosphonic acid acrylate, Initiators, Stabilizers, Water
Variolink II luting composite	Ivoclar Vivadent, Schaan, Liechtenstein	Adhesive	Hydroxyethylmethacrylate, Dimethacrylate, Highly dispersible silicon dioxide, Initiators, Stabilizers
Monobond S	Ivoclar Vivadent, Schaan, Liechtenstein	dual-cure activator	Solvent, initiators
		Resin cement	Bis-glycidylmethacrylate, Triethyleneglycol dimethacrylate, Urethane dimethacrylate, Benzoyl peroxide, Ytterbium trifluoride
		Silanization agent	3-Trimethoxysilylpropylmethacrylate (MPS) 1.0% in solution in 52% ethanol and 47% distilled water, pH 4
Total etch jumbo	Ivoclar Vivadent, Schaan, liechtenstein	Etching gel	37% Phosphoric acid

(bottle 2) was applied to dentin by a microbrush and it was slightly air dried. Then the excess adhesive was removed by paper point and cured for 20 seconds.

Group 4 (AdheSE Dual-cure)

The stages related to applying the primer were done like group 3. For bonding stage, one drop of dual-cure activator was added to one drop of AdheSE bonding and then it was applied to the root canal dentin by a microbrush, then it was slightly air dried and the excess adhesive was removed by the paper point and cured for 20 seconds.

Before cementation of the post into the canal in all groups, 37% phosphoric acid gel was applied to the post surface, thoroughly rinsed by water and dried. Then one layer of silane coupling agent, Monobond S (Ivoclar Vivadent, Schaan, Liechtenstein), was applied to the post surface for 60 seconds, dried by air stream and then the treated post was left on a clean slab up to the time of cementation. Variolink II (Ivoclar Vivadent, Schaan, Liechtenstein) base-catalyst mixture inserted to the canal by using Lentulo (Dentsply, Maillefer, Ballaigues, Switzerland) for all groups. After applying cement on the post and placing in canal, the resin luting agent was light-cured for 40 seconds through the post. Tip of the light curing unit was placed in direct contact with the coronal end of the post. During light curing process, the root was covered by aluminum foil to avoid light penetration from root lateral surfaces. After cementation, specimens were stored in a lightproof box for 24 hours.

In the next stage, each specimen was cut into three slices including coronal, middle, and apical (2 ± 0.1 mm thickness) using a low-speed diamond saw (Isomet; Buehler Ltd., Lake Bluff, IL, USA) with the water coolant, perpendicular to the tooth and post long axis. The real thickness of the slices (h) and the post diameter in coronal (r_1) and apical (r_2) were measured by digital caliper with 0.01 mm accuracy (Mitutoyo CD15, Mitutoyo Co., Kawasaki, Japan) under stereomicroscope (Olympus, DP12, Hamburg, Germany) and the bonding area (S) was calculated by $S = \pi (r_1 + r_2) \sqrt{h^2+(r_1-r_2)^2}$ in mm^2 for each slice [Figure 1].

Push-out bond strength tests were performed using a customized stainless steel supporting base with a hole to support the specimen. A cyanoacrylate adhesive (Zapit, DVA, Anaheim, CA, USA) was applied to dentin on the coronal side to secure specimens to the push-out device supports during testing. Then each post-dentin section was attached to the device, ensuring that the coronal surface of the post-dentin section faced the device and the post was centered over the hole [Figure 2]. The post segments were loaded with a cylindrical plunger, 0.9 mm in

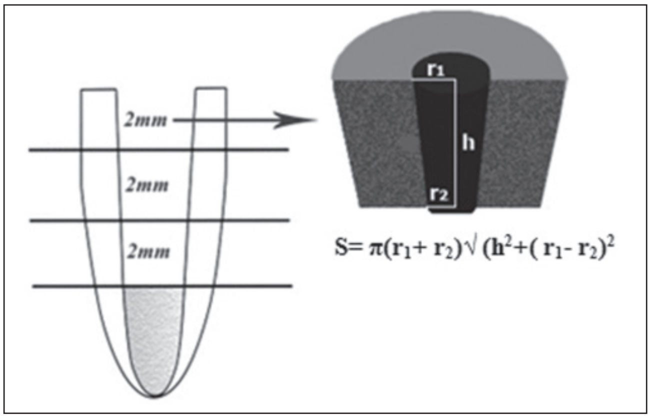

Figure 1: Schematic illustration of bonding area total calculation and preparation of coronal, middle, and apical post/dentin section for push-out test

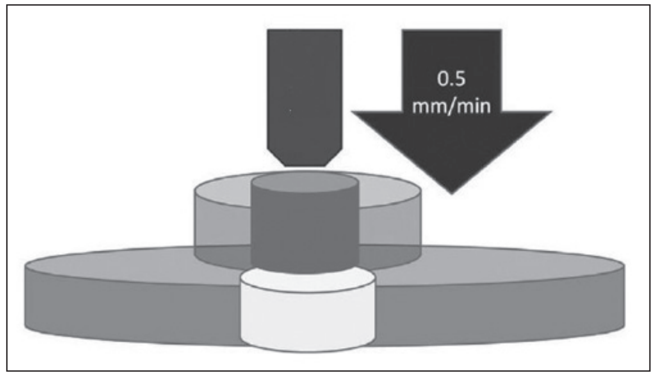

Figure 2: Schematic representation of push-out test

diameter, centered on the post segment and avoiding contact with the surrounding dentin surface. Loads were applied from an apical to coronal direction with respect to individual test specimens with a universal testing machine (M350-10CT Testometric, Lancashire, United Kingdom) at a crosshead speed of 0.5 mm/min.

The maximum load was recorded in time of post dislodgement in Newton (N) and it was converted in MPa by dividing the applied load by the bonded area (S):

Bond strength (MPa) = Debonding force (N)/Total bonding area (S) (mm^2)

After testing, the mode of failure was determined for all slices under a stereomicroscope (Olympus, DP12, Germany) at 40× magnification. The failure modes were categorized in five score as follow:

Score 1-Adhesive failure between the post and the resin cement (no cement on the post)

Score 2-Mixed failure (0-50% cement on post surface)

Score 3-Mixed failure (50-100% cement on post surface)

Score 4-Adhesive failure between the dentin and the resin cement (the post was covered by resin cement)

Score 5-Cohesive failure in dentin

The push-out bond strength data was first confirmed by Kruskal-Wallis tests for their normal distribution. A three-way analysis of variance (ANOVA) was subsequently performed with post space region, adhesive system and polymerization mode as fixed factors and push-out bond strength as the dependent. The Tukey test was used for post hoc comparisons. The level of significance was set at $P < 0.05$ for all the tests. The data were analyzed by Statistical Package for Social Sciences (SPSS) Version 13.0 (SPSS, Chicago, IL, USA).

RESULTS

Three-way ANOVA showed that post space region, adhesive system and only the interaction between post space region and polymerization mode were factors affecting push-out bond strength ($P < 0.05$) [Table 2].

Data showed that the highest mean bond strength values were obtained for group 4 (15.54 ± 6.90 MPa) and the lowest ones were obtained for group 1 (10.07 ± 7.45 MPa). Tukey test revealed that only the difference in bond strength between groups 1 and group 4 was significant ($P = 0.02$). The push-out bond strength test data is shown in Table 3.

The chi-square test showed that there were significant differences in failure pattern scores within groups, which have been tested in this study ($P < 0.05$). Evaluating the failure pattern scores indicated that the most failures were adhesive failure between post and resin cement (score 1), except for group 4 that showed the most failure mode related to the score 2. There was no dentin cohesive failure (score 5) and adhesive failure between the dentin and resin cement (score 4) in all groups [Table 4].

DISCUSSION

Different methods are used to measure the bond strength between the resin cement and the root canal dentin such as microtensile, push-out, and pull-out tests.[7] Push-out test is based on inducing

Table 2: Three-way analysis of variance (ANOVA) results

Source of variation	D_f	Sum of Squares	Mean Square	F	*P* value
Post space region (PSR)	2	3789.08	1894.54	115.46	<0.001
Adhesive system (A)	1	527.73	527.73	32.16	<0.001
Polymerization mode (PM)	1	49.06	49.06	2.99	0.08
(PSR)*(A)	2	9.24	4.62	0.28	0.75
(PSR)*(PM)	2	479.572	239.79	14.614	<0.001
(A)*(PM)	1	0.08	0.083	0.005	0.94
(PSR)*(A)*(PM)	2	10.39	5.2	0.32	0.73
Error	108	1772.05	16.41		
Total	120	26231.25			

Table 3: Push-out bond strength (standard deviation) in different adhesive systems and polymerization modes

Adhesive	Excite Light-cure (MPa)	Excite Dual-cure (MPa)	AdheSE Light-cure (MPa)	AdheSE Dual-cure (MPa)
Region				
Coronal	18.61 (4.48)[1;ab]	15.09 (3.06)[1;a]	24.33 (6.07)[1;b]	19.26 (4.81)[1;ab]
Middle	9.15 (3.34)[2;a]	13.66 (3.51)[1;ab]	12.81 (5.49)[2;ab]	18.04 (7.53)[1;b]
Apical	2.44 (1.05)[3;a]	5.14 (1.57)[2;b]	5.49 (2.43)[3;b]	9.33 (2.88)[2;c]

Different superscript numbers in each column are indicating significant differences among different root sections ($P < 0.05$). Different superscript letters in each row are indicating significant differences among different adhesive systems ($P < 0.05$)

Table 4: Failure pattern scores distribution in the groups

Group	Score				
	1	2	3	4	5
Excite Light-cure	15	14	1	–	–
Excite Dual-cure	21	9	–	–	–
AdheSE Light-cure	17	10	3	–	–
AdheSE Dual-cure	14	16	–	–	–

shear stress between dentin-cement and also post-cement interfaces, which are comparable with clinical situation. This test provides better estimating of the bond strength than regular shear tests since in this test the shear occurs perpendicular to the bond interface, so it is considered as a real shear test.[8] Push-out test is more reliable than microtensile test because there are many premature failures in microtensile test and also the data distribution is less in push-out test.[9] Besides, Soares *et al.* revealed that the push-out test is more suitable than microtensile test for evaluation of glass fiber post bonding to the root canal dentin.[10]

Two-shot technique was used in this study which means the adhesive and the resin cement were cured in different stages since according to Scanning Electron Microscopic (SEM) study by Ferrari *et al.*, one-shot polymerization may result in reducing hybrid layer quality and resin tag formation especially in the apical third.[11] Also, one-shot polymerization may cause more gaps in the interface of the adhesive and resin cement (30%) in comparison with two-shot polymerization (10%).[12]

Based on Potesta *et al.* study, two-step self-etch adhesives have higher bond strength than two-step etch and rinse adhesives, which may be due to elimination of acid etching and rinsing in self-etch adhesives and less technique sensitivity[13] that is in agreement with our study. In this study, it was indicated that the bond strength of the self-etch adhesive was significantly more than the etch and rinse adhesive in apical region, which may be due to inadequate rinsing of acid etching gel and improper moisture control that resulted lower bonding quality in etch and rinse adhesives like the results of Potesta *et al.* [13] and Akgungor and Akkayan [6] studies.

There are some studies showing opposite results that two-step etch and rinse adhesives have higher bond strength than two-step self-etch adhesives due to incomplete dissolution of the smear layer in self-etch adhesives.[14,15]

There is a concern about self-etch adhesives for the ability to penetrate into a thick smear layer (like the one appearing in the cleaning and shaping stages of root canal therapy). However, the suspicion that thick smear layers may interfere with the diffusion of self-etch primers into the underlying intact dentin was not confirmed.[16]On the other hand, the microbrush, which was used in this study may cause uniform resin tag formation in different canal regions especially in the apical region.[17] Also, applying resin cement by a lentulo inside the root canal is an effective way to reduce the void in resin cement and cause uniform distribution of the cement along the root canal.[6]

Bonding mechanism to the dentin root canal is micromechanical because of adhesive penetration to the demineralized dentinal surface and formation of hybrid layer, resin tag, and also adhesive lateral branches.[18]

The results of the current study indicated that in all four groups, the bond strength is decreasing from the coronal to the apical regions which may be due to decreased density and the diameter of dentin tubules towards the apical.

In two SEM studies done by Ferrari *et al.*, it was concluded that dentin tubules density in coronal one-third is more than apical and middle one-thirds and the diameter of the dentin tubules decreases towards the apical. The hybrid layer thickness and the number of resin tags decrease from the coronal to the apical and the lateral branches of the dentin tubules are only visible in middle and coronal one-thirds.[19,20] On the other hand, penetration of the resin is reduced in apical regions because of decreased pressure of the microbrush,[11] and the quality of hybrid layer in apical one-third is lower than coronal and middle regions.[21]

One of the other reasons for having higher bond in the coronal region is that this region is easier to etch and apply adhesives and also is more accessible.[22]

Perdigao *et al.*[23] and Aksornmuang *et al.*[24] indicated that the bond strength in the coronal is higher than the middle and apical regions.

According to the results of this study, despite the highest rate in light transmission to deeper parts with FRC Postec Plus in comparison with other fiber posts,[25] dual-cure adhesives in the apical region indicates higher bond strength than light-cure adhesives, which may b due to reduced light intensity in the apical and less Degree of Conversion (DC) in light-cured adhesives and luting cement.[3] Dual-cure adhesives are less dependent on the light curing unit irradiance.[26] Thereby, the difference between the bond strength in dual-cure adhesives in different parts of the root canal was less in comparison with light-cure ones in this study and the bond strength of dual-cure adhesives was more uniform in different parts of the root canal. However, Akgungor and Akkayan[6] and Faxton *et al.*[27] have concluded different results that the bond strength of the light-cure adhesives was higher than dual-cure ones (Clearfil liner bond 2V, Kurary Co., Ltd., Okayama, Japan). They described the results in a way that light-cure bonding material includes photo initiator and acidic 10-Methacryloyloxydecyl dihydrogen phosphate (10-MDP) (phosphate monomer), while the dual-cure activator only includes the initiator without any MDP. When the bonding and the activator are mixed together, the photo initiator and MDP concentration is decreased and which result in reduction of the degree of conversion. So, ability of bond to root canal dentin is decreased with dual cure adhesives.

Despite the incompatibility between acidic monomer in self-etch adhesives, acidic monomer and amine part of dual-cure or self-cure composites,[28] Dual-curing, self-etching adhesive (AdheSE DC) includes a composition called ternary catalysts (chemical co-initiator), which solves this problem.[29]

In this study, the highest failures were seen in the post-resin cement interface. This finding is in agreement with other studies.[30,31] From the coronal to the apical region, score 1 failures were decreased while scores 2 and 3 failures were increased which may be due to decrease in DC and mechanical properties of the resin cement in the middle and apical regions which have been resulted by decreasing in light intensity in those regions and thereby cohesive failures happened inside the resin cement.

Based on the previous studies, thermocycling and mechanical cycling do not have any effects on the push-out bond strength of fiber posts to root canal.[32,33] Therefore, they were not performed in this study.

CONCLUSION

According to the results and the limitation of this *in vitro* study, two-step self-etch adhesive systems indicated higher bond strength than two-step etch and rinse adhesive systems. The dual-cure adhesive has higher bond strength than the light-cure adhesive especially in the apical area of the root canal.

ACKNOWLEDGMENTS

This study was resulted from a student thesis supported by Kerman University of Medical Sciences. The authors thank Kerman University of Medical Sciences and Kerman Oral and Dental Diseases Research Center for financial support and Dr. Jahani for statistical analysis.

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How to cite this article: Ebrahimi SF, Shadman N, Nasery EB, Sadeghian F. Effect of polymerization mode of two adhesive systems on push-out bond strength of fiber post to different regions of root canal dentin. Dent Res J 2014;11:32-8.

Source of Support: Nil. **Conflict of Interest:** None declared.