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ORIGINAL ARTICLE

The effect of luting cement thicknesses on the push-out bond strength of the fiber posts

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Abstract

Objective. The aim of this study was to evaluate the effect of luting cement thicknesses on the push-out bond strength of the fiber posts. ***Materials and methods.*** Sixty human maxillary canine teeth were endodontically treated. Post spaces were prepared and root specimens randomly divided into three groups: Group 1: etch-and-rinse (Variolink II/Exite DSC), Group 2: self-etch (Panavia F2.0/ED primer) and Group 3: self-adhesive (Clearfil SA Cement). Then each group was divided into four sub-groups according to the cement thickness, as follows: Sub-group 1: 0.35 mm, Sub-group 2: 0.25 mm, Sub-group 3: 0.15 mm, and Sub-group 4: 0.05 mm. Three slices of 1 mm thickness were obtained from each root specimen ($n = 15$). Push-out tests were performed and data was analyzed with two-way ANOVA and Tukey tests. ***Results.*** The etch-and-rinse system (Variolink II) had a significantly higher bond strength compared with the other systems ($p < 0.05$). The thickest cement group (0.35 mm) had a significantly lower bond strength compared with the 0.15 and 0.05 mm groups in the etch-and-rinse and self-adhesive groups ($p < 0.05$). In the self-etch group, the cement thicknesses did not significantly affect the bond strength ($p > 0.05$). ***Conclusions.*** The etch-and-rinse system offered better bonding to root dentine than the self-adhesive and self-etch systems. The increases in cement thickness significantly reduced the bond strength of fiber posts to root dentine for both the etch-and-rinse and self-adhesive systems.

Key Words: *bond strength, cement thickness, fiber posts, self-adhesive, resin cements*

Introduction

Fiber posts were developed in the early 1990s to restore root-filled teeth with excessive loss of coronal tooth structure as an alternative to cast post and core-and-metal dowels [1]. Current fiber posts are composed of unidirectional glass fibers embedded in a resin matrix made of epoxy resin or its derivates that strengthens the structure of the post [2]. Fiberglass posts have a high flexural strength and their modulus of elasticity is close to that of dentine, minimizing the transmission stress to the canal walls and reducing the risk of root fracture [3–5]. Furthermore, fiber posts can provide more aesthetic outcomes. It has also been reported that the cementation of the fiber post to the root dentine using adhesive techniques increases post retention and reduces microleakage at the dentin–cement interface [6,7].

Various luting agents combined with adhesives have been recommended for bonding fiber posts into root canals. These materials can be classified according to adhesive approaches as etch-and-rinse, self-etch or self-adhesive techniques. The etch-and-rinse technique requires a wet dentin substrate to achieve optimal bonding [8]. However, it is difficult to control the surface wetness due to limited access to the deep and narrow post space in a root canal [9]. Self-etching adhesives are generally applied on dry dentine and do not require rinsing with phosphoric acid, thereby solving the problem of dentine wetness control [10]. Recently formulated self-adhesive cements require no pre-treatment of the tooth surface and thus simplify the cementation procedure [11]. The bonding mechanism of self-adhesive cements is based on micromechanical retention and chemical adhesion [12,13].

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Although a vertical root fracture is the complication that results in the greatest damage, the most common cause of failure is loss of retention due to debonding between fiber post resin and/or resin root canal dentine interfaces as a result of inadequate bond strength [14,15]. A number of studies have shown that bonding to root canal dentine can be influenced by various factors including luting agents, limited moisture control, the unfavorable C-factors, type of post, the use of eugenol-based endodontic sealer and light transmission through the post [14–20].

However, little is known about the effects of cement thickness on the bond strength of fiber posts cemented with different kinds of luting agents. Several previous studies have addressed how a thicker cement layer may contribute to the debonding of posts [21,22]. Conversely, Perez et al. [23] have shown that bond strength was not impaired by increased cement thickness. Therefore, the optimal thickness of resin cements surrounding the fiber post is still unclear.

The purpose of this *in-vitro* study was to evaluate the effects of luting systems (etch-and-rinse, self-etch and self-adhesive approaches) and cement thicknesses on the bond strength of fiber posts. The working hypothesis was that cement thickness influences *in-vitro* dentin bond strengths of fiber posts.

Materials and methods

Sixty recently extracted human maxillary canine teeth with straight root canals stored in 0.1% sodium hypochlorite at 4°C were used in this study. Teeth with curved roots, wide canals, open apices, root cracks or previous endodontic treatment were not included. Tissue remnants and debris were cleaned and roots that were 16 mm in length were obtained after sectioning the coronal portion. The working length was established at 1 mm from the apex. All the root canals were instrumented by the step-back technique using K-files (Mani Inc., Tochigi, Japan) up to ISO size 40. Coronal thirds were shaped with sizes 2–4 Gates-Glidden burs (Mani Inc., Tochigi, Japan). Through the instrumentation, the canals were irrigated with a 2.5% sodium hypochlorite solution (Caglayan Chemistry, Konya, Turkey). Final irrigation was accomplished with 3 ml of EDTA solution followed by 5 ml of distilled water.

The root canals were dried with absorbent paper points and all root canals were filled using a resin-based sealer (AH Plus; Dentsply, Konstanz, Germany) and cold lateral condensation of gutta-percha points (Diadent, Seoul, Korea). The roots were then stored at 37°C with 100% humidity for 1 week.

The gutta-percha was removed with a size 2 Peaso reamer (Mani Inc., Tochigi, Japan) and the post space was standardized using low-speed post drills (Snowlight post blue size #16; Carbotec, Ganges, France) to create an 11-mm-deep and 1.7-mm-diameter post space as circular in all specimens used in this study. After preparation, the post space was cleaned with distilled water and dried with absorbent paper points. The specimens were randomly assigned to three groups of 20 teeth each, according to type of adhesive luting systems: Group 1; etch-and-rinse: Variolink II/ Exite DSC (İvoclar Vivadent, Schaan, Liechtenstein); Group 2; self-etch: Panavia F2.0/ED primer (Kuraray, Osaka, Japan); and Group 3; self-adhesive: Clearfil SA Cement (Kuraray). Each group was divided into four sub-groups according to the cement thickness created, as follows: Sub-group 1: 0.35-mm cement thickness was obtained using 1.0 mm diameter fiber post (Snowlight post white size #10); Sub-group 2: 0.25-mm cement thickness was obtained using 1.2-mm diameter fiber post (Snowlight post yellow size #12); Sub-group 3: 0.15-mm cement thickness was obtained using 1.4-mm diameter fiber post (Snowlight post red size #14); and Sub-group 4: 0.05-mm cement thickness was obtained using 1.6-mm-diameter fiber post (Snowlight post blue size #16). Prior to the cementation, the posts were cleaned with alcohol. The adhesive luting systems were applied by strictly following the manufacturers' instructions (Table I). All of the posts were then centrally seated to full depth using finger pressure and light curing was performed for 20 s with an LED light curing unit (Monitex BlueLex GT1200, Taipei; Taiwan). All samples were created by a single trained operator. All root specimens were stored at 37°C with 100% humidity for 24 h.

The root specimens were sectioned perpendicularly to their long axis using a low-speed diamond saw (Isomet, Buehler Ltd., Lake Bluff, IL) under a water coolant. Three slices of 1 mm thickness were obtained from each root ($n = 15$). The first slice was excluded to prevent the influence of excess coronal material. Parallel portions of fiber posts that matched the coronal and middle portions of the root were included in the study. The cement thickness for each slice was verified by using photographs of specimens obtained with a stereomicroscope (SZ40 Olympus, Tokyo, Japan) under 20× magnification. The push-out test was conducted using a universal testing machine (Elista, Istanbul, Turkey) by applying a load at 0.5 mm/min from the apical to coronal direction by using a 1-mm diameter metallic plunger until bond failure occurred. The load at failure was recorded in Newtons and converted into MPa by dividing the failure load by the bonding area (A). The bonding area was calculated using the following formula: $A = 2\pi rh$, where π is the constant 3.14, r represents the post radius and h represents the thickness of the slice.

After the push-out testing, all slices were analyzed under a stereomicroscope at 20× magnification to

Table I. Evaluated materials: Composition, manufacturers, lot numbers and application.

Material	Adhesive type	Manufacturer	Lot number	Composition	Application
Syntac® (Group 1)	Dentin etching + Bonding agent (Total Etch)	Ivoclar vivadent, Schaan, Liechtenstein	N23886	Phosphoric acid gel (37%)	Apply to the prepared dentin. Use a syringe tip to push the etchant into any restricted areas of the preparation, leave for 10–15 s on dentin. Remove all etchant gel with a vigorous water spray for at least 5 s
			N26866	Primer: TEGDMA, PEGDMA, maleic acid and acetone	Apply Syntac Primer with the brush on the cavity and gently rub in, wait at least 15 s and dry thoroughly. Do not rinse
			N33795 N30513	Adhesive: PEGDMA and glutaraldehyde Heliobond: Bis-GMA, TEGDMA, stabilizers and catalysts	Apply Syntac Adhesive, leave it for 10 s and dry the cavity with an air syringe. Do not rinse. Apply Heliobond a thin layer. Light-cure for at least 10 s
Variolink II (Group 1)	Dual polimerizing resin cement	Ivoclar vivadent, Schaan, Liechtenstein	N23645	Base: Bis-GMA, TEGDMA, UDMA, barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, and spheroid mixed oxide	Dispense and mix equal amounts of paste Catalyst and Base, than coat posts with mixed cement
			N16895	Catalyst:Bis-GMA, TEGDMA, UDMA, dibenzoyl peroxide	
ED Primer (Group 2)	1-step self etching pimer+	Kuraray, Osaka, Japan	00144A	ED Primer A: HEMA, 10-MDP, 5-NMASA, water, accelerator	Mix equal amounts of ED PRIMER liquids A and B. Apply to coronal and post-hole tooth structure then wait for 60 s. Gentle air dry to remove excess primer
			00268A	ED Primer B: 5-NMASA, water, accelerator, sodium benzene sulphinate	
Panavia F (Group 2)	Dual polimerizing resin cement	Kuraray, Osaka, Japan	00366A	Paste A: Silanated silica, microfiller, 10-MDP, dimethacrylates, photo/ chemical initiator	Dispense and mix equal amounts of paste A and B, than coat posts with mixed cement
			00066A	Paste B: Silanated barium glass, surface-treated NaF, dimethacrylates, chemical initiator	
Clearfil SA Cement (Group 3)	Self-adhesive Resin cement	Kuraray Tokyo, Japan	0017BA	Bis-GMA, TEGDMA, 10-MDP, barium glass, silica, sodium fluoride	Dispense and mix equal amounts of paste A and B with special tips, than coat posts with mixed cement

10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; HEMA, 2-hydroxyethyl methacrylate; Bis-GMA, bisphenyl-glycidyl-methacrylate; TEGDMA, triethylene glycol dimethacrylate; 5-NMASA, N-Methacryloyl-5-aminosalicylic acid; PEGDMA, polyethylene glycol dimethacrylate.

determine the mode of failure by a single trained operator. The failure mode was classified into five types [24]: (1) adhesive between the post and resin cement (no cement visible around the post); (2) mixed, with resin cement covering 0–50% of the post surface; (3) mixed, with resin cement covering 50–100% of the post surface; (4) adhesive between resin cement and root canal (post enveloped by resin cement); and (5) cohesive in dentin.

After assessing the normality of data distribution and homogeneity of group variances, the mean push-out bond strengths of each group were analyzed using two-way ANOVA to evaluate the effects of the two experimental factors; that is, the type of adhesive and

Table II. Bond strengths in Mpa (means and standard deviations) for various luting agents and cement thicknesses.

	Cement thickness			
Groups	0.35 mm	0.25 mm	0.15 mm	0.05 mm
VLII	2.88 ± 0.25^{b}	3.23 ± 0.47^{ab}	3.64 ± 0.57^{a}	3.62 ± 0.58^{a}
PF	1.49 ± 0.27^{c}	1.57 ± 0.23^{c}	1.68 ± 0.38^{c}	1.71 ± 0.33^{c}
CS	1.89 ± 0.32^{c}	2.21 ± 0.33^{cd}	2.53 ± 0.46^{e}	2.65 ± 0.36^{e}

The different superscript letter indicates statistically significantr difference in same column and same line ($p > 0.05$).

the thickness of the cement and luting system. Post-hoc comparisons were performed using Tukey's multiple comparison test. Statistical significance was set in advance at $p = 0.05$.

Results

The mean and standard deviation push-out bond strength values for each luting system and cement thickness are displayed in Table II.

Push-out bond strength was found to vary significantly according to type of adhesive system ($p < 0.01$). The etch-and-rinse adhesive system (Variolink II) had significantly higher bond strengths compared with the other adhesive system ($p < 0.05$). The self-etch adhesive system (Panavia F) showed significantly lower bond strengths compared with the other systems ($p < 0.05$). There was significant interaction between the luting systems and cement thickness ($p < 0.05$).

Within the etch-and-rinse and self-adhesive groups, bond strength was significantly affected by the cement thickness ($p < 0.05$). Bond strength of these groups decreased with the increasing cement thickness; however, significant differences were observed only between the highest cement thickness group (0.35 mm) and the 0.15 and 0.05 mm groups ($p < 0.05$). In addition, a significant difference was observed between the 0.25-mm and 0.05-mm sub-groups of the self-adhesive system (Clearfil SA Cement). Although the self-etch system showed a slight decrease in bond strength with increasing cement thickness, differences among its sub-groups were insignificant ($p > 0.05$).

Table III exhibits the analysis of failure modes in each group. The predominant failure modes of the etch-and-rinse, self-adhesive and self-etch system groups were mixed, mixed and adhesive (cement-dentine) and adhesive (cement-post and cement-dentine), respectively. Thicknesses of the cements used had no effect on failure modes of the tested posts for each adhesive system.

Discussion

The present study investigated the effect of cement thickness on bond strength of fiber posts after luting with different adhesive systems using a thin-slice push-out test method. The luting cements were selected due to the different conditioning methods. To create the different thicknesses of cements used in the present study, post spaces were prepared by using a standard post drill and standard fiber posts with different diameters were used in combination with the luting agents. The Snowlight post used in this study is radiopaque, translucent and cylindrical with a long apical cone. To obtain standard cement thickness

Table III. Failure types occurred in each group.

Groups	Cement thickness	Adhesive: post–cement	Mixed 0–50%	Mixed 50–100%	Adhesive: cement–dentin	Cohesive	Total
Variolink II	0.35	0	2	9	4	0	15
	0.25	0	1	11	3	0	15
	0.15	0	1	12	2	0	15
	0.05	0	0	10	5	0	15
Celarfil SA Cement	0.35	0	1	6	8	0	15
	0.25	0	2	6	7	0	15
	0.15	0	2	4	9	0	15
	0.05	0	2	9	4	0	15
Panavia F	0.35	8	0	3	4	0	15
	0.25	6	1	3	5	0	15
	0.15	5	0	2	8	0	15
	0.05	1	0	5	9	0	15

throughout the slices, apical portions of the posts were not included due to their tapered design.

Several methods have been performed to measure the bond strength to root dentine, such as microtensile, shear test, pull-out and push-out tests [25]. The thin-slice push-out test has been reported to be a practical tool for evaluating the bond strength of fiber posts [25]. This method has some advantage over the microtensile and shear strength tests, including the absence of premature failures, the ease of aligning samples for testing and the lower susceptibility to small variations among specimens and to variations in stress distribution [26,27]. It has been found to be dependable in bond strength evaluations of 1-mm-thick samples [28]. Hence, the thin-slice push-out test was used in the present investigation.

Self-etch and self-adhesive resin cements were developed in order to reduce the number of application steps and technique sensitivity compared to conventional resin cements while obtaining comparable results [29]. In contrast to this claim, in the present study the etch-and-rinse luting system revealed significantly higher bond strength than the self-etch and self-adhesive systems. Similarly, Goracci et al. [30] showed that the push-out bond strength of an etch-and-rinse system was higher than that of the self-etch and self-adhesive systems. A possible explanation for the higher push-out bond strength of the etch-and-rinse system could be the phosphoric acid (with a pH of ≈ 0.2) used with Variolink II, which is more effective than self-etch and self-adhesive systems in dissolving the thick smear layer created on root canal walls during post space preparation [30]. The acidic resin monomers in the self-etch ED Primer from Panavia F 2.0 (10-methacryloyloxydecyl dihydrogen phosphate) and in the self-adhesive cement Clearfil SA Cement (10-methacryloyloxydecyl dihydrogen phosphate), both with a pH of ≈ 2.0, seemed to be less effective. In addition to micromechanical interlocking through hybridization, specific functional monomers of mild self-etching adhesives (pH ≈ 2.0) were shown to interact chemically with residual hydroxyapatite crystals that remain available in the hybrid layer [31]. The monomer 10-MDP can readily adhere to residual hydroxyapatite in the hybrid layer and this bond was reported to be very stable [31,32]. However, according to the results of this *in vitro* study we speculate that, unlike coronal dentin, the contribution of additional chemical interaction to bond strength is inadequate for root canal dentine. Kececi et al. [33] also concluded that the etch-and-rinse system resulted in higher bond strength values than the self-adhesive system, thus corroborating the present findings. Mazzoni et al. [10] addressed how the etch-and-rinse system was the most stable luting procedure compared with the self-etch and self-adhesive systems. Radovic et al. [34] evaluated bond strength of etch-and-rinse, self-etch and self-adhesive systems and concluded that the self-etch approach may offer less favorable adhesion to root dentine in comparison with the other systems. On the other hand, the present results contradict the outcome of another study that revealed significantly lower push-out bond strength for the etch-and-rinse system compared with the self-adhesive system [35].

The push-out bond strength of the self-adhesive system was significantly better than that of the self-etch system and this result is consistent with the study of Zorba et al. [20]. Toman et al. [11] also showed that displacement resistance values for the self-adhesive system were significantly higher than for the self-etch system. Self-adhesive cements contain multifunctional phosphoric acid methacrylates that demineralize the tooth structure and react with the hydroxyapatite of the hard tissue [20,36]. In addition, self-adhesive systems exhibit moisture tolerance, which may explain the superior bonding performance of the self-adhesive system to the self-etch system in the present study because of difficulties in moisture control of post space after rinsing the root canal [35]. Conversely, several previous studies reported similar bond strength for the self-adhesive system compared with the self-etch system [13,30].

Cement thickness has been considered as an important factor in the adhesive failure between luting systems and dentine because too-thick cements have been shown to lead to post debonding [22]. It has been addressed that if the cement thickness is too great, microporosities and polymerization shrinkage are likely to be present [37]. To solve this problem, several studies have recommended using the thinnest cement layer to increase the bond strength. Therefore, four different cement thicknesses (0.35, 0.25, 0.15 and 0.05 mm) were used to evaluate the effect of cement thickness on post bond strength in the present study. The present study found that the push-out bond strength of fiber posts decreased as the cement thickness increased, although it is not significant for the self-etch system group. When the cement was too thick (0.35 mm), significantly lower bond strengths were observed for the etch-and-rinse and self-adhesive systems. These results could be explained by reduced shrinkage of the thinner cement results in less stress at the dentine-post interfaces [38].

There are limited studies evaluating the effect of cement thickness on the bond strength of fiber posts in conjunction with the luting systems. D'Arcangelo et al. [39] investigated the effect of cement thickness on the pull-out strength of a fiber post using a self-etch system for cementation of the fiber post. They reported that when the cement thickness was too great, the bond strength was significantly decreased, in agreement with the present study, but the thinnest cement layer does not guarantee the highest bond strength values. In a push-out test, Perez et al. [23] showed that the increase in resin cement thickness did not significantly decrease the bond strength of fiber post cemented with the multiple bottle total-etch system.

Analyses of the failure modes in the present study revealed no cohesive failures within the dentine for all groups and no adhesive failures between the post and resin cement for etch-and-rinse and self-adhesive system groups. Bond strength in etch-and-rinse groups appeared to be superior to the other systems because the predominant mode of failure was mixed type (with resin cement covering 50–100% of the post surface). Self-etch system groups demonstrated more adhesive failure between post and cement compared with the other groups. Therefore, the bond strength between post and cement could be considered as the limiting factor of the measured bond strength values [35]. Additionally, failure modes did not vary according to the cement thickness used. The adhesive system used may be more influential than the thickness of cement used in the present study on bond strength of fiber posts.

The tested hypothesis was accepted as the type of luting system and cement thickness significantly affect the bond strength of fiber posts. The increases in cement thickness significantly reduce the bond strength of fiber posts to root dentine for both the etch-and-rinse and self-adhesive systems. The etch-and-rinse system offers better bonding to root dentine than the self-adhesive and self-etch systems. Both the close adaptation of fiber posts to root dentine and the type of adhesive luting system used to bond the fiber post to the root dentin may hold great importance for the clinical longevity of fiber post restorations.

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