Effects of Different Luting Agents on Bond Strengths of Fiber-reinforced Composite Posts to Root Canal Dentin

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Purpose: To evaluate the bond strength between two fiber posts (FRC Postec and DT Light Post) and different composite resins following different surface treatments of the posts.

Materials and Methods: One hundred sixty extracted teeth were divided into sixteen groups (n = 10). After pretreatment of the post surface with (1) no treatment, (2) silanization, (3) sandblasting + silanization or (4) tribochemical coating, the posts were either luted with the resin cements provided by the manufacturers of the post system or with a core buildup material. Push-out tests were performed in a universal testing machine until the post segment was dislodged from the root section. Data were analyzed using ANOVA. Multiple comparisons were performed using Tukey's test.

Results: FRC Postec achieved significantly higher bond strengths than DT Light Post ($p < 0.0001$). Cementation with the core buildup material showed significantly higher bond strengths than the resin cement provided by the post manufacturers ($p < 0.0001$).

Conclusion: Post type, type of surface treatment and type of resin cement were significant factors for bond strength. Luting with a core buildup material significantly increased the bond strengths.

Keywords: fiber post, tribochemical treatment, silane, core buildup resin, push-out bond strength.

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Fiber-reinforced composite (FRC) posts are commonly used for the restoration of root-filled teeth with reduced crown structure[8] to ensure adequate retention of the core buildup. In clinical studies, it has been shown that failure of adhesively luted fiber posts often occurs due to debonding of the post.[11,28] Many investigations have been conducted concerning improvement of the bond strengths between the post and the root canal dentin, including different pretreatment techniques of the post surface,[5,21,31,48] pretreatment of root canal dentin,[22,33] or use of different luting agents.[7,14,34] Chemical pretreatment of FRC posts includes silanization[16,51] and etching with hydrofluoric[29] or phosphoric acid.[46] Mechanical pretreatment (eg, sandblasting with alumina particles) results in roughening of the post surface and an increased surface area for bonding. The CoJet system (3M ESPE; Seefeld, Germany) is a chairside system for intraoral use. By sandblasting with silicate-coated alumina particles, a silicate layer is welded onto the surface by high spot heat produced by sandblasting pressure in a process referred to as tribochemical coating. After application of silane, a chemical bond is achieved between the resin cement and the conditioned surface. CoJet treatment of FRC posts has been described in several investigations, but contradictory results have been obtained.[6,38-40] The manufacturers of post systems often provide different composite resins for post cementation and the subsequent core buildup. The use of one composite resin for both indications would be a simplification of the clinical procedure. A few studies have been performed regarding the use of core buildup materials for post cementation.[2,21,33,36] However, no consistent conclusion or recommendation for adhesive luting of FRC posts can be drawn from these studies.

Currently, various luting agents and corresponding adhesive systems are available for bonding FRC posts to root canal dentin. Depending on the conditioning method, these

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materials can be divided into etch-and-rinse systems and self-etching adhesives. Several in vitro studies reported conflicting results regarding bond strengths of different adhesive systems to root canal dentin.[24,27,30,41,52]

The purpose of this in vitro study was to evaluate the bond strengths between two different prefabricated FRC posts after different pretreatments of the post surface. A comparison was performed of the bond strengths of the luting agents provided with the post system and a core buildup material. It was hypothesized that bonding of resin cement to FRC posts was influenced by the type of post, the type of surface treatment, and the type of adhesive system and luting agent.

MATERIALS AND METHODS

Sample Preparation

One hundred sixty single-rooted extracted teeth previously stored in 0.1% thymol solution were used for this study. The teeth were divided into sixteen experimental groups (n = 10) with each group containing three maxillary incisors, three mandibular premolars, and four mandibular or maxillary canines. The specimens were embedded in an acrylic block (Paladur, Heraeus Kulzer; Hanau, Germany), positioned in a low-speed diamond saw (Exakt 300, Exakt Apparatebau; Norderstedt, Germany) and shortened to a length of 17 mm under constant water cooling by cutting off the coronal part of the respective tooth. Root canals were mechanically enlarged using sizes 1-3 Gates Glidden burs (VDW, Munich; Germany) in descending order in a crown-down technique. Each root canal was irrigated between instrumentations with 5 ml sodium hypochlorite (3%). The root canals were enlarged to a depth of 12 mm with a low-speed drill provided by the manufacturers of the two post systems, following irrigation with 5 ml NaOCl (3%) and 3 ml EDTA (17%) and drying with sterile paper points. All specimens were prepared by one practitioner in a standardized procedure. Two different fiber-reinforced composite posts were used in this study: FRC Postec (Ivoclar Vivadent; Schaan, Liechtenstein) and DT Light Post (VDW). The composition of the posts is presented in Table 1. Eighty FRC Postec and 80 DT Light Post posts size 1 were tried in and inserted, depending on the type of surface treatment and resin cement system. The distribution of the sixteen experimental groups is shown in Table 2.

Surface Treatments of the Posts

In all groups, the posts were cleaned with alcohol (80%) for 60 s as recommended by the manufacturers. Four different kinds of surface treatment of the posts were performed:

- Group A: no further treatment
- Group B: silanization (Monobond S, Ivoclar Vivadent) for 60 s
- Group C: sandblasting using alumina particles (particle size 150 µm, 3 bar pressure) in an extraoral sandblasting device for 2 s at a distance of 5 cm (Harnisch & Rieth; Winterbach, Germany) and silanization (Monobond S) for 60 s
- Group D: tribochemical coating with the CoJet system (particle size 30 µm, 2.5 bar pressure) for 10 s at a distance of 10 cm, silanization (Espe Sil, 3M ESPE) for 60 s and bonding (VisioBond, 3M ESPE).

The materials and devices used for the different surface treatment are listed in Table 3.

Luting Procedures

After performing of the different surface treatments, 80 posts (40 FRC Postec and 40 DT Light Post) were luted with the resin cements and bonding agents provided by the manufacturers of the two post systems: Excite DSC (Ivoclar Vivadent) and Variolink II (Ivoclar Vivadent) for FRC Postec and Prime & Bond NT + Self Cure Activator (Dentsply DeTrey; Konstanz, Germany) and Calibra (Dentsply DeTrey) for DT Light Post. Prior to application of both bonding agents, the root canals were etched with phosphoric acid gel (37% H_3PO_4), and after 15 s it was rinsed from the post space with distilled water. Excess water was removed with a gentle stream of air and paper points. Luting procedures of FRC Postec were performed with Excite DSC, a dual-polymerized single-bottle dentin bonding agent. It was applied for 20 s to the post space walls with a microbrush coated with chemical initiators, which was provided by the manufacturer. Excess material was absorbed by use of paper points, and the primer was gently air dried. Equal amounts of the dual-polymerizing resin luting cement's base and catalyst (Variolink II) were mixed manually. For cementation of DT Light Post, the dual-curing bonding agents Prime & Bond NT and Self Cure Activator were mixed in equal amounts and applied for 20 s to the root canal using a microbrush. Excess primer was removed with a gentle air stream and paper points. The base and catalyst of Calibra, a dual-curing resin cement, were manually mixed following the instructions provided by the manufacturer.

Luting of the other 80 posts (40 FRC Postec and 40 DT Light Post) was performed with a core buildup material (Luxacore, DMG; Hamburg, Germany) and a self-etching adhesive system (Clearfil Liner Bond 2V, Kuraray; Frankfurt a. M., Germany). One drop of Clearfil Liner Bond 2V Primer A and B was mixed and applied to the root canal walls with a microbrush for 20 s. Excess primer solution was removed with paper points, and the primer was gently air dried. Following the same scheme, a 1:1 mixture of Bond A and Bond B was used as a dual-polymerizing bonding agent. Luxacore is a self-curing resin cement provided in an automixing device. The luting cements and bonding agents used in each experimental group and the chemical composition of the tested materials are summarized in Table 4.

In all cases, the resin cement was applied into the prepared post space with a disposable tip, as well as onto the post surface using a spatula before inserting the posts into the root canals. The bonding agents and resin cements were light cured for 60 s with a halogen curing light (800 mW/cm^2 output, 3M ESPE) through the post, with the tip of the light unit directly in contact with the coronal end of the post. The optical power density was varified with a curing radiometer (Model 100, Demetron Research; Danbury, CT, USA).

Table 1 FRC posts used in this study

Material	Manufacturer	Post diameter (in mm) of the different root sections	Composition
FRC Postec	Ivoclar Vivadent, Schaan, Liechtenstein	Coronal: 1.48 (coronal side); 1.45 (apical side) Middle: 1.45 (coronal side); 1.41 (apical side) Apical: 1.41 (coronal side); 1.24 (apical side)	Glass fibers (61.5% weight) Matrix: urethane dimethacrylate, triethylene glycol dimethacrylate Additional contents: ytterbium trifluoride, highly dispersed silicon dioxide
DT Light Post	VDW, Munich, Germany	Coronal: 1.30 (coronal side); 1.20 (apical side) Middle: 1.20 (coronal side); 1.10 (apical side) Apical: 1.10 (coronal side); 1.00 (apical side)	Quartz fibers (60% volume) Matrix: epoxy resin

Table 2 Distribution of the 16 experimental groups (n = 10) according to the post system, surface treatment, resin cement, and bonding agent

	FRC Postec				DT Light Post			
	No treatment	Silane	Al_2O_3 + silane	CoJet + silane	No treatment	Silane	Al_2O_3 + silane	CoJet + silane
Variolink II/ Excite DSC	A1	B1	C1	D1	-	-	-	-
Calibra/ Prime & Bond NT + Self Cure Activator	-	-	-	-	A2	B2	C2	D2
Luxacore/ Clearfil Liner Bond 2V	A3	B3	C3	D3	A4	B4	C4	D4

Group A: no further treatment; group B: silanization for 60 s; group C: sandblasting with alumina for 2 s and silanization for 60 s; group D: tribochemical coating for 10 s and silanization for 60 s, bonding.

Table 3 Materials for post surface treatments used in this study

Material	Manufacturer	Composition	Application
Monobond S	Ivoclar Vivadent; Schaan, Liechtenstein	1% 3-methacryloxypropyl trimethoxysilane (3-MPS), ethanol/water-based solvent	Apply to the post surface, air dry after 60 s
Sandblasting device	Harnisch + Rieth; Winterbach, Germany	Aluminium oxide (particle size 150 µm)	Sandblasting at a distance of 5 cm at 3 bar for 2 s
CoJet system	3M ESPE; Seefeld, Germany	Silicated CoJet sand (particle size 30 µm)	Sandblasting at a distance of 1 cm at 2.5 bar for 10 s
EspeSil	3M ESPE	1% 3-methacryloxypropyl trimethoxysilane (3-MPS), ethanol/water-based solvent	Apply to the post surface after tribochemical coating, air dry after 60 s
VisioBond	3M ESPE	Bisacrylate, aminodiol methacrylate, camphorquinone, benzyldimethylketale, stabilizers	Apply to the post surface after tribochemical coating and silanization

Table 4 Resin cements and bonding agents used in this study

Material	Manufacturer	Bonding agent	Composition of composite resins	Composition of primers	Polymerization mode of composite resins	Conditioning method
VariolinkII	Ivoclar Vivadent; Schaan, Liechtenstein	Excite DSC	Matrix: Bis-GMA, urethane dimethacrylate, triethylene glycol dimethacrylate Fillers: barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, spheroid mixed oxide	HEMA, Bis-GMA, glycerine dimethacrylate, phosphoric acid acrylate, highly dispersed silicon dioxide, ethanol, catalysts, stabilizers; Microbrush: coated with initiators	Dual	Etch and rinse (37% H_3PO_4, 15 s)
Calibra	Dentsply DeTrey; Konstanz, Germany	Prime & Bond NT + Self Cure Activator	Base: Barium boron fluoroalumino silicate glass, bis-phenol A diglydidylmethacrylate, polymerizable dimethacrylate resin, hydrophobic amorphous fumed silica, titanium dioxide, camphorquinone Catalyst: Barium boron fluoroalumino silicate glass, bis-phenol A diglydidylmethacrylate polymerizable dimethacrylate resin, hydrophobic amorphous fumed silica, titanium dioxide, benzoyl peroxide	Adhesive: PENTA, TEGDMA, Bis-GMA, amorphous silicone dioxide, cetylamine hydrofluoride, acetone Self-Cure Activator: aromatic sodium sulfinate, acetone, ethanol	Dual	Etch-and-rinse (37% H_3PO_4, 15 s)
Luxacore	DMG; Hamburg, Germany	Clearfil Liner Bond 2V, Kuraray; Osaka, Japan	Bis-GMA, barium glass, pyrogene silica	Primer A: MDP, HEMA, hydrophilic dimethacrylate, N-N-diethanol p-toluidine, photo-initiator, water Primer B: HEMA, hydrophilic dimethacrylate, water Bond A: MDP, HEMA, Bis-GMA, hydrophobic dimethacrylate, CQ, silanated colloidal silica Bond B: HEMA, Bis-GMA, hydrophobic dimethacrylate, BPO, N-N-diethanol p-toluidine, CQ, silanated colloidal silica	Chemical	Self-etching adhesive

10-MDP: 10-methacryloyloxydecyl dihydrogenphosphate; HEMA: 2-hydroxyethyl methacrylate; CQ: camphorquinone; BPO: benzoylperoxide; PENTA: dipentaerythritol penta acrylate monophosphate; bis-GMA: bisphenol A diglycidyl methacrylate; TEG-DMA: triethylene glycol dimethacrylate.

Table 5 Mean push-out bond strengths (MPa) and standard deviation according to the different root thirds, surface treatments and resin cements

	Root canal third	No treatment	Silane	Al_2O_3 + silane	CoJet + silane
FRC Postec					
Variolink II	coronal	13.83 ± 8.94	9.85 ± 9.28	16.43 ± 8.82	19.37 ± 6.84
	middle	4.61 ± 1.71	1.86 ± 0.85	6.24 ± 1.10	8.88 ± 2.85
	apical	1.19 ± 0.69	0.79 ± 0.35	3.42 ± 1.03	2.94 ± 1.87
Luxacore	coronal	15.23 ± 2.86	15.36 ± 7.53	21.78 ± 7.36	30.06 ± 6.94
	middle	8.98 ± 1.48	6.64 ± 1.39	9.29 ± 2.65	17.07 ± 4.51
	apical	5.22 ±1.89	2.02 ± 1.47	3.79 ± 2.25	8.17 ± 2.81
DT Light Post					
Calibra	coronal	12.23 ± 3.32	6.24 ± 3.69	16.58 ± 3.40	15.79 ± 9.84
	middle	3.53 ± 1.79	0.84 ± 0.63	7.47 ± 1.18	8.44 ± 6.40
	apical	0.52 ± 0.52	0 ± 0	2.17 ± 1.78	1.28 ± 2.04
Luxacore	coronal	15.43 ± 5.43	16.45 ± 7.12	26.14 ± 6.27	24.73 ± 5.64
	middle	9.91 ± 2.00	6.69 ± 1.69	11.20 ± 3.15	17.46 ± 4.67
	apical	4.61 ± 1.73	3.21 ± 1.31	2.58 ± 1.30	7.68 ± 2.13

After cementation, each specimen was embedded in an individual form (President, Coltene/Whaledent; Altstätten, Switzerland) filled with epoxy resin (Paladur, Heraeus Kulzer) with the long axis of the post perpendicular to the ground. Subsequently, the specimens were fixed in the low-speed diamond saw (Exakt 300, Exakt Apparatebau), which enabled perpendicular sectioning into three 2-mm-thick slices along the root axis with a diamond disk. The first cervical slice (approximately 1 mm) was discarded for removing the oxygen-inhibited outer layer of the resin cement. Each slice was marked on its coronal side with an indelible marker according to the root canal third (apical, middle, coronal). For prevention of water sorption into the fiber-reinforced posts, transparent nail varnish (L'Oréal; Düsseldorf, Germany) was applied on both surfaces of the disks. Afterwards, all specimens were stored for 24 h at 37°C in artificial saliva without mucin. Thermocycling was performed for 2000 cycles in deionized water from 5°C to 55°C with a dwelling time of 30 s in each bath and a transfer time of 2 s.

Push-out Test

The push-out tests of the 480 specimens were performed by applying a compressive load to the apical aspect of each slice with a cylindrical punch (diameter 0.65 mm) attached to a universal testing machine (Zwick; Ulm, Germany). The punch tip only contacted the post upon loading, without stressing the surrounding root canal walls.[17] Loading was performed at a crosshead speed of 1 mm min^{-1} until the post segment was dislodged from the root slice. A maximum failure load value (in N) was recorded and converted into MPa, considering the bonding area (mm^2) of the post segments. Post diameters were measured on each surface of the post/dentin sections using a digital caliper (Table 1), and the total bonding area for each post segment was calculated using the formula of a conical frustrum: $\pi\ (R + r)\sqrt{(R - r)^2 + h^2}$, where pi is the constant 3.14, R represents the coronal post radius, r the apical post radius and h the thickness of the slice.

Microscopic Evaluation of the Fracture Modes

Dislodged specimens were examined under a stereomicroscope (Möller-Wedel; Wedel, Germany) at 24X magnification both from the cervical and from the apical direction to determine the failure mode, which was classified into three types: a) adhesive between post and resin cement, b) adhesive between resin cement and dentin and c) cohesive inside the resin cement.

Statistical Analysis

Push-out bond strengths of the three different root thirds were summarized and mean values were used for statistical analysis to demonstrate the overall performance of one experimental group. Data were analyzed using SAS 9.1 software (SAS Institute; Cary, NC, USA). To investigate the effect of the different surface treatments, a homogeneous analysis of variance using the SAS Procedure PROC GLM was performed. Multiple comparisons were calculated using the Tukey adjustment. The results were regarded as significant if the p-value was less than 0.05.

RESULTS

The push-out bond strengths according to the coronal, middle, and apical root thirds are shown in Table 5. The significantly highest bond strengths were measured for the combination of FRC Postec, pretreatment with CoJet and luting with the core buildup material Luxacore

($p < 0.0001$). The type of post system was found to have a significant influence on bond strength ($p < 0.0001$), with FRC Postec achieving higher bond strengths than DT Light Post. For both post systems, luting with Clearfil Liner Bond 2V/Luxacore resulted in significantly higher bond strengths ($p < 0.0001$) than the adhesive systems and resin cements provided by the manufacturers (Excite DSC/Variolink II and Prime & Bond NT/Calibra, resp). In addition, bond strengths were significantly affected by the region of the root canal ($p < 0.0001$). The significantly highest bond strengths were obtained in the coronal third in comparison to the middle and apical third ($p < 0.0001$). Moreover, the bond strengths of the middle root canal third were significantly higher than in the apical third ($p < 0.0001$).

Microscopic analysis of the 480 specimens after push-out testing revealed mostly cohesive failure inside the resin cement for all root canal thirds (n = 240). Adhesive failure between the resin cement and dentin occurred in 156 cases. Only 22 specimens failed adhesively between the post and the resin cement. Sixty-two samples could not be categorized microscopically due to inability to determine the failure mode. Distribution of the fracture modes according to the different root thirds are presented in Table 6. Due to the low incidence of adhesive failures between post and resin cement, the influence of the factor "post surface treatment" was not calculated statistically.

Analysis of the categorized specimens demonstrated that the use of Clearfil Liner Bond 2V/Luxacore resulted predominantly in cohesive failures inside the resin cement for both post systems (FRC Postec: 78.2%, DT Light Post: 58.0%). Luting with adhesive systems and resin cements provided by the post manufacturers resulted in adhesive failures between dentin and resin cement (FRC Postec: 42.6%, DT Light Post: 51.0%) as well as in cohesive failures (FRC Postec: 44.4%, DT Light Post: 49.0%).

DISCUSSION

Bond strengths were investigated using a push-out model that results in a shear stress at the interface between post and cement,[47] which is comparable to the stresses under clinical conditions.[13] Taking into account the relative weakness of the post root bond, Goracci et al[17] reported that the push-out test seems to be the most accurate and reliable technique to measure the bonds of fiber posts to root canal dentin compared with conventional and modified microtensile tests. For this reason, this testing model was preferred for the present study. However, there are speculations that the effect of friction seems to contribute to the bond strengths of fiber posts using a push-out model.[15]

In this study, FRC Postec posts showed significantly better results than DT Light posts. This finding is in contradiction to an investigation by Perdigao et al,[35] who demonstrated no significant differences in bond strengths between FRC Postec and DT Light Posts cemented with the resin adhesive system provided by the respective manufacturer. Another recent study[20] reported that selection of the fiber post appears to be more important for high bond strength than choice of luting material.

The differences in bond strengths between DT Light Post and FRC Postec might be explained by different chemical compositions of the fibers and matrixes and the resulting interactions with different surface treatments and luting agents. Bitter et al[7] showed that bond strengths to FRC posts and zirconium-oxide posts were significantly affected by the type of luting agent and the type of post.

Three different resin luting agents were used in this study. The chemical-curing core buildup material Luxacore in combination with the self-etching adhesive system Clearfil Liner Bond 2V revealed significantly higher bond strength values compared to the resin cements and bonding agents provided by the manufacturers of the two post systems. In contrast, Putignano et al[36] showed that cementation of DT Light posts with a core buildup material Unifil Core (GC; Tokyo, Japan) resulted in no significant difference in bond strengths in comparison to the corresponding resin cement (Calibra). Magni et al[21] used the luting agents Variolink II and Multilink (Ivoclar Vivadent) and the core buildup material MultiCore Flow (Ivoclar Vivadent), and also found no significant influence of the luting agent on the bond strength of FRC Postec posts. The major advantage of the use of a core buildup material is the facilitation of the clinical procedure, which is easier and less time consuming, and the prevention of incompatibilities among different bonding agents and resin cements. There are no data in the available literature concerning the bond strengths of FRC posts in combination with the core buildup material Luxacore. The differences in bond strength of the resin cements used in this study may be due to differences in chemical composition (eg, filler content) of the cements. Another reason for the better performance of Luxacore could be attributed to fewer voids inside the resin cement as a result of the automixing procedure,[2,33] in contrast to the manual mixing of Variolink II and Calibra. Also, the mechanical properties of Luxacore, which is classified as a filled composite resin, may contribute to better bond strength due to higher stability of the adhesive interface.

Cementation with Clearfil Liner Bond 2V/Luxacore resulted in significantly higher bond strengths than the bonding agents provided by the manufacturers of the two post systems. Microscopic evaluation revealed predominantly cohesive failures when Clearfil Liner Bond 2V/Luxacore was applied. Under the conditions of the present study, the self-etching approach offered more favorable adhesion to root canal dentin in comparison to etch-and-rinse systems. The bond strength to dentin, as well as to the post, was higher compared with the stability of the resin cement itself. These results are confirmed by Tanumiharja et al,[42] who found mainly cohesive failures inside the resin cement after the use of Clearfil Liner Bond 2V. In contrast, a recent study demonstrated that debonding in specimens treated with a self-etching system (ED Primer II, Kuraray) occurred more frequently on the root dentin side.[37] In this study, the use of etch-and-rinse adhesive systems resulted in adhesive failures between dentin and resin cement as well as in cohesive failures inside the resin cement. On the other hand, Rathke et al[37] found predominantly adhesive failures between the post and the resin cement after the application of two dif-

Table 6 Distribution of the fracture modes according to the different root thirds

Group	Root canal third	Adhesive failure between resin cement and dentin	Adhesive failure between resin cement and post	Cohesive failure inside the resin cement	Specimen cannot be evaluated
A1	coronal	3	1	5	1
	middle	4	1	4	1
	apical	3	1	4	2
A2	coronal	1	0	7	2
	middle	3	2	5	0
	apical	3	4	1	2
A3	coronal	1	0	9	0
	middle	1	0	8	1
	apical	4	0	6	0
A4	coronal	5	0	4	1
	middle	3	0	4	3
	apical	5	0	5	0
B1	coronal	4	4	2	0
	middle	4	3	3	0
	apical	3	2	3	2
B2	coronal	1	0	6	3
	middle	2	0	5	3
	apical	1	0	7	2
B3	coronal	1	2	5	2
	middle	1	0	9	0
	apical	1	0	9	0
B4	coronal	4	0	6	0
	middle	2	0	7	1
	apical	2	0	8	0
C1	coronal	9	0	0	1
	middle	2	0	7	1
	apical	6	0	1	3
C2	coronal	3	0	5	2
	middle	5	0	3	2
	apical	4	0	4	2
C3	coronal	2	0	6	2
	middle	4	0	3	3
	apical	0	0	9	1
C4	coronal	5	0	5	0
	middle	3	0	2	5
	apical	7	0	2	1
D1	coronal	2	0	8	0
	middle	3	2	0	5
	apical	3	0	6	1
D2	coronal	2	0	8	0
	middle	8	0	0	2
	apical	3	0	6	1
D3	coronal	5	0	4	1
	middle	2	0	8	0
	apical	0	0	10	0
D4	coronal	5	0	4	1
	middle	5	0	4	1
	apical	6	0	3	1
		n = 156	n = 22	n = 240	n = 62

ferent etch-and-rinse systems. The use of self-etching primers has been advocated to overcome the problems associated with the moist application technique of single-bottle adhesives.[12,23] Self-etching primers eliminate the conditioning, rinsing, and drying steps and may cause less damage to dentinal surfaces compared to acidic conditioners.[43,44,49]

Nevertheless, recommendations concerning an optimum conditioning method for root canal dentin still remain controversial. Valandro et al[45] reported that multiple-bottle, etch-and-rinse adhesive systems provided higher pull-out strengths of FRC posts when compared to a single-bottle etch-and-rinse, and single-step self-etching adhesive system. A recent study demonstrated that higher bond strengths to coronal dentin were achieved using a three-step etch-and-rinse system compared to a two-step etch-and-rinse system and a self-etching system.[24] In contrast, similar or higher bond strengths in different regions of coronal dentin were demonstrated for self-etching primers compared to etch-and-rinse adhesive systems.[1,19,42] Tanumiharja et al[42] found that Clearfil Liner Bond 2V exhibited the highest bond strengths to occlusal dentin compared to etch-and-rinse systems. They speculated that this result may have been attributed to the combined conditioning and priming of Clearfil Liner Bond 2V in one step. The acidic conditioning primer dissolves the smear layer and incorporates it into the primer, as it demineralizes dentin and envelops the collagen fibers and hydroxyapatite crystals.[32] It is assumed that no voids exist, since demineralization of the inorganic component and resin infiltration into the collagen fibers occurs simultaneously to the same depth of demineralized dentin.[18] Additionally, the light-activated initiator contained in the primer presumably enhances adhesion to dentin.[25]

The bond strengths obtained in the present study varied between the coronal, medium and apical root canal third. In all groups, the bond strengths in the coronal third were significantly higher than in the medium and apical third. These discrepancies can be explained by morphological differences in terms of tubule orientation and tubule density between various regions of root canal dentin.[10,26] Several authors also detected significant decreases of bond strengths from the coronal to the apical third.[4,9,22,34,50,53] Obviously, bonding problems may occur in deeper areas of the root canal due to inadequate visualization and difficulties in the application procedure of luting agents.[54] In contrast, some studies did not reveal any significant influence of the root canal region on bond strengths.[2,3]

Under the conditions of this study, it can be concluded that the interaction between the type of post, type of treatment, and type of adhesive system and resin cement significantly influenced the bond strengths. Analysis of failure mode indicated that most failures occurred inside the resin cement or between the root canal dentin and the resin cement. This finding suggested that the pretreatment of the post surface was not the most important factor for failure. Therefore, further research is necessary to improve the adhesion to root canal dentin as well as the mechanical properties of luting agents.

CONCLUSIONS

Within the limitations of this study, it can be concluded that the type of FRC post, the type of surface treatment, and the type of bonding and luting agents significantly influenced push-out bond strengths. Tribochemical coating of FRC Postec posts and luting with a self-etching adhesive system (Clearfil Liner Bond 2V) and a core buildup material (Luxacore) resulted in significantly higher bond strengths than all other combinations of post, surface treatment, and bonding agent. The use of a self-etching adhesive and a resin cement suitable for both post cementation and core buildup represents a promising alternative to the resin cements provided by the post system manufacturers because of simplifying the clinical procedure. Silanization of FRC posts seems to have no significant effect on bond strength.

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Clinical relevance: Within the limitations of this in vitro study, the use of a self-etching adhesive system and cementation of FRC posts with a core buildup material is recommended in order to improve the bond strengths and to simplify the clinical procedure.