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Effectiveness of bonding fiber posts to root canals and composite core build-ups

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This study investigated the effects of fiber posts, silanization, and luting agents on the interfacial strength to root dentin and composite cores. Root canals of 120 crownless human teeth were instrumented. Three different posts (opaque and translucent), with and without silane treatment, were bonded using etch-and-rinse, self-etch, and self-adhesive luting agents. The restored roots were built up with dual-curing composite. After storage in water for 24 h at 37°C, 2-mm-thick slices were cut from each sample: one from the composite core and one from the restored root. Interfacial push-out bond strengths of the posts were determined in a universal testing machine. Failure modes were analyzed using scanning electron microscopy. The post type and the luting agent had significant effects on both the post-to-dentin and post-to-core strengths. Silanization did not significantly influence post-to-dentin strengths, but enhanced post-to-core strengths. With etch-and-rinse luting agents, debonding occurred predominantly between the post and the cement, while the self-etch and self-adhesive luting agents showed more failures on root dentin. No failures occurred between the composite core and the cement. The combination of translucent posts and etch-and-rinse dual-curing luting agents can positively influence the retention of fiber posts in root canals. Silanization seems to be less relevant for intra-root canal bonding, but may have beneficial effects on post-to-core strengths.

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Endodontically treated teeth that have lost a large amount of coronal tooth substance and are exposed to shearing chewing forces frequently require the placement of a post inside the root canal to help retain the restoration above it (1). Current clinical procedures rely on the use of prefabricated fiber posts that are bonded to the root canal dentin (2). One of the advantages of fiber posts is a modulus of elasticity (stiffness) similar to that of dentin (1–3). As indicated by the results of both *in vitro* studies (2) and clinical trials (4) this may reduce the incidence of unrestorable root fractures. However, information about the clinical behaviour of fiber posts from randomized controlled clinical studies is still scarce (5). In combination with a direct resin composite build-up, post-and-core restorations can be placed chairside in one appointment without any additional laboratory costs. In addition to the dentin-like elasticity of the posts, the adhesive bond between the different substrates (i.e. coronal and root dentin, luting agent, fiber post, and composite core build-up) is thought to be responsible for reducing the risk of root fractures (1, 3).

Although adhesive bonding is generally associated with an increase in fracture resistance and post retention (6, 7), several *in vitro* studies have shown that the bonding of fiber posts to root canals and composite core build-ups may be associated with various problems, for example (i) the difficulty of light curing inside the post space (8), (ii) a high cavity configuration factor resulting in a high polymerization shrinkage of the luting cement (9), (iii) a relatively low bond strength of composites to root dentin compared with that of composites to coronal dentin (10), (iv) potentially adverse effects of endodontic irrigants and sealers on dentin bond strength (11, 12), (v) the intrinsic permeability of simplified bonding systems as well as their chemical incompatibility with self-curing or dual-curing luting cements (13), and (vi) the weak bond between fiber post surfaces and composites (14). In parallel to these *in vitro* findings, clinical studies have reported that the most common cause of failure is debonding of the fiber posts (2, 4, 5). Recently, various materials and procedures were investigated to determine whether they could enhance the bonding effectiveness of fiber posts, for example, the use of light-transmitting translucent post types and the mechanical and/or chemical treatment of the post surface, followed by different kinds of adhesive treatment, and conflicting results were obtained (10, 12, 14–23). According to the adhesive strategy recommended for the bonding of fiber posts, the currently available resin-based cements and accompanying bonding systems can be classified as etch-and-rinse, self-etch, and self-adhesive luting agents (23). However, many of these investigations centred on post-to-dentin evaluations. Only a few studies also focused on the interfaces between the post and luting cement or composite core build-up (19). When selecting an appropriate luting protocol, preference should be given to methods that are well established in daily practice and that do not weaken the integrity and mechanical strength of the fiber post (21).

The aim of the present study was to evaluate the influence of three types of fiber posts and four different luting agents on the interfacial push-out strength to root canal dentin as well as to resin composite core build-ups. In addition, it was evaluated whether or not silane treatment of the post has beneficial effects on the post retention, both in the root canal and in the core build-up. The null hypotheses tested were that (i) the interfacial strength of fiber posts is neither influenced by the type of post nor by the luting agent used and (ii) silane treatment of the posts has no effect on the bond strengths.

Material and methods

Specimen preparation

One-hundred and twenty human teeth that were free from fillings and caries, and that had been stored in 1% chloramine T solution after extraction, were used in this study. Attention was paid to selecting single-rooted teeth with almost circular and straight root canals of comparable length. The crowns of the teeth were cut off using a diamond-coated separating disc (WOCO 50/Med; Conrad, Clausthal-Zellerfeld, Germany) under running water, so that the root canal ran perpendicularly to the cutting surface. The root canals were instrumented with Hedstrom files (Dentsply Maillefer, Ballagues, Switzerland) to remove the pulp tissue. The canal drills recommended by the different post manufacturers were then used to prepare the post spaces. The following cylindroconical post types were used: an opaque quartz fiber post (DT White Post size #3, batch 0305A; VDW, Munich, Germany); a translucent quartz fiber post (DT Light Post size #3, batch 0304C; VDW); and a translucent glass fiber post (FRC Postec size #3, batch GL0009; Ivoclar Vivadent, Schaan, Liechtenstein). In each fiber post group ($n = 40$), the posts were bonded using four different luting agents: an etch-and-rinse bonding system in combination with a self-curing compomer cement (PD); an etch-and-rinse bonding system combined with a dual-curing resin cement (EV); a self-etch primer/dual-curing resin cement (EP); and a self-adhesive dual-curing resin cement without adhesive pretreatment (RU) (Table 1). All posts were cleaned with 70% alcohol for 60 s. In each luting subgroup ($n = 10$), 5 posts were used without silane treatment (S–), serving as untreated controls, while 5 posts (S+) were treated with a one-component silane-coupling agent (Monobond-S, batch F65849; Ivoclar Vivadent) for 60 s and then dried with a gentle stream of air. The root canals were irrigated with 3 ml of 0.9% NaCl and dried using paper points. Next, the root canals were conditioned and the posts were luted, strictly according to the respective manufacturer's instructions (Table 2). Gross excess cement was removed, leaving a thin even coating on the cylindrical part of the posts protruding from the root canal. A disposable brush was used to spread the thin layer over the coronal part of the post. The composite cores were built up using a dual-curing hybrid composite (MultiCore HB, batch G06807; Ivoclar Vivadent). For this purpose, the base and catalyst pastes of the composite were mixed in a 1:1 ratio and applied in bulk from a Centrix syringe. Subsequently, the core build-ups were light cured from each side for 40 s using a halogen light-curing unit (500 mW cm^{-2} light intensity; Spectrum 800; Dentsply DeTrey, Konstanz, Germany). The composite core build-ups measured 3.7 mm in height and 4.5 mm in diameter. They were located below the retentive circular grooves of the posts.

Table 1

Overview of the luting agents used in the study

Code	Manufacturer	Bonding system (batch) composition	Luting cement (batch) composition
PD	Dentsply DeTrey, Konstanz, Germany	Prime & Bond NT (0312001521) Self Cure Activator (030708) PENTA, TEGDMA, Bis-GMA, CAF, DMA, TMA, silica, photoinitiator, NAS, acetone, ethanol	Dyract Cem Plus (03100002395) TiO_2, GL, phosphate modified polymerizable monomers, carboxyl acid-modified macromonomers, initiator, stabilizer, reactive diluent
EV	Ivoclar Vivadent, Schaan, Liechtenstein	Excite DSC (F61488) HEMA, DMA, phosphonic acid acrylate, silica, initiator, stabilizer, ethanol	Variolink II (Base: F67602, Catalyst: F68165) Bis-GMA, UDMA, TEGDMA, GL, ytterbium trifluoride, BPO, initiator, stabilizer
EP	Kuraray, Osaka, Japan	ED Primer II (41114) 10-MDP, 5-NMSA, HEMA, water, sodium benzene	Panavia F 2.0 (41114) 5-NMSA, 10-MDP, BPO, DMA, GL, silica, sodium fluoride, accelerator, initiator
RU	3M Espe, Seefeld, Germany	–	RelyX Unicem (170831) methacrylated phosphoric acid ester, DMA, GL, silica, initiator, stabilizer, acetate, calcium hydroxide, polymer

Bis-GMA, Bisphenol A diglycidylmethacrylate; BPO, benzoylperoxide; CAF, cetylamine hydrofluoride; DMA, dimethacrylate; GL, glass; HEMA, 2-hydroxyethyl methacrylate; 10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; NAS, sodium p-toluenesulfinate; 5-NMSA, *N*-methacryloyl-5-aminosalicylic acid; PENTA, dipentaerythritol pentaacrylate monophosphate; TEGDMA, triethylene glycol dimethacrylate; TiO_2, titanium dioxide; TMA, trimethacrylate; UDMA, urethane dimethacrylate.

Table 2

Application of the luting agents (according to the manufacturers' directions)

Luting cement	Conditioning of the root dentin	Luting of the post
Dyract Cem Plus	Apply DeTrey Conditioner 36 gel (36% phosphoric acid) for 15 s, rinse for 10 s, dry lightly with paper points, mix one drop of Prime & Bond NT and Self Cure Activator, apply mixture for 20 s, apply a gentle stream of air for 5 s	Mix one scoop of powder and one drop of liquid for 30 s, line post surface, lute post, remove excess luting cement; self-cures in 4 min
Variolink II	Apply Total Etch gel (37% phosphoric acid) for 15 s, rinse for 10 s, dry lightly with paper points, apply Excite DSC with a rubbing motion for 10 s, apply a gentle stream of air for 5 s	Mix base and catalyst paste in a 1:1 ratio for 10 s, line post surface, lute post, light cure for 40 s after the removal of excess luting composite
Panavia F 2.0	Mix one drop of both ED Primer II liquids A 2.0 and B 2.0, apply mixture for 30 s, apply a gentle stream of air for 5 s	Mix universal and catalyst paste in a 1:1 ratio for 20 s, line post surface, lute post, light cure for 20 s after the removal of excess luting composite
RelyX Unicem	No pretreatment	Mix activated capsule for 15 s (CapMix, 3M Espe), line post surface, lute post, light cure for 20 s after the removal of excess luting composite

Push-out test

The specimens were embedded in self-curing resin (Technovit 4071; Kulzer, Wehrheim, Germany) in a specially developed flask (Fig. 1). The three different post types, which fitted exactly into the matching flask insert, were placed vertically at the centre of the resin. After the resin had set, the blocks were removed from the flask and stored in water for 24 h at 37°C according to the standard ISO/TS 11405:2003 'Dental materials – Testing of adhesion to tooth structure'. Then, two slices were cut from each block: one slice was cut from the core build-up with the cylindrical part of the post, while the other was cut from the cervical root third with the conical part of the post. For this purpose, the blocks were secured to a sectioning machine (WOCO 50/Med; Conrad) and cut perpendicular to the post axis at the same level of the respective root and core build-up. Next, the surfaces of the approximately 2.1-mm-thick slices were polished with 600-grit silicon carbide paper in a polishing machine under water cooling (WOCO SF 20; Conrad). The thickness of the slices was continuously checked using a digital caliper (ODI 00 D; Kroeplin, Schlüchtern, Germany) until they were reduced to 2.0 ± 0.05 mm. The interfacial push-out bond strength was measured in a universal testing machine (Zwicki 1120; Zwick, Ulm, Germany) at a cross-head speed of 0.5 mm min^{-1}. The same flasks as those used for embedding the specimens were used for the push-out test (Fig. 1). The posts were loaded vertically to their surface using the matching set composed of a punch and flask insert until the post segments dislodged from the root canal or the core build-up. To enable the pushed-out post to pass through the hole of the flask insert, the diameter of the hole in the flask inserts was 0.15 mm larger than that of each post type. The punch was aligned so that it only contacted the post upon loading. The interfacial strength (MPa) was calculated as the quotient of the maximum force required to dislodge the post and the bonding area: $\sigma = F/\pi hd$ [where F was the load (in N), and h and d were the height and the diameter of the post segment, respectively (in mm)].

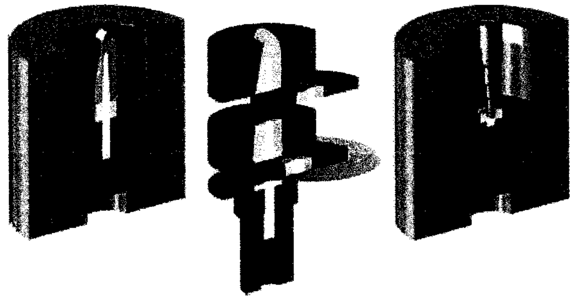

Fig. 1. Schematic drawing illustrating the slice preparation and the push-out set-up in the same flask.

Statistics

All statistical tests were performed using SPSS for Windows, version 14.0 (SPSS, München, Germany) at a $P < 0.05$ level of significance. Because the data of the post-to-dentin strength ($P = 0.495$) and post-to-core strength ($P = 0.882$) subsets, as well as the data of all the measurements ($P = 0.875$), were normally distributed, as indicated by the Kolmogorov–Smirnov test, a three-way analysis of variance (ANOVA) was used to determine the effects of (i) the post type, (ii) the type of luting agent, and (iii) post silanization, and to detect any significant interactions between these three variables. Multiple comparisons were performed using the Tukey test.

Scanning electron microscopy

All the slices used for the push-out test were split into two at the weakest point and prepared for examination under the scanning electron microscope. In order to make the dentin tubules clearly visible, the inner surface of the root canal was etched with 34.5% phosphoric acid (Vococid; Voco, Cuxhafen, Germany) for 30 s and then rinsed and dried. The etched root canal walls and the pushed-out post segments were mounted on a carrier and sputter-coated with gold at 25 mA for 2 min (Emitech K550; Röntgenanalytik Messtechnik, Taunusstein, Germany). The failure modes were classified according to the predominant location of luting cement remnants, as detected when analyzed under the scanning electron microscope (Leica Stereoscan 420; LEO-Elektronenmikroskopie, Oberkochen, Germany) at 90× magnification, as follows.

1. Adhesive failure between the dentin (root sections) and core (core sections), respectively, and the luting cement, indicated by remnants of luting cement predominantly adhering to posts.
2. Adhesive failure between the post and luting cement, indicated by remnants of luting cement predominantly adhering to dentin (root sections) or no remants of luting cement detectable on post surfaces (core sections).
3. Mixed failures, indicated by comparable amounts of cement remnants adhering to posts and root canal dentin (root sections) or composite cores (core sections).

Results

The results of the interfacial strength measurements are shown in Tables 3 and 4. Both the type of post and the type of luting agent used had significant effects on the post-to-dentin ($P < 0.0001$ in each case) and post-to-core ($P = 0.004$ in each case) strengths. Silanization did not significantly influence post-to-dentin strengths ($P = 0.497$), but enhanced post-to-core strengths ($P = 0.039$). The interaction among the post, luting agent, and silanization represented a significant factor in the post-to-dentin strength ($P = 0.007$). The highest mean post-to-dentin strength was measured using the translucent FRC Postec bonded with the etch-and-rinse luting agent, EV (32.4 MPa), and the lowest mean post-to-dentin strength was measured using the opaque DT White Post bonded with the etch-and-rinse luting agent, PD (10.6 MPa). Mean post-to-core strengths were highest when the silane-treated translucent FRC Postec was used in combination with the self-adhesive luting agent, RU (31.7 MPa), and lowest when the opaque DT White Post was used with the etch-and-rinse luting agent, EV (17.4 MPa).

Table 3

Mean (MPa) and standard deviation of the post-to-dentin strengths

Luting agent	Silane	Post type		
		DT White Post	DT Light Post	FRC Postec
Etch-and-rinse				
PD	+	18.15 (10.85)^{AB}	17.91 (8.40)†	19.26 (9.26)^{a}
	–	10.56 (5.78)^{A}	27.70 (7.39)†§	22.19 (3.85)^{ab}
EV	+	23.10 (4.18)^{AB}	31.68 (7.09)§	29.66 (5.87)^{ab}
	–	23.02 (4.43)^{AB}	22.75 (3.65)†§	32.41 (4.37)^{b}
Self-etch				
EP	+	14.56 (5.10)^{AB}	24.31 (5.07)†§	22.18 (6.20)^{ab}
	–	20.11 (6.96)^{AB}	20.14 (3.53)†	23.37 (4.26)^{ab}
Self-adhesive				
RU	+	23.29 (4.70)^{B}	28.99 (7.09)†§	23.06 (7.23)^{ab}
	–	18.80 (4.21)^{AB}	23.37 (2.03)†§	24.68 (6.41)^{ab}

Within each fiber post group ($n = 40$), luting subgroups labelled with the same letter or character are not significantly different ($P > 0.05$, Tukey test). For explanation of the luting agent codes see Table 1.

Table 4

Mean (MPa) and standard deviation of the post-to-core strengths

Luting agent	Silane	Post type		
		DT White Post	DT Light Post	FRC Postec
Etch-and-rinse				
PD	+	26.50 (6.20)	25.66 (8.83)	27.54 (2.78)
	–	26.11 (5.58)	22.94 (5.36)	27.48 (9.80)
EV	+	24.52 (9.38)	17.81 (6.64)	26.43 (4.51)
	–	17.40 (4.44)	17.92 (3.37)	24.31 (3.64)
Self-etch				
EP	+	19.63 (7.58)	28.89 (7.97)	25.57 (1.67)
	–	19.47 (5.80)	20.68 (5.71)	23.52 (6.95)
Self-adhesive				
RU	+	29.30 (5.16)	21.42 (6.69)	31.71 (0.74)
	–	24.74 (7.16)	23.54 (6.22)	28.57 (4.65)

Within each fiber post group ($n = 40$), no significant differences were found between the luting subgroups ($P > 0.05$, Tukey test). For explanation of the luting agent codes see Table 1.

The results of the failure analysis are shown in Figs 2 and 3. In the specimens involving the

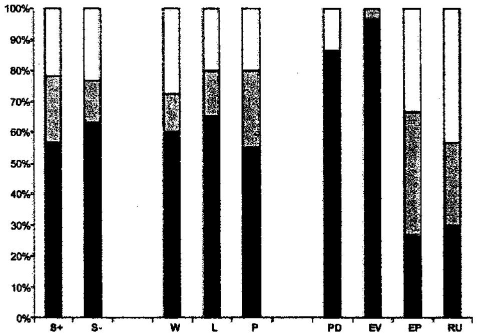

Fig. 2. Proportional prevalence of failure modes (%) after the post was pushed out of the root canal dentin. Luting agent codes (EP, EV, PD, RU) are explained in Table 1. L, DT Light Post; P, FRC Postec; S, Silane; W, DT White Post. Black bars represent adhesive failure between the post and the luting cement; grey bars represent adhesive failure between dentin and the luting cement; and yellow bars represent mixed failure.

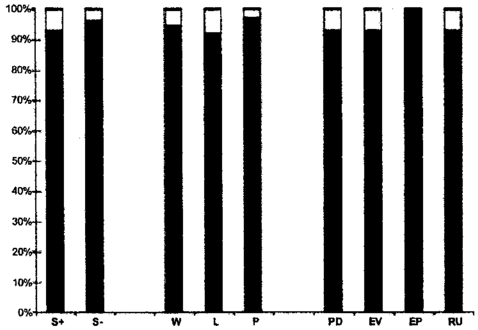

Fig. 3. Proportional prevalence of failure modes (%) after the post was pushed out of the composite core build-up. Luting agent codes (EP, EV, PD, RU) are explained in Table 1. L, DT Light Post; P, FRC Postec; S, Silane; W, DT White Post. Black bars represent adhesive failure between the post and the luting cement and yellow bars represent mixed failure. No adhesive failures occurred between the core and the luting cement.

etch-and-rinse luting agents EV (97%) and PD (87%), debonding of the posts from the root canals occurred predominantly between the post and the cement (Fig. 4A,B). By contrast, debonding in the specimens treated with the self-etch luting agent, EP (40%), occurred more frequently on the root dentin side. In the specimens treated with the self-adhesive luting agent, RU, the bond of the cement with the post was similar to that with the root dentin. However, the localization of the luting cement was not dependent on silanization or on the type of post used. The failure analysis of the composite core build-up revealed that hardly any residue of the luting cement remained on the posts (Fig. 4C). The localization of the luting cement was not dependent on silanization or on the type of post or luting agent used.

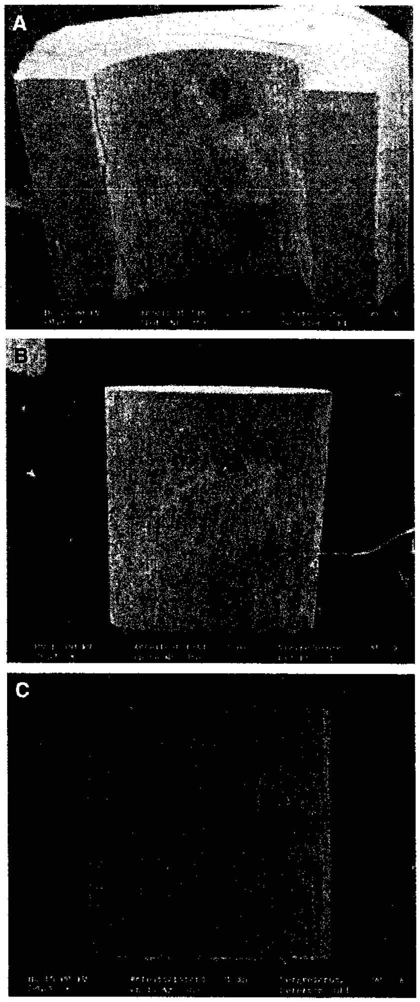

Fig. 4. Scanning electron micrographs of failed specimens. (A) Inner surface of the root canal. Almost the entire dentin is covered with luting cement (Variolink II, bonding system Excite DSC). (B) The corresponding post segment (silane-treated FRC Postec) after being pushed out of the root canal. Only small amounts of residual luting cement are visible. (C) After being pushed out of the composite core build-up. Hardly any luting cement remains on the post surface. The fibers of the post are visible. Original magnification 90×.

Discussion

In the present study, the push-out test was performed because it is considered to be the most appropriate method for measuring the retention of posts (22). As the retention of fiber posts to root canal dentin and composite core build-ups was influenced by the different post types and classes of luting agents, the first null hypothesis had to be rejected.

When the fiber posts were pushed out of the root canal, the adhesion of the luting cement was shown to depend primarily on the type of luting agent used. The posts were bonded using different bonding systems and their matching luting cements. The self-adhesive resin cement, RelyX Unicem, represented an exception, because it is used without a bonding system. In conjunction with the dual-curing Variolink II and the self-curing Dyract Cem Plus, which are both applied according to the etch-and-rinse-technique, most of the cement residue was found on the root dentin walls. Based on these scanning electron microscopy findings and the fact that Variolink II achieved higher post-to-dentin strengths than Dyract Cem Plus, one can assume that the two luting cements established bonds of different strengths to the post. This may be partially attributed to the dual-curing mechanism of the Variolink II system, which improves the polymerization of the bonding system as well as that of the luting cement surrounding the fiber post. Particularly in the translucent post groups (FRC Postec and DT Light Post), the dual-curing luting cement may have been polymerized by both the light applied from the top of the post space and also the light transmitted through the post. When these dual-curing luting cements are light-cured, the highest conversion rate is reached (24). Consequently, the physico-mechanical properties (25) and the bond strength (26) are enhanced. However, among the post groups tested, the other two dual-curing luting agents revealed lower post-to-dentin strengths than Variolink II, which correspond with the push-out test results of a previous study (20). Micromorphological investigations have shown that etching the dentin with phosphoric acid (with a pH of ≈ 0.2) completely dissolves the smear layer, while the use of self-etch bonding systems has a variable effect on the smear layer as a consequence of their different degrees of aggressiveness (20, 27). 'Milder' self-etch bonding systems have been shown to partially dissolve the smear layer (28). This must also have been the case for the self-etch and self-adhesive luting agents used in the present study. When viewed under the scanning electron microscope, the specimens treated with these two luting agents exhibited more failures on the root dentin side than the specimens conditioned with the two etch-and-rinse luting agents. The acidic resin monomers in the one-step self-etch ED Primer II from Panavia F 2.0 (10-methacryloyloxydecyl dihydrogen phosphate) and in the self-adhesive cement RelyX Unicem (methacrylated phosphoric acid ester), both with a pH of ≈ 2.0, seemed to be less effective. They were unable to etch through the thick smear layer, which was produced during the preparation of the post space in the root canal with slow-speed drills (20, 22). Nevertheless, the bonding mechanism of this self-adhesive cement is not yet completely understood, but is known to differ from that of self-etch luting agents, like the Panavia F 2.0 system, as a low demineralization effect, and no distinct hybrid layer of the dentin was observed during micromorphological examinations (26, 29, 30). As proposed by the manufacturer, the initially anhydrous cement may bond to the smear layer via the mechanisms of water generation and subsequent water recycling, which raise its initial pH to a neutral level of 7 shortly after its application. Its interaction with dentin may be too superficial to establish a tight bond between the fiber post and root dentin (23). Microleakage was shown to be higher in the root canals in which fiber posts had been bonded with RelyX Unicem than in those bonded with the etch-and-rinse and self-etch luting agents (23).

The present study verified the less-than-optimal adhesion of composites to fiber posts. As a result of differences in chemistry, no bonding can be expected between the methacrylate-based resins of the luting cement or build-up composite and the polymerized epoxy or polyvinylester resin matrices of fiber posts (2, 14, 19, 21). Although the dimethacrylate resin matrix of the FRC Postec post may appear to be more advantageous in coupling to methacrylate-based resins (18), the three different posts were almost free from luting cement residue after they had been pushed out of the composite core build-up. Consequently, it was concluded that most of the luting cement adhered to the build-up composite. The highly cross-linked polymer matrix between the post fibers may be responsible for the lack of adhesion, as the monomers of the applied luting cement cannot penetrate into the cross-linked structure (2, 19, 31). As the prefabricated posts are polymerized with a high degree of conversion, and oxygen-inhibition layers have to be removed to facilitate handling, there are no free radicals available with which to polymerize (31). This situation is similar to that encountered when attempting to establish a bond to processed and heat-cured composites (32). By contrast, the better adhesion to the core build-up may be attributed to the fact that free radical polymerization can occur and the chemical composition of the build-up composite is similar to that of the luting cement. To some extent, the chemical compatibility could also account for the higher post-to-core strengths of the FRC Postec post compared with that of the other posts tested, because the MultiCore build-up composite is produced by the same manufacturer and may thus be more compatible with this post in terms of its chemical composition. Further factors, such as the density, size, and distribution of the fibers, surface texture, and fabrication process might also have influenced the interfacial push-out strengths. However, this can only be speculated, as much of this information is kept confidential by the manufacturers.

Regarding the effect of the silane pretreatment of the posts, the second null hypothesis was confirmed as far as the post-to-dentin bond was concerned, but had to be rejected with regard to the post-to-core bond. Moreover, the mode of failure was not influenced by the silane treatment. This is probably because of the limited area on the post surface exhibiting exposed glass/quartz fibers or filler particles. Chemical adhesion after silane treatment of the post surfaces may only be established to exposed fibers or filler particles (2, 15, 33). However, the entire silane reaction mechanism still remains a subject that is not fully understood (33). Previous studies have reported conflicting results regarding the efficiency of silanization on the bond strength of fiber posts to the luting cement and composite core build-up (2, 15–19, 21). The primary factors influencing its efficiency include the type of silane (pH, solvent content, silane molecule, molecule size) and the application mode used (33). The silane employed in our study is a prehydrolyzed one-component solution (3-methacryloxypropyl-trimethoxysilane). The water needed for the agent to become reactive is obtained from the surrounding air. However, if water from the air humidity gets into the bottle during silane application, dimers, trimers, and oligomers of the silane may form and thus impair the effectiveness of the silane solution (33). It has been suggested that this effect may be less pronounced in two-component silane-coupling agents where the active silane forms freshly by hydrolysis when the two components are mixed (16, 17).

Although the 24-h bond strengths measured in this study seem promising, further *in vitro* studies are indicated to investigate the long-term bonding behaviour in a simulated oral environment. Longer storage times, in combination with thermocycling and/or mechanical loading, may promote degradation and hydrolysis effects along the bonding interfaces, which may compromise the durability of the bond. From the results of the present study, we can conclude that the retention of fiber posts to root canals and composite core build-ups is influenced by the type of post and luting agent selected. When using dual-curing resin cements, the choice of translucent fiber posts and an etch-and-rinse bonding system can be considered to positively influence the bonding effectiveness to root dentin, at least in the short-term. Silanization of the fiber posts with a ready-to-use silane seems to be less relevant for intra-root canal bonding, but may have beneficial effects on the bond between the post and the composite core build-up.

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