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ORIGINAL ARTICLE

Fiber post placement with core build-up materials or resin cements—An evaluation of different adhesive approaches

GUIDO STERZENBACH[1], GHALEB KARAJOULI[1], MICHAEL NAUMANN[2], INGRID PEROZ[1] & KERSTIN BITTER[3]

[1]*Department of Prosthodontics, Geriatric Dentistry and Craniomandibular Disorders, University School of Dental Medicine, ChartitéCentrum 3, Charité - Universitätsmedizin Berlin, Germany,* [2]*Department of Prosthetic Dentistry, University of Ulm, Germany, and* [3]*Department of Operative Dentistry and Periodontology, University School of Dental Medicine, ChartitéCentrum 3, Charité - Universitätsmedizin Berlin, Germany*

Abstract

Objective. To compare push-out bond strength of fiber-posts luted with different adhesive approaches to root canal dentin. ***Materials and methods.*** Forty maxillary first incisors were decoronated and endodontically treated. Specimens were randomly distributed into five groups ($n = 8$) and fiber-posts (DentinPost coated, Komet) were inserted using five different luting materials: etch-and-rinse adhesive systems and corresponding core-and-post material in groups 1 (DentinBond/DentinBuild, Komet) and 2 (XP Bond + SCA/Core-X flow, Densply), self-adhesive resin cements in groups 3 (RelyX Unicem, 3M Espe) and 4 (SmartCem 2, Dentsply) and a self-etch adhesive/resin cement in group 5 (ED-Primer II/Panavia F 2.0, Kuraray). The roots were sectioned into eight 1 mm thick serial slices and within 48 h push-out bond strength was investigated. Statistical analyses were performed using non-parametrical Kruskal-Wallis H-test and Mann-Whitney U-test for differences between experimental groups at $p < 0.05$. The failure modes were analyzed using Chi square test. ***Results.*** The bond strength [MPa] (mean/min–max) for groups 3 (12.35/3.60–32.44), 4 (13.52/4.48–30.69) and 2 (11.15/5.23–35.58) were significantly higher ($p < 0.001$) compared to groups 1 (6.66/2.34–24.89) and 5 (7.41/0.28–34.18). Adhesive failure between dentin and luting agent was the most frequent failure mode. ***Conclusions.*** Bond strength of fiber-posts adhesively luted to root canal dentin was significantly higher when self-adhesive resin cements were used. One (group 2) of the tested core-and-post materials/etch-and-rinse adhesive achieved comparable bond strength values.

Key Words: *bonding technique, root canal, fiber posts, push-out, self-adhesive resin cements*

Introduction

For post-endodontic restorations various luting agents and adhesives systems, respectively, have been proposed to bond fiber-reinforced composite (FRC) posts to root canal dentin. Compared to conventional post cementation adhesive post luting offers less mikroleakage [1,2], improved retention [3,4] and load capability [5]. However, post decementation turned out to be one of the most frequent types of failure *in vivo* [6–10]. Thus, a durable bond to root canal dentin to seal the endodontic environment is considered to be the major issue in longevity of post-endodontic restorations.

According to the way they interact with the smear layer current adhesives are attributed to one of the three bonding strategies/techniques [11]:

(1) etch-and-rinse adhesives with a separate acid-etching step to remove the smear layer,
(2) self-etch adhesives include acidic monomers making the smear layer permeable without removing it, and
(3) self-adhesive resin cements, which show a different cement/dentin interface.

Compared to coronal dentin bonding within the root canal is still a challenge due to morphological characteristics [12] and unfavorable conditions regarding

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Correspondence: Dr med dent Guido Sterzenbach, University School of Dental Medicine, CharitéCentrum 3, Charité - Universitätsmedizin Berlin, Department of Prosthodontics, Geriatric Dentistry and Craniomandibular Disorders, Assmannshauserstr. 4-6, 14197 Berlin, Germany. Tel: +49 30 450 562 724. Fax: +49 30 450 562 912. E-mail: guido.sterzenbach@charite.de

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the application of adhesive techniques within the root canal [13]. The high cavity-configuration factor (C-factor) [14] inside the root canal is crucial regarding polymerization stress due to volumetric shrinkage. As a result of high shrinkage stress and lower bond strength de-bonding can occur [15].

A literature review [16] on fiber-post bonding summarized that the etch-and-rinse technique combined with the use of dual-curing adhesive systems and cements revealed the most predictable methodology for luting fiber-posts. In contrast, impaired visibility could exacerbate the adhesive procedure in the depth of the root canal and remnants of water and/or acid could remain inside the root canal and may hamper the bonding performance [13,17]. Consequently, simplified adhesive approaches, e.g. self-etch adhesives and self-adhesive resin cements might be favorable. Comparative studies focused on the evaluation of bonding to root canal dentin demonstrate contradictory results. Some studies showed significantly higher push-out bond strength values for a self-etch adhesive [18] and self-adhesive resin cements compared to an etch-and-rinse adhesive [19] while others found less favorable bond strengths of the self-etching approach compared to etch-and-rinse adhesives and self-adhesive resin cements [20]. Again, when luting glass fiber posts within the root canal a greater bonding potential was referred for an etch-and-rinse adhesive than for a self-etch adhesive and a self-adhesive resin cement [21]. Furthermore, it was shown using Confocal Laser Scanning Microscopy that the etch-and-rinse adhesive approach revealed a more uniform and thicker hybrid layer formation [22,23] with shorter, compared to self-etch adhesives, but considerably denser resin tag formation [24]. In contrast to self-adhesive resin cements no or less hybrid layer formation and resin tags were observed [21,22]. It was assumed that the multifunctional monomers were unable to etch through the smear layer formed in the root canal [21]. Interestingly, while in both studies the same morphological characteristics were evaluated, the push-out bond strengths found were diametrically opposed for the same self-adhesive resin cement. Consequently it is important to elucidate the fiber-post bond strength to root canal dentin related to different bonding techniques.

Current developments tend to adhesively restore the weakened endodontically treated teeth with fiber-post and composite core in a one-stage core-and-post procedure [25], whereas core build-up will immediately follow post cementation using the same composite material (core-and-post materials). Such a procedure could reduce the technique sensitivity, hazards of possible incompatibility of different composites (interface between cement and core material) and the time necessary to complete the core-and-post treatment procedure. Resin core composites have proper mechanical properties to ensure the stabilization of the remaining tooth structure and adequate crown retention. The filler content of these materials is higher compared to flowable resins since reducing of the filler volume result in lower hardness [26]. The increased mechanical properties could in turn negatively affect the luting ability. High shrinkage stress and increased microleakage formation was found for resin materials with high elastic modulus [27–29], indicating a significant correlation between filler content and contraction stress.

Currently, only little comparative data are available evaluating the push-out bond strength of core-and-post materials with corresponding etch-and-rinse adhesives and luting materials typically used for post cementation, based on a self-etch adhesive and self-adhesive bonding technique.

Hence, the aim of the present study was to test the working hypotheses that the push-out bond strength to root canal dentin depends on both the bonding technique and the composite resin used for fiber post cementation.

Materials and methods

Forty sound human maxillary central incisors were selected from a tooth bank. The teeth were stored in 0.5% chloramin solution for at least 1 year post-extraction. After removing all debris from the root surface with scaler and pumice the teeth were stored in distilled water at 7°C. The teeth were decapitated at the cement–enamel junction at the mesio-proximal level with diamond burs under continuous water cooling perpendicular to their long axis. According to the residual root length the teeth were randomly divided into five groups ($n = 8$). Instrumentation of the root canal was performed at a working length of -1 mm from the apical foramen by gradual circumferential filing to ISO size 60 (Antaeos-VDW, Munich, Germany) and intermitted rinsing with 1 ml of 1% sodium hypochlorite solution after each file change. Prior to post space preparation no further obturation was performed. The root canals were shaped with tapered low speed drills without water at 1800 rpm (ER System ISO 110, Komet, Gebr. Brasseler, Lemgo, Germany) to achieve a post length within the root canal of 12 mm. In all specimens glass-fiber reinforced composite posts, preconditioned with an adhesion promoting polymer coating (ER DentinPost Coated, Komet, Gebr. Brassler, Lemgo, Germany; LOT 505345), were used for post placement. The materials used for post placement were applied according to manufacturers' instructions:

Etch-and-rinse adhesive/core-and-post material

Group 1: DentinBond/DentinBuild (Komet, Gebr. Brasseler, Lemgo, Germany; LOT 168746/168644). The cavity walls were etched with 37% phosphoric acid for 20 s. The canal was rinsed with water for 20 s using an endodontic syringe and afterwards moderately dried with air and paper points, leaving the surface moist. Two consecutive coats of DentinBond Primer/adhesive were applied within 10 s by means of a single-use micro brush. Excessive material inside the post space was removed with absorbent paper points and gently air-dried and light cured (Translux PowerBlue, Heraeus Kulzer, Hanau, Germany) for 10 s, respectively. DentinBuild was applied to post and into the post space using the Minimix syringe provided by the manufacturer. The post was seated applying slight pressure and lightly rotation. Final light-curing was performed for 20 s.

Group 2: XP Bond + Self Cure Activator (SCA)/core-X flow (Dentsply, Konstanz, Germany; LOT 0811000869, 080726/0810002810). The cavity walls were etched for 15 s (DeTrey Conditioner 36, Dentsply DeTrey, Konstanz, Germany). After rinsing for 15 s the water was removed with a gentle air blast and paper points without complete desiccation. XP Bond with SCA in equal ratio were mixed for 5 s and applied using Root Canal Applicator Tips (Dentsply) for 20 s. Excess was removed with paper points and gently air-dried for 5 s. The post was brushed with XP Bond/SCA mixture and air-dried. After applying Core-X flow into the post space using root canal applicator tips the post was seated. Light curing was performed through the post for 20 s.

Self-adhesive resin cement

Group 3: RelyX Unicem (3M Espe, Seefeld, Germany; LOT 367488). The post spaces were rinsed with 1 ml of a 1% solution of sodium hypochlorite that followed, immediately rinsing with water and drying with paper points.

RelyX Unicem was applied into the root canal with RelyX Unicem Aplicap using Elongation Tips (3M Espe). The posts were seated and the material was light-cured for 40 s.

Group 4: SmartCem 2 (Dentsply, Konstanz, Germany; LOT 081126). Rinsing of the post space, material application and the post seating were similar to group 3. SmartCem 2 was applied into the roots with the help of a Mixing Tip. Light-curing was performed for 40 s.

Self-etch adhesive/adhesive luting agent

Group 5: ED Primer II/Panavia F 2.0 (Kuraray Europe, Frankfurt am Main, Germany; LOT 00273B, 00148A/00069B, 00386B). After water rinsing and removing of residual water with paper points fluid A and B of ED Primer II was mixed at a ratio of 1:1 for 10 s and applied to the root canal using a single-use microbrush for 30 s. Excess was removed using paper points and gently air-dried. Panavia F 2.0 paste A and B in an equal ratio was mixed for 20 s and applied onto the post. The posts were seated applying slight pressure and rotation. The composite resin was light-cured for 40 s.

Immediately after post placement the roots were embedded in acrylic resin (Technovit 4004, Kulzer, Wehrheim, Germany) parallel to the post axis to ensure that the sectional plane is perpendicular to the post axis. After the embedding procedure the push-out tests were performed within 48 h. Prior to sectioning of the roots into eight 1 mm thick serial slices (Isomet low speed saw, Buehler, Düsseldorf, Germany) the specimens were stored in distilled water at 37°C for at least 24 h (ISO/TS 11405:2003). No slice failed during the sectioning procedure.

Each slice originates from the portion of the root that contained the conical part of the post. The thickness of each slice was measured with a digital micrometer (Ø 2 mm, measuring accuracy 1 µm, Mahr, Göttingen, Germany) (Table I). The post diameter was measured from the coronal and apical portion of each slice using a calibrated measuring scale within the object lens of a stereomicroscope (Stemi SV11, Carl Zeiss Jena, Jena, Germany) at 50× magnification (Table I).

The push-out test was performed using a universal material testing machine (Zwick, Roell, Ulm, Germany). According to the diameter of the post at the apical aspect of the slices the steel punch pins (Ø 1.6 mm, 1.0 mm and 0.8 mm) with diameter smaller than the post diameter were used. The load was applied in an apical-coronal direction with a cross-head speed of 0.5 mm/min. Load application stopped automatically when a decrease of maximum loading force ($F_{\max}$) of 10% was measured. The load at debonding ($F_{\max}$) was recorded and the bond strength was calculated [MPa] for $F_{\max}$ [N] per bonded area (A [mm^2]). The area A resulted from the formula $A = \pi(R_1 + R_2)\sqrt{(R_1 - R_2)^2 + h^2}$, where R_1 represent the coronal and R_2 the apical arc radius of the post segment and h is the thickness of the slice.

After the push-out test, analysis of failure mode for each slice was conducted using a stereomicroscope (Stemi SV11, Carl Zeiss Jena, Jena, Germany) at 50× magnification. Failure modes were categorized into one of four predominant patterns:

(a) adhesive failure between dentin and luting agent,
(b) adhesive failure between luting agent and post,
(c) combined cohesive and adhesive failure and
(d) damage within the post.

Table I. Experimental groups with descriptive data; for failure mode accentuated data indicating standardized residuals >2.0.

Composite		Thickness (mm)	F_{max} (N)	Bonded area (mm^2)	Bond strength (MPa)	Failure mode (%)	Voids (%)
DentinBuild	*n*	64				92.2[a]	35.9
	median	0.956	34.25	4.844	6.66	6.3[b]	
	min	0.840	11.00	3.397	2.34	0[c]	
	max	1.060	143.90	6.187	24.89	1.6[d]	
Core-X flow	*n*	64				82.8[a]	6.3
	median	0.959	52.10	4.788	11.15	0[b]	
	min	0.869	19.50	3.646	5.23	10.9[c]	
	max	1.018	208.40	5.992	35.58	6.3[d]	
Unicem	*n*	63				74.6[a]	23.4
	median	0.957	54.70	4.550	12.35	17.5[b]	
	min	0.282	12.00	1.693	3.60	4.8[c]	
	max	1.019	166.80	6.148	32.44	3.2[d]	
SmartCem 2	*n*	64				71.9[a]	6.3
	median	0.960	65.00	4.940	13.52	12.5[b]	
	min	0.833	18.90	3.468	4.48	15.6[c]	
	max	1.030	177.00	6.203	30.69	0[d]	
PanaviaF 2.0	*n*	63				81[a]	14.1
	median	0.945	35.90	4.875	7.41	17.5[b]	
	min	0.806	1.00	3.536	0.28	0[c]	
	max	1.240	198.70	7.714	34.18	1.6[d]	

[a] adhesive failure between dentin and luting agent; [b] adhesive failure between luting agent and post; [c] combined cohesive and adhesive failure; [d] damage within the post, not shown.
voids: appearance of inhomogeneities (e.g. voids and bubbles).

Additionally, each slice was checked for the appearance of inhomogeneity (e.g. voids and bubbles).

The results were analyzed statistically using PASW Statistics 18 (SPSS inc., Chicago, IL). According to the Kolmogorov-Smirnov test push-out bond strengths values for each group were not normally distributed. Hence, the between-group differences and the differences between the coronal and apical part of the roots were calculated using the Kruskal-Wallis H-test and the Mann-Whitney U-test as post-hoc testing with a p-value of ≤ 0.05. The failure modes were analyzed using the Chi-square test. All test were two-sided at $\alpha = 5\%$.

Results

Table I shows the descriptive data for the thickness of the slices, the maximum load at de-bonding, calculated bonded area, push-out bond strength and the predominant failure modes. The comparison of median values of the push-out bond strengths between the groups revealed significant differences ($p < 0.001$; Kruskal-Wallis H-test).

The bond strength calculated for the self-adhesive groups SmartCem 2 (group 4) and RelyX Unicem (group 3) and for the etch-and-rinse material used in group 2 (XP Bond + SCA with core-X flow) were comparable and significantly higher ($p < 0.001$; Mann-Whitney U-test) than that for DentinBond with DentinBuild (group 1) and for the self-etch adhesive ED Primer II with Panavia F 2.0 (group 5) (Figure 1).

Similarly the bond strength differ significantly between the groups for coronal and apical roots segments ($p < 0.001$; Kruskal-Wallis H-test). However, significant differences between the coronal and apical portion within a group was only found in group 1 ($p = 0.015$; Mann-Whitney U-test), while the median bond strength was significantly lower in the apical (5.92 MPa) than the coronal portions of the roots (7.76 MPa).

Chi-square analysis revealed significant differences between the groups regarding the predominat failure mode ($p < 0.001$). The most frequent failure mode was adhesive failure between the luting agent and root dentin (Table I, Figure 2). Failure mode d (damage within the post) was observed at eight slices. The appearance of inhomogeneities (Figures 2–4) was significantly dependent on the luting agent used ($p < 0.001$; Chi-square test). In group 1 significantly more (standardized residuals >2.0) air bubbles and voids were noticed (36% of the slices, $n = 23$) than in the other groups.

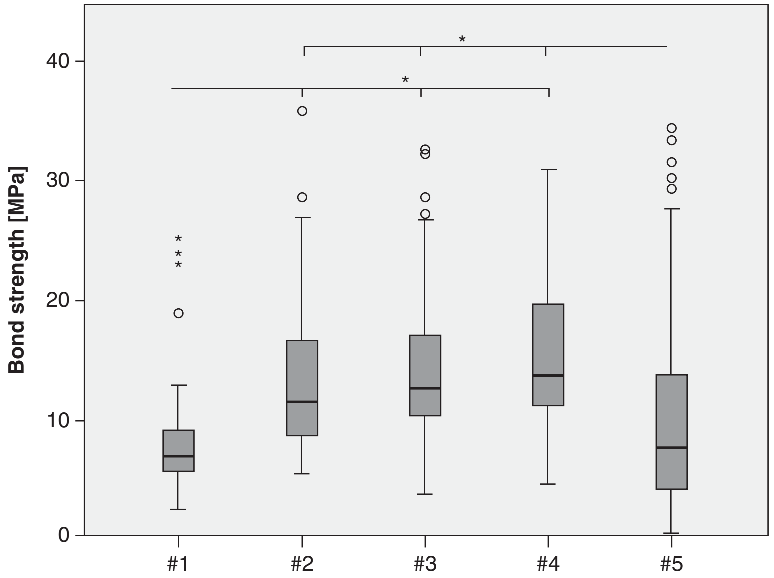

Figure 1. Box plots of groups, $*p < 0.001$; (I) DentinBuild; (II) Core-X flow; (III) RelyX Unicem; (IV) SmartCem 2; (V) Panavia F2.

Discussion

The push-out bond strengths of pre-coated glass-fiber-reinforced composite posts adhesively luted to root canal dentin were evaluated regarding three different bonding techniques. The calculated bond strength values were significantly affected by the luting material. The self-adhesive resin cements demonstrated significantly higher bond strength values compared to the self-etch adhesive and one material of the etch-and-rinse group. An adhesive failure between luting agent and root dentin was the most frequent failure mode. The appearance of inhomogeneities was significantly affected by the luting agent used.

Bond strengths of fiber posts to root canal dentin can be detected by various testing approaches, as for example micro tensile tests, pull-out and push-out tests [30,31]. The push-out test appears to be more efficient and dependable [32] and demonstrated a more homogenous stress distribution by finite-element analysis than the micro-tensile technique [31]. The thin-slice push-out test has been shown to be more reliable and easy to use. Moreover, regional differences of post adhesion inside the root canal, i.e. variations between cervical, middle and apical thirds of the root, can be evaluated [30].

Polymerization with light activation of dual-curing luting materials including RelyX Unicem resulted in higher bond strengths than without light polymerization [33]. The luting materials used in the present study were dual-curing and initially light-cured.

The results of the present study are corroborated by other investigators, who evaluated the bond strengths to root canal dentin using the push-out method and obtained significantly higher bond strength for the self-adhesive cement RelyX Unicem, compared to

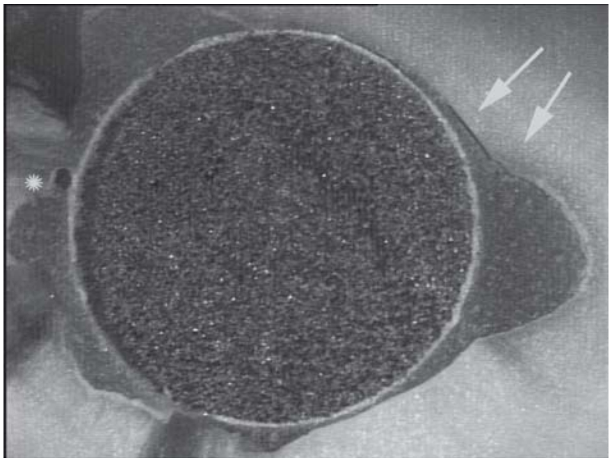

Figure 2. Group 1 coronal slice, arrows shows failure mode a, asterisk shows inhomogeneity.

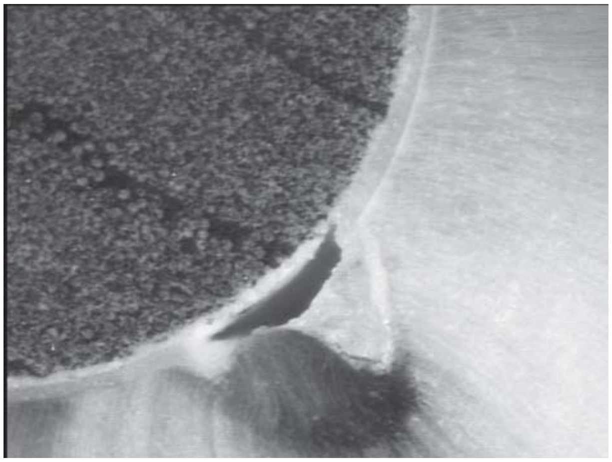

Figure 3. Group 1 coronal slice, show inhomogeneity, no luting material between polymer coating of the post and dentin.

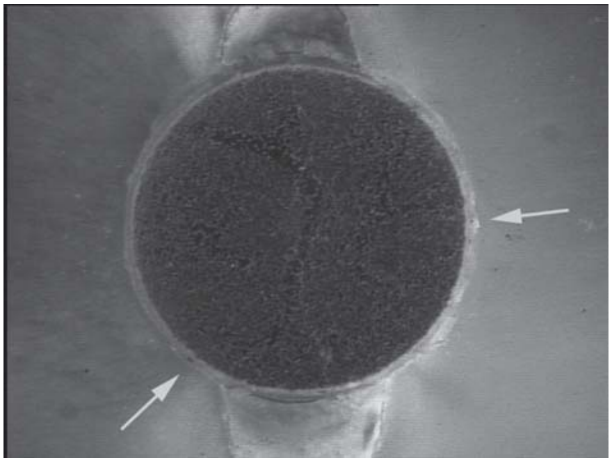

Figure 4. Group 3 coronal slice, arrows shows inhomogeneities within the luting material.

self-etch adhesives ED Primer/Panavia F or ED Primer II/Panavia F 2.0 [20,22,34]. In contrast, no significant differences [35,36] or significantly lower bond strengths of RelyX Unicem compared to ED Primer II/Panavia F 2.0 [37] were reported to coronal dentin using the micro-tensile bond strengths test. Higher seating force improves the bond strengths of both materials to coronal dentin [36,38]. Although the posts were seated within the root canal with slight finger pressure and slight rotation the bond strength for ED Primer II/Panavia F 2.0 was significantly lower, indicating that seating force seems to be of minor impact for bond strength to root canal dentin.

Morphological evaluations revealed that the adhesive mechanism to dentin formed by self-adhesive resin cements is mainly based upon micro-mechanical retention [22,39], physical adhesion, such as hydrogen bonding or dipole–dipole interactions [40] and strong chemical interaction with Ca ions derived from the hydroxyapatite [41]. The ability of the acidic monomers to demineralize dentin and dissolve the thick smear layer inside the root canal seems to be negligible [22] due to the rapid rise in pH through reactions between phosphoric acid groups and alkaline filler [42].

Bond strength measurements were performed within 24–48 h after post placement. For self-adhesive resin cements an increase in bond strength to root canal dentin after 24 h of water storage has been shown [43]. Similarly, after thermocycling (5000 cycles), Bitter et al. [34] found an increase of push-out bond strength for RelyX Unicem. Hygroscopic expansion could be an explanation for higher bond strength for self-adhesive resin cements, suggesting that frictional retention contributes to the interfacial strength inside the root canal. In contrast, long-term storage (12 months) in a chloramin solution as well as thermo-mechanical aging negatively affect the *in-vitro* performance of resin-based composites, including self-adhesive resin cements, used for the core-and-post treatment procedure [44]. In the present study, no aging or rather simulation of clinical function, i.e. thermocycling, cyclic mechanical loading or long-term storage of the specimens was realized. Thus, clinical recommendations with regard to the longevity of post-and-core restorations based on the present data are limited.

Self-etch adhesives include acidic monomer solutions either making the smear layer permeable to allow a formation of hybrid layer interface or hybridized smear layer. The penetrating ability of the dentin smear layer is dependent to smear layer thickness and aggressiveness of self-etch monomers [45]. When the self-etch monomer does not etch profoundly enough, the adhesive will be unable to establish a firm bond with the intact dentin. Accordingly, failure is likely to occur at the orifices of dentin tubules forming ‘smear plugs’, which inherent bonding to the intact dentin is very low [46]. Recently it was shown that filler debonding and subhybrid-layer failure in mild self-etch adhesives occurred after 6-month water storage and it was suggested that these failure modes could be attributed to insufficient encapsulation of the surface smear layer [47]. The system immanent self-etch adhesive to Panavia F 2.0, ED Primer II used in the present study is a mild [45] self-etch adhesive (initial pH 2.4, manufacturers’ information) including 10-methacryloyloxydecyl dihydrogenphosphat (10-MDP) as etching monomer. It could be speculated that the bond strength is affected by insufficient dissolution of the smear layer and represents the bonding of the smear debris to dentin. For ED Primer including 10-MDP considerably less resin tags formation and a smaller and less uniform hybrid layer was found compared to an etch-and-rinse approach [23]. Furthermore, it was speculated that one reason for these sub-hybrid-layer failures is incomplete infiltration of adhesive monomers into demineralized dentin, due to inhibited polymerization by residual water, leading to remaining unpolymerized acidic monomers that continue to etch dentin [48]. The limited access to the dentin surface within the root canal might hamper the well-directed air-drying. Therefore, the content of residual water inside the root canal is difficult to control compared to coronal dentin. Accordingly, complete evaporation of the solvent by air-drying is likely. A decrease of the adhesive layer, which has to be realized by air-drying, will promote solvent removal [49]. Remaining solvent in the adhesive inside the root canal may jeopardize polymerization due to dilution of monomers and may result in voids and hence in incomplete hybridization [50].

The reported bond strengths of etch-and-rinse adhesives to root canal dentin compared to self-etch adhesives and self-adhesive resin cements are inconsistent and seem to be dependent on the luting material used [18–21]. This is in accordance with the results of the present study since we found significant differences between both etch-and-rinse adhesives. Recently, Ferrari et al. [29] showed for adhesive post cementation that luting materials with higher filler content (max 70 w%) revealed increased polymerization stress compared to composites with lower filler content (max 50, 30 or 10 w%).The experimental resin materials with a higher filler content resulted in significantly decreased push-out bond strength and increased interfacial nanoleakage. Both resin luting materials used with etch-and-rinse adhesives in the present study are considered as core build-up materials. The filler content, i.e. filler weight and filler volume of Core-X flow (69 w% and 49 v%, manufacturer information) and DentinBuild (68 w% and 52 v%, manufacturer information) is comparable to other resin core composites [26]. However, the push-out bond strength of Core-X flow was significantly higher than for DentinBuild, indicating that filler content seems to be of minor impact with respect to bond strength performance inside the root canal for these two materials. To throw a glance at the inhomogeneities found in the cement layer significantly more inhomogeneities for the DentinBuild group were found and the homogeneous cement interface detected for Core-X flow correlated with significantly higher bond strength values compared to DentinBuild.

Recently, Watzke et al. [51,52] have demonstrated that the appearance of voids and bubbles within the cement interface of luted FRC posts depends on the application method used. For the self-adhesive resin cement (RelyX Unicem) they found significantly fewer inhomogeneities with the use of a flexible root canal shaped application aid. For both core-and-post materials in the present study, the endodontic application aids provided by the respective manufacturers were used. In contrast to that of Core-X flow the shape of the endodontic application aid of DentinBuild have a wider diameter. It was not possible to apply the material from the bottom of the post cavity to the cervical part. We analyzed only the existence of voids and bubbles and not the dimension or location within the cement layer. For RelyX Unicem 23% of the specimens demonstrated inhomogeneities, but voids and bubbles revealed minor dimensions compared to DentinBuild and were located within the cement layer (Figure 4). The cement interface of DentinBuild shows comparatively major voids and bubbles mostly at the cement/dentin interface. Due to these imperfections the bonded area decreased and as a result the ability of the luting material to sufficiently adhere to the root canal dentin is reduced. Thus, further investigations are needed to evaluate the correlation between inhomogeneities within the dentin–cement interface of adhesively luted posts within the root canal and bond strength values.

The present study revealed that several aspects such as penetrating ability of the resin components related to the filler content, the correlation of post space irrigation/cleaning methods and different adhesive approaches have to be elucidated in more detail.

Conclusion

The bond strength of fiber posts adhesively luted to root canal dentin is significantly higher when self-adhesive luting cements were used. With one of the tested core-and-post materials/etch-and-rinse adhesives comparable bond strength values were feasible. The use of the investigated self-etch adhesive system offered less bond strength within the root canal. Bond strength inside the root canal seemed to be more dependent on the applied luting agents than on the adhesive approach applied.

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