DOI: 10.1111/jopr.12271

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Influence of Cement Type and Relining Procedure on Push-Out Bond Strength of Fiber Posts after Cyclic Loading

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Keywords
Bond strength; cyclic loading; fiber post; resin cement; root canal.

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Financial support from FAPERGS Foundation-Brazil through grant 2012/082012–7.

The authors deny any financial affiliations related to this study or its sponsors.

The authors deny any conflicts of interest.

Accepted July 30, 2014

doi: 10.1111/jopr.12271

Abstract

Purpose: The aim of this study was to evaluate the influence of cement type and relining procedure on push-out bond strength of fiber posts (FPs) after cyclic loading.
Materials and Methods: Forty bovine incisor roots were divided into four groups: group 1, FP luting with RelyX Unicem; group 2, FP relined with resin composite (FPC) luting with RelyX Unicem; group 3, FP luting with RelyX ARC; group 4, FPC luting with RelyX ARC. Afterwards, half the specimens were exposed to 250,000 cycles in a controlled chewing simulator. With the other half of the specimens in each group, the push-out test was performed 24 hours after FP luting (immediate groups). All roots were sectioned transversely, producing 1-mm-thick slices, and the push-out test was performed. Statistical analysis was performed using ANOVA and the Tukey test for post hoc comparisons ($\alpha = 0.05$).
Results: FPC had higher bond strengths than FP ($p < 0.05$). RelyX Unicem showed higher bond strength than RelyX ARC ($p < 0.05$). Cyclic loading did not significantly affect the bond strength value ($p > 0.05$).
Conclusion: The relining procedure and the cement type are important factors for the bond strength of FPs to root dentin.

Fiber posts (FPs) are frequently used to contribute to the support and retention of coronal restorations and crowns, and are considered a practical and economical option for restoring endodontically treated teeth suffering from large hard tissue loss.[1] However, the cement thickness can vary widely because of the mentioned morphological differences along the root canal[2] and increased structural damage caused by endodontic instrumentation. Therefore, the use of a FP relined with resin composite has been proposed to create individualized intraradicular posts with a better adaptation to the root canal.[3,4]

Various luting agents and accompanied adhesives that either follow a self-etch or etch-and-rinse approach can be used to bond FPs into root canals. In addition to conventional cements, self-adhesive resin cements have also been proposed for adhesive cementation of posts and indirect restorations.[5,6] These materials are expected to overcome the problems of the technique-sensitive application of multistep cements and adhesive bonding agents. This is a matter of great importance in a confined space like the root canal, where limited control of moisture and the absence of direct field of vision impede the various procedures, and make bonding to root canal dentin unpredictable.[6]

Optimizing bond strength between cement and dentin is of crucial importance. The inadequate bond strength of cements used for luting root canal posts can lead to failure of the restoration and an increased possibility of subsequent microleakage and failure of the endodontic treatment.[7] Therefore, the aim of this study was to evaluate the influence of cement type and relining procedure on push-out bond strength of FPs after cyclic loading. The hypotheses were that: (1) FPs relined with resin composite show higher bond strength than FPs that

Table 1 Resin cements used and application protocols

Cement	Classification	Application protocol
RelyX Unicem	Self-adhesive resin cement	The internal root dentin was washed only with distilled water and dried with paper points. The dual-polymerizing resin luting material RelyX Unicem (3M ESPE) was mixed and injected into the root canal with an appropriate Centrix syringe (20 G) (DFL, Rio de Janeiro, Brazil). Subsequently, the FP or FPC was covered with cement, seated inside the root canal, and kept under finger pressure for 20 seconds; the excess cement was then removed. The cement was light-polymerized for 30 seconds on each surface (i.e., buccal, palatal, mesial, and distal), resulting in a 2-min light polymerization cycle using a halogen light-polymerizing unit (Radii device; SDI, São Paulo, Brazil) with 450 mW/cm^2 light intensity.
RelyX ARC	Resin cement	The canal walls were etched with 37% phosphoric acid for 30 seconds, washed with distilled water for 1 min, and dried with absorbent paper points. Next, two layers of primer (Adper Scotchbond Multi-Purpose) were applied with a microbrush (KG Sorensen) and after 20 seconds, the excess primer was removed with absorbent paper points. A single layer of bonding agent (Adper Scotchbond Multi-Purpose) was applied with a microbrush, excess adhesive was removed with absorbent paper points, and the layer was light-activated for 40 seconds. Subsequently, the FP or FPC was cemented into the root canal similarly to the above group.

Table 2 Three-way ANOVA results of push-out bond strength test

Source of variation	Type III sum of squares	DF	Mean square	*F*	*p*
Corrected model	840.299[a]	7	120.043	105.919	<0.0001
Intercept	3167.031	1	3167.031	2794.420	<0.0001
Post	244.319	1	244.319	215.574	<0.0001
Luting	592.550	1	592.550	522.834	<0.0001
Loading	0.063	1	0.063	0.056	0.814
Post × Luting	0.101	1	0.101	0.089	0.765
Post × Loading	1.111	1	1.111	0.980	0.323
Luting × Loading	0.040	1	0.040	0.035	0.852
Post × Luting × Loading	2.115	1	2.115	1.866	0.173
Error	262.935	232	1.133		
Total	4270.266	240			
Corrected total	1103.234	239			

DF, degrees of freedom; *F*, *F*-test statistic; *p*, probability.
[a]$R^2 = 0.762$ (Adjusted $R^2 = 0.754$).

are not relined and (2) cements tested herein present similar bond strength.

Materials and methods

Specimen preparation

Methods were similar to those in a previously reported study.[8] Forty freshly extracted bovine incisors with anatomically similar root segments and fully developed apices were selected. Each tooth was decoronated below the cementoenamel junction perpendicular to the longitudinal axis using a slow-speed water-cooled diamond disc (Isomet 2000; Buehler Ltd., Lake Bluff, IL). The roots were cut to a uniform length of 14 mm from the apical end. The apices of the teeth were sealed with a temporary filling material.

All root canals were prepared by one trained operator. Pulp tissue and the predentin were removed, and the root canals were enlarged using #6 Largo burs (Maillefer, Ballaigues, Switzerland) and a #130 file (Maillefer) in all roots. All the roots presented the same inside size diameter. The apical end (1 mm) was left unprepared to prevent the apical extrusion of solutions and luting cement. Roots were rinsed with 5 mL of physiological saline solution (0.9% NaCl) to remove remaining debris and then randomly divided into four groups according to post system and luting cement (n = 10): group 1, FP luting with RelyX Unicem; group 2, FP relined with resin composite (FPC) luting with RelyX Unicem; group 3, FP luting with RelyX ARC; and group 4, FPC luting with RelyX ARC.

The prepared root canals received either relined or nonrelined FPs; a 1.5-mm diameter glass fiber-reinforced epoxy post system (Reforpost; Angelus, Londrina, Brazil) was used. The fiberglass posts were cleaned with ethanol, and immediately after applying the adhesive system (Adper Scotchbond Multi-Purpose; 3M ESPE, St Paul, MN) to the post, it was light polymerized for 20 seconds on each side (FP groups). For the relining procedure, the FP was treated as previously described.

Table 3 Mean bond strength (in MPa) and the respective standard deviations (±) obtained in each experimental condition

Cyclic loading	Post	Resin cement	
		RelyX Unicem	RelyX ARC
Immediate group (no cyclic loading)	FP	4.08 (0.98)^{aB}	1.06 (0.92)^{bB}
	FPC	6.38 (1.23)^{aA}	3.07 (1.01)^{bA}
Cyclic loading	FP	4.35 (1.28)^{aB}	1.00 (0.75)^{bB}
	FPC	6.00 (1.03)^{aA}	3.11 (1.21)^{bA}

FP, fiber post; FPC, fiber post relined with resin composite. Means followed by different lowercase letters in the same row and uppercase letters in the same column are significantly different ($p < 0.05$). There is no significant difference between immediate group and cyclic loading ($p = 0.814$).

Afterwards, the canal walls were lubricated with a hydrosoluble gel; the FP was covered with resin composite Z250 (B0.5; 3M ESPE) and inserted into the canal. After the removal of excess resin, the tip of the light-curing unit was placed over the post, and the device was activated for 20 seconds. After composite resin polymerization, the post was clamped with needlenose pliers and removed from the canal. The completion of the polymerization of the FPC was performed outside the root canal for 40 seconds. Copious rinsing removed the lubricant gel from the root canal. The cements used for luting and the details of the luting procedures are described in Table 1.

For half the specimens in each group, the push-out test was performed 24 hours after FP luting (immediate groups). The other half was subjected to cyclic loading after crown preparation.

Crown preparation and cyclic loading

To restore the coronal portion, the incremental technique was used to place composite resin Z250 around the posts to make filling cores. To standardize the size of the cores, an acetate matrix was used to position the last layers. The matrix was made in a vacuum plasticizer from a core model 7 mm high and 4 mm in diameter. All specimens were finished with a diamond bur (No. 3216; KG Sorensen, Barueri, Brazil) mounted on a high-speed handpiece with water spray. Specimens were prepared to receive complete crowns with a reduction of 1.5 mm and ferrule of 2.0 mm. Standardized crowns were obtained for all teeth and cemented with RelyX ARC. Rectangular stops with a central concavity were made on the palatine face of the patterns to locate and stabilize the metal tip during cyclic loading.

The teeth were embedded in epoxy resin (Araldite, Araltec Chemicals Ltda. Hunstman, Guarulhos, Brazil) and condensation silicone to simulate the artificial periodontal ligament, up to 2 mm short of the cervical portion, using a circular metal matrix (25 mm in diameter × 20 mm high). The set (tooth, matrix, and resin) remained immobile for 72 hours to ensure resin setting. All specimens were immersed in artificial saliva and exposed to 250,000 cycles of mechanical fatigue in a controlled chewing simulator (ER 11000 Plus; Erios, São Paulo, Brazil) at 37°C. The force was applied 3 mm below the incisal edge on the palatal surface of the crowns at a frequency of 2.6 Hz. A 30 N force was chosen. The mechanical loading pattern was equivalent to 1 year of clinical function.[9] The 30 N force mimicked previously measured occlusal forces that occur during mastication and swallowing with restored dentitions.[10]

Push-out test: specimen preparation, post dislodgment, and failure pattern analysis

Each root was cut horizontally with a slow-speed water-cooled diamond saw (Isomet 2000) to produce two slices of approximately 1 mm thickness. Seven slices were obtained from each root canal. The first slice was excluded. Thus, six slices were considered from each root canal (five teeth – six slices for root = 30 slices for each group).

The push-out test was performed by applying a 0.5 mm/min load at the apex in the direction of the crown until the FP relined segment was dislodged from the root slice. Care was also taken to ensure that the contact between the punch tip and the FP section occurred over the most extended area possible to avoid the notching effect of the punch tip on the FP's surface.

To express the bond strength in MPa, the load at failure recorded in Newtons was divided by the area (mm^2) of the post/dentin interface. The formula $\pi(R+r)[(h^2+(R–r)^2]^{0.5}$ was used to calculate the bonding area, where R represents the coronal root canal radius, r the apical root canal radius, and h the slice thickness. The thickness of each slice was measured using a digital caliper (Vonder, Curitiba, Brazil), and the total bonding area for each root canal segment was measured under 20× magnification with a stereoscope (Lambda Let 2, ATTO Instruments Co., Hong Kong, China) and the ImageLab 2.3 software (University of São Paulo, São Paulo, Brazil). This same software was used to analyze the fracture mode. Thus, the fractured specimens were observed from the cervical direction and the apical direction to classify the failure pattern into five types:[8] (1) adhesive between the FP and resin cement (no cement visible around the post); (2) mixed, with resin cement covering 0% to 50% of the post's diameter; (3) mixed, with resin cement covering 50% to 100% of the post's surface; (4) adhesive between resin cement and root canal (post enveloped by resin cement); and (5) cohesive in dentin.

The bond strength of 30 slices in each group was averaged. Bond strength data were analyzed using three-way ANOVA to examine the effects of the post system, luting system, and cyclic loading. Post hoc multiple comparison was achieved using the Tukey honestly significant difference (HSD) test, with the significance level set at $\alpha = 0.05$.

Scanning electron microscopy (SEM) analysis

One root of each group was prepared and analyzed by SEM. The specimens were sputter-coated with gold in a Denton Vacuum Desk II Sputtering device (Denton Vacuum, Cherry Hill, NJ) and observed by SEM (JSM-5600LV, JEOL Ltd., Tokyo, Japan). Thus, the interfacial micromorphology was also observed.

Results

The results of the 3-way ANOVA of push-out data are listed in Table 2. No significant interaction occurred between the three factors in this study ($p = 0.173$). Statistical analysis indicated that the type of resin cement and the post significantly affected

Table 4 Failure mode distribution in the experimental groups

Group	RelyX Unicem										RelyX ARC									
	Static loading					Dynamic loading					Static loading					Dynamic loading				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
FP	-	9	8	12	1	2	6	8	13	1	-	-	13	17	-	1	1	6	22	-
FPC	3	7	12	6	2	-	4	13	12	1	-	1	4	25	-	-	-	8	20	2

FP, fiber post; FPC, fiber post relined with resin composite.

Failure Mode: 1, adhesive between the FP and resin cement; 2, mixed, with resin cement covering 0% to 50% of the post's diameter; 3, mixed, with resin cement covering 50% to 100% of the post's surface; 4, adhesive between resin cement and root canal; and 5, cohesive in dentin.

the bond strength values ($p < 0.05$); however, there was no significant difference between immediate group and after cyclic loading ($p = 0.814$).

The means and standard deviations are presented in Table 3. The post hoc Tukey test revealed that the FPC had higher bond strengths than FP ($p < 0.05$). RelyX Unicem showed higher bond strength than RelyX ARC ($p < 0.05$). Cyclic loading did not significantly affect the bond strength value ($p > 0.05$).

Table 4 shows the failure modes observed in each group. The mixed failure types 2 and 3 were predominant with RelyX Unicem; while RelyX ARC showed a predominance of adhesive between the resin cement and root canal (type 4). FPC/RelyX Unicem showed a predominance of mixed failure types 2 and 3; and FP showed mainly adhesive failure between the resin cement and root canal (type 4).

On the basis of SEM analysis, a small thickness of the luting cement was observed with post relining. On the other hand, in the groups without post relining, a large thickness of the luting cement and bubbles in the luting cement were observed (Fig 1).

Discussion

In this study, root canal instrumentation was performed with sodium chloride because the aim was not to evaluate the influence of the pretreatment of root dentin with chemical solutions. Previous studies evaluated the influence of auxiliary chemical substances and root canal sealers.[11,12]

For a long time, cast metal post and core systems have been used for intraradicular retention, but they have disadvantages, such as a high modulus of elasticity, increasing the possibility of irrecoverable fractures of the remaining tooth structure.[13-16] FPs have widely been used to restore endodontically treated teeth with a severe loss of dental structure to improve the retention of the build-up material, as an alternative to cast metal post and core systems.[1-3,17] According to Zicari et al,[18] current FPs are "composed of unidirectional fibers (carbon, quartz, or glass) embedded in a resin matrix.[19] Fibers are responsible for resistance against flexure, while the resin matrix provides resistance against compression stress and may interact with functional monomers contained in the adhesive cements.[18,20] Because their elastic modulus is similar to that of dentin, they distribute stresses along the post/cement/dentin interface and to the remaining tooth structure more uniformly, thus avoiding stress concentration and minimizing the risk of vertical root fractures."[15-19,21]

In this study, FP relined with resin composite presented higher push-out bond strength values than fiberglass posts to root dentin. Therefore, the first hypothesis was supported by the results; the relining procedure influenced the bond strength of FP. Customizing the post increases its adaptation to the root walls and reduces the thickness of the resin cement[3] (Fig 1). Closer contact between cement and dentin is also important to improve frictional retention of the post.[22] Frictional retention is directly proportional to the contact area (the larger the contact surfaces, the better the retention).[3] In addition, a higher post-to-root canal adaptation increases the sustained pressure during cementation. The application of sustained pressure results in better contact between the cement/post assembly and the dentin and reduces blister formation in the cement.[23] This may help explain the high values of bond strength in groups where the relining procedure was performed. According to Macedo et al[3] it seems that the relining procedure increases FP retention by improving the contact between the cement and the adhesive rather than by reducing the defects observed in thin cement layers. Furthermore, Barcellos et al[16] showed that the roots restored with FPC had higher fracture resistance than FP and cast post and core. Another factor that these authors observed was that the FPs resulted in an increased number of reparable failures while the cast post and core resulted in an increased number of irreparable failures.

The nonrelined fiberglass posts showed the lowest bond strength values to root dentin. This is probably due to the mismatch between the diameters of the post space and the FP remains (Fig 1). Prefabricated posts do not fit well into elliptical canals or flared canals that result from carious extension, trauma, pulpal pathosis, or iatrogenic misadventure.[24] In such cases, if the post does not fit the canal well, the layer of resin cement might be excessively thick, favoring the formation of air bubbles and predisposing the post to debonding.[4] Blisters can act as flaw-initiating sites during testing, interfering with the fracture strength. The increase of resin cement thickness may also increase the polymerization stress because of the stress development increases associated with an increased volume of resin cement.[25,26] One solution for this issue is to reline the FP with resin composite, as demonstrated in this study.

In the present study, it was shown that the factor *resin cement* significantly affected the push-out bond strengths of the used posts. Therefore, the second hypothesis was rejected by the results. The bond strength value for the self-etch cement RelyX Unicem was higher than that of conventional

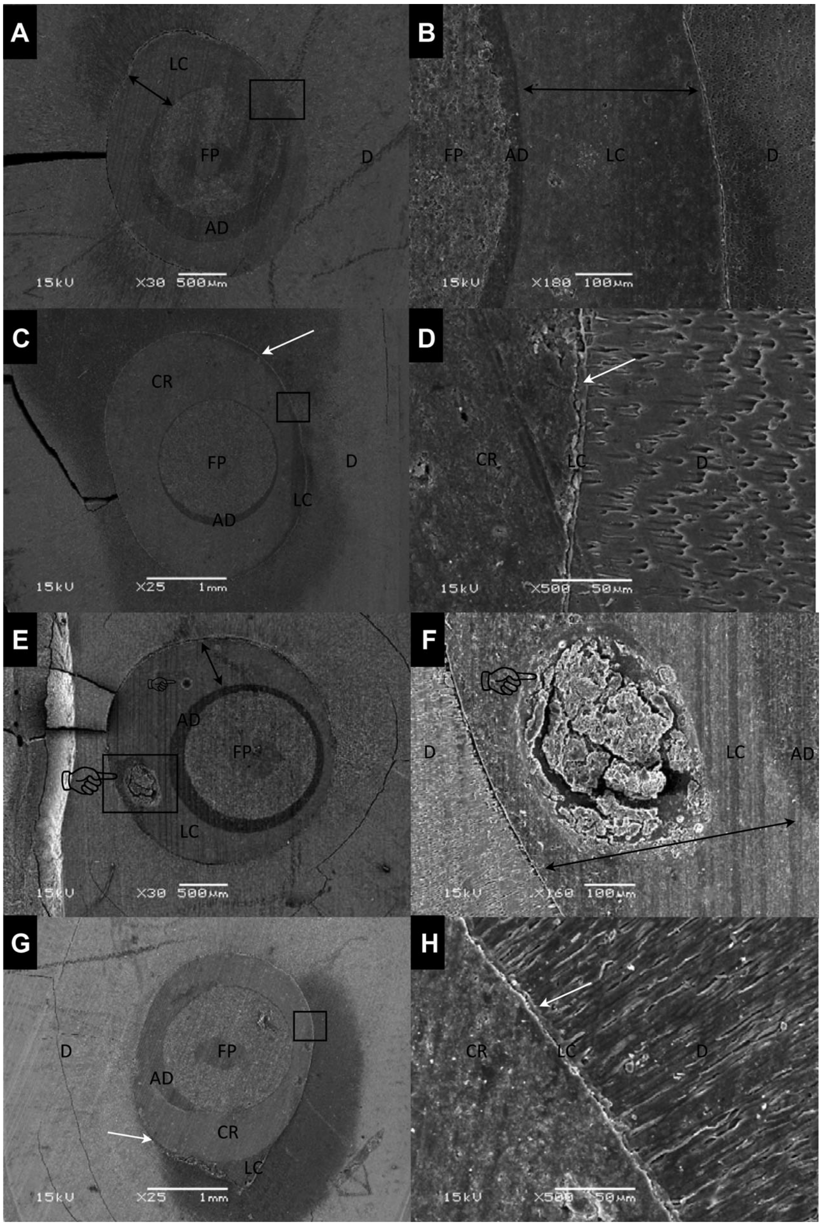

Figure 1 Representative SEM micrographs of the experimental groups before the push-out test. A and B, fiber post luting with RelyX Unicem; C and D, fiber post relined with resin composite luting with RelyX Unicem; E and F, fiber post luting with RelyX ARC; and G and H, fiber post relined with resin composite luting with RelyX ARC. In magnification of the black square, A, B, E, and F show a large thickness of the luting cement (black arrow); moreover, C, D, G, and H show a small thickness of the luting cement (white arrow). FP, fiber post; AD, adhesive system; LC, luting cement; CR, composite resin; D, dentin; Pointer, bubbles in luting cement.

RelyX ARC. RelyX Unicem is composed of bifunctional methacrylate groups, whose acid nature allows for tooth demineralization and posterior infiltration by means of the adhesive system, resulting in micromechanical retention.[27] This luting material consists of methacrylate monomers with bonded phosphoric acid groups and at least two unsaturated C═C double bonds. Therefore, the bond to the tooth structure is based on the principle that monomers react with basic salts and hydroxyapatite in the tooth structure.[28] For the RelyX Unicem cement, bonding releases free radicals, which can be initiated by exposure to light or by using mechanisms of oxidation-reduction, which characterize the three aspects of cement polymerization: acid/base reaction, curing, and polymerization in the absence of light. These characteristics allow polymerization of the cement throughout the length of the root canal.[29] Furthermore, self-adhesive resin cements appear to have low shrinkage because of their viscoelastic properties, leading to superior intimate contact of the resin cement with the root canal walls and, thereby higher frictional resistance.[30]

The bond strength values obtained for the RelyX ARC groups were lower than the self-adhesive cement. Possible reasons could be that RelyX ARC's high polymerization shrinkage and the resulting stress could impair the bonding to the root dentin.[31] This increases the dependency on mechanical properties of the cement for improving post retention. Despite being a dual-cured material, deeper portions of cement are inaccessible to light, rendering the material dependent on chemical curing. This can reduce the degree of conversion of the cement and consequently affect its mechanical properties.[32] In addition to the abovementioned factors, it has been recently reported that when two-step adhesive systems are used, it is possible to observe that the smear layer is still attached to dentin substrate (after etching) and water drops on the adhesive surface.[33] Self-etching cements make the bonding procedure more user-friendly, eliminating the risk of overetching and overdrying. The use of adhesive system and resin cement is more technique-sensitive than self-etching cements, with proper adjustment of the post to dentin being difficult. Therefore, such negative factors may have contributed to the gap formation at the cement/dentin interface.

Regarding the fracture analysis, it should be emphasized that the predominant type of failure with the use of FP and RelyX ARC was adhesive, implying that the weak link was the bond between the resin cement and root canal dentin. The quality of the bond with the use of FPC and RelyX Unicem seemed to be superior because the predominant type of failure was mixed. This suggests that the bond between the resin cement and root canal dentin was less affected than in the groups with FP and RelyX ARC (Table 3). Based on these findings, the push-out test showed higher values when self-etch resin cement and FPC were used.

Conclusion

The relining procedure and the cement type are important factors for the bond strength of FPs to root dentin.

Acknowledgments

The authors would like to thank Angelus for their donation of fiber posts.

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