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Better Glass-fiber Post Preservation in Teeth with Ferrule When Subjected to Chewing

CP Gré • DP Lise • RQ Ramos • B Van Meerbeck • LCC Vieira • GC Lopes

Clinical Relevance

A 2.0-mm remaining dentin ferrule in root-canal–treated premolars helps to hold adhesively luted glass-fiber posts in place underneath crowns exposed to chewing.

SUMMARY

Objectives: To evaluate the influence of ferrule effect and mechanical fatigue aging on glass-fiber post push-out bond strength (PBS) to root-canal dentin at different root thirds of premolars.

Methods and Materials: Thirty-two sound maxillary premolar teeth were collected, and randomly assigned to two experimental groups (n=16): 'Remaining Dentin Ferrule' (RDF) = coronal crown cut 2.0 mm above the cemento-enamel junction (CEJ); 'Without Dentin Ferrule' (WDF) = coronal crown cut at the cemento-enamel junction. Teeth were endodontically treated, post spaces were prepared up to 10.0-mm depth from CEJ, and glass-fiber posts were cemented using a dual-cure self-adhesive composite cement. Standardized cores were built using a light-cure composite, upon which tooth cores were prepared using a 1.5-mm taper ogival-end diamond bur. Crowns were handmade using self-cure acrylic resin and cemented using the aforementioned composite cement. Half of the specimens were subjected to 1,200,000 cycles of mechanical fatigue in a chewing simulator (F = 'Fatigue'), while the other half were stored in distilled water at 37°C

Cristina Parise Gré, DDS, MS, PhD, GC Europe NV Leuven, Belgium

Diogo Pedrollo Lise, DDS, MS, PhD, Department of Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, SC, Brazil

Renato Quirino Ramos, DDS, MS, Department of Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, SC, Brazil

Bart Van Meerbeek, DDS, MS, PhD, KU Leuven (University of Leuven), Department of Oral Health Sciences, BIOMAT & UZ Leuven (University Hospitals Leuven), Dentistry, Leuven, Belgium

Luiz Clovis Cardoso Vieira *In Memoriam*, DDS, MS, PhD, Department of Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, SC, Brazil

*Guilherme Carpena Lopes, DDS, MS, PhD, Department of Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, SC, Brazil

*Corresponding author: Rua Delfino Conti, 1240, Campus Trindade, Florianópolis, Santa Catarina, Brazil 88036-020; e-mail: guilherme.lopes@ufsc.br

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for 1 week (C = 'Control'). All specimens were horizontally sectioned into 1.0-mm thick slices prior to PBS test; the failure modes were assessed using stereomicroscopy and scanning electron microscopy (SEM). Data were analyzed for each root third using two-way analysis of variance (ANOVA) followed by Tukey HSD post-hoc test; frequency distribution was compared by Chi-square test (α=0.05) and post-hoc comparisons with Bonferroni.

Results: The mean PBS in MPa (SD) were = RDF_F = 10.4 (2.9); WDF_F = 6.9 (1.7); RDF_C = 14.5 (2.7); WDF_C = 14.2 (2.9). Similar PBS were found for the root thirds. For all root thirds, significant differences were found for both the factors Dentin Ferrule and Fatigue, and their interaction ($p<0.05$). The lowest PBS was found for specimens without dentin ferrule subjected to chewing fatigue ($p<0.001$). Most failures occurred at the composite cement/dentin interface, followed by mixed and composite cement/glass-fiber post interfacial failures. There was a significant increase in mixed failures for the WDF_F group ($p<0.001$).

Conclusion: Absence of 2.0-mm remaining dentin ferrule in premolars resulted in a higher decrease of the glass-fiber posts' PBS to dentin after mechanical fatigue, irrespective of root third.

INTRODUCTION

Clinicians routinely use intra-radicular posts to ensure retention of prosthetic crowns when restoring root-canal treated teeth with severe loss of coronal structure.[1-3] Prefabricated glass-fiber posts are intra-radicular posts that became popular among dentists during the last years because their placement requires a relatively short time without any dental lab involvement.[4-6] Cast metal posts may cause staining of the surrounding dentin due to metal corrosion. Even prefabricated stainless steel metallic posts are still unaesthetic compared to tooth-colored glass-fiber posts that enable placement of more translucent restorative materials with a better esthetic outcome.[7,8] Furthermore, the Young's Modulus (E) of glass-fiber posts is similar to that of dentin, which results in a more uniform stress distribution through the remaining tooth structure, along with a lower incidence of root fractures.[4,9,10] However, the excessive stress and strain accumulation at the adhesive interface may contribute to the clinical complication most frequently reported in literature, namely glass-fiber post de-bonding.[4,11-13]

Considering other factors that might have an influence on the long-term survival of post-and-crown restorations, a recent systematic review[14] concluded that posts with high E have better performance when there is no ferrule, as compared to posts with E similar to that of dentin. Thus, the traditional cast metal posts are still indicated in the absence of a ferrule.[14,15] Several finite element analysis (FEA) studies have also suggested that the presence of the so-called ferrule effect may change the distribution of occlusal stress and decrease its accumulation along the adhesive interface.[6,16-20] Among the limited number of long-term clinical trials published on glass-fiber posts, a 6-year follow-up conducted by Ferrari and others[21] reported a lower success rate (39%) for premolars restored with post-and-crown restorations without dentin ferrule. However, the number of glass-fiber posts debonding was exactly the same for both groups with and without dentin ferrule; the difference between success rates was hence related to other failures such as post/core fractures or endodontic failures. Laboratory studies reported immediate bond strength of different post-and-core systems luted using dual-cure composite cements to root-canal dentin.[22,23] However, damage associated with stress caused by occlusion and cyclic chewing in a clinical situation is often not simulated in laboratory studies.[24] Nevertheless, it is not (yet) clear whether absence of remaining dentin ferrule helps to maintain the dentin bond strength of glass-fiber posts cemented with self-adhesive composite cement in premolars restored with post-and-crown restorations that are exposed to a mechanical aging protocol. Thus, the aim of this *in vitro* study was to evaluate the influence of remaining dentin ferrule and mechanical fatigue aging on the glass-fiber post push-out bond strength (PBS) to root-canal dentin at different root thirds of premolars. The null hypotheses tested were that (1) absence of ferrule and (2) mechanical fatigue aging do not have a negative influence on fiber-post PBS to root dentin.

METHODS AND MATERIALS

Sound maxillary premolars extracted for orthodontic reasons were collected from donors. Thirty-two teeth having similar mesiodistal and buccolingual dimensions at the cemento-enamel junction (CEJ) and a root length of 15±1.0 mm were selected, cleaned with a hand scaler, examined for possible defects or cracks, and stored in 0.5% chloramine at 4°C. Teeth were used up to 3 months after extraction. They were embedded in self-cure acrylic resin (JET, Clássico, São Paulo, SP, Brazil) 2.0 mm apically to the CEJ. Impressions of teeth crowns were taken using polyvinyl siloxane impression material (Express XT, 3M Oral Care, St. Paul, MN, USA) to further use the molds for subsequent provisional crown fabrication.

The experimental procedure is schematically illustrated in Figure 1. Half of the selected teeth had their coronal structure cut 2.0 mm above the CEJ to preserve a remaining dentin ferrule (RDF = Remaining Dentin Ferrule), while the other half were cut at the CEJ to not preserve a dentin ferrule (WDF = Without Dentin Ferrule); for the WDF, a double-faced diamond disk coupled to a precision-cutting machine (Isomet 1000, Buehler, Lake Bluff, IL, USA) was used under constant water cooling. Afterwards, teeth were endodontically treated by a single operator following the step-back technique. Each root canal was prepared up to size #30 (K-File, Dentsply Sirona, Ballaigues, Switzerland) at 1.0 mm from the apex. Preceding the use of each instrument, the root canal was irrigated with 2.5% sodium hypochlorite, upon which the root canal was dried with absorbent paper points. Root canals were obturated using the gutta-percha lateral condensation technique with an epoxy resin-based root-canal sealer (Top Seal, Dentsply Sirona). Coronal access was temporarily filled with a glass-ionomer filling material (Maxxion R, FGM, Joinville, SC, Brazil).

After storage in distilled water at 37°C for 24 hours, post spaces of 12.0-mm length were prepared for the RDF specimens versus the 10.0-mm length for the WDF specimens; this was done using a Gates-Glidden drill (Dentsply Sirona) followed by a standardized low-speed drill of the glass-fiber post system (Exacto, Angelus, Londrina, PR, Brazil). Translucent double taper glass-fiber posts (Exacto #1, Angelus) with 1.4-mm coronal diameter and 0.7-mm apical diameter were positioned in the post spaces and cut at 4.0 mm above the CEJ. The glass-fiber posts were removed from the root canals and cleaned with 96% ethanol. A silane primer (Silano, Angelus) was applied, left on the surface for 60 seconds, and dried with compressed air for 15 seconds. Post spaces were rinsed with distilled water and dried with absorbent paper points. A dual-cure self-adhesive composite cement (RelyX Unicem 2, 3M Oral Care) was handled following manufacturer's instructions, inserted into a nozzle needle tip (AccuDose 20ga NeedleTubes, Centrix, Shelton, CT, USA), and applied into the prepared post space. Glass-fiber posts were inserted into the post spaces and held in position under a constant weight of 1.0 kilograms, upon which the cement was light-cured for 40 seconds using a light-emitting diode light-curing unit (Bluephase 20i, Ivoclar Vivadent, Schaan, Liechtenstein) with an output of

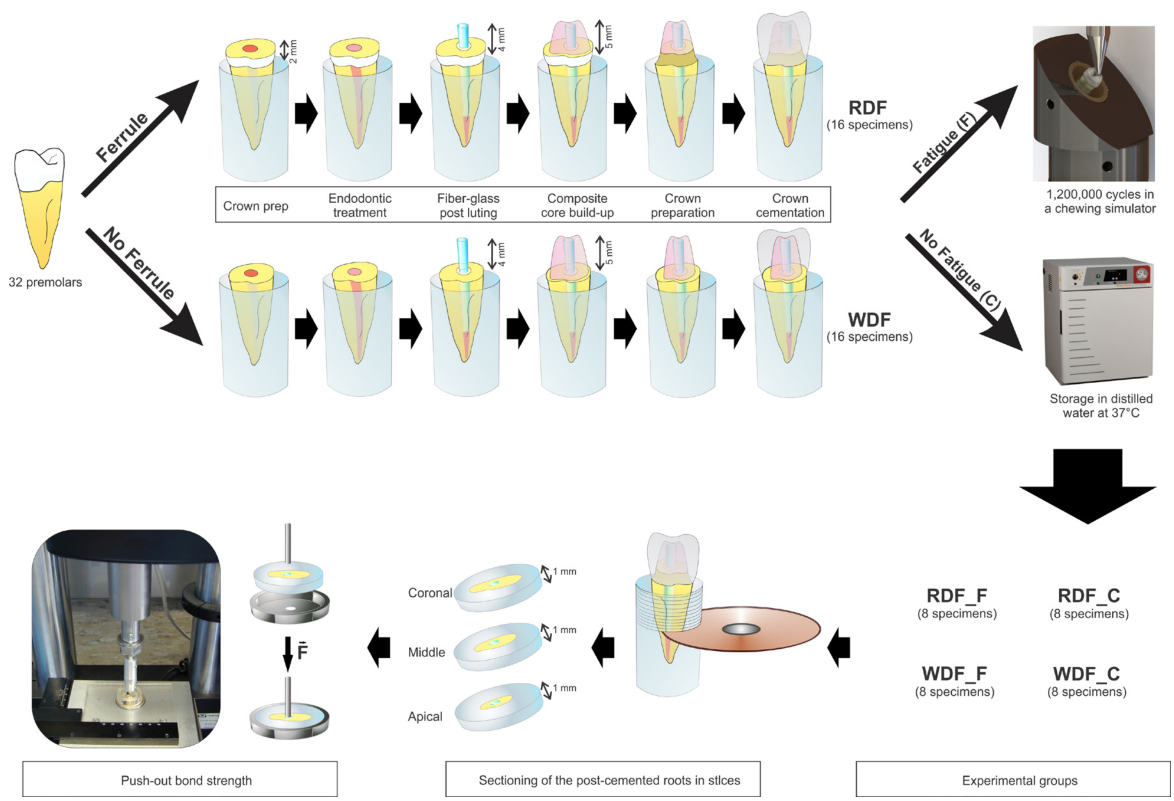

Figure 1. Schematic illustrating the study set-up.

1,200 mW/cm^2, measured with a light spectrometer (MARC-RC, BlueLight Analytics, Halifax, NS, Canada). After bonding procedures at the coronal area using a two-step etch-and-rinse adhesive (Adper Single Bond Plus, 3M Oral Care), standardized cores of 5.0 mm height were built with the aid of a transparent polyethylene core build-up matrix (CoreForms #11, KaVo Kerr, Brea, CA, USA) using a micro-hybrid light-cure resin composite (Filtek Z250, 3M Oral Care) in increments. Each 2.0-mm increment was light-cured for 20 seconds. A high-speed 1.5-mm taper ogival-end diamond bur (#3216, KG Sorensen, São Paulo, SP, Brazil) was used for crown preparation. The diamond bur was changed after five crown preparations. Tooth preparation involved a 1.5-mm chamfer finishing line at the buccal side and a 0.5-mm chamfer finishing line lingually. The composite cores were finished and polished with abrasive discs (Sof-Lex 2382C and 2382F, 3M Oral Care). Self-cure acrylic resin (JET, Clássico, Campo Limpo Paulista, SP, Brazil) was poured into each polyvinyl siloxane mold and positioned on the corresponding tooth, in order to produce an acrylic resin crown with the original tooth anatomy. After self-curing, the acrylic resin crowns were finished, polished, and cemented using a dual-cure self-adhesive composite cement (RelyX Unicem 2, 3M Oral Care).

After 1-week storage in distilled water at 37°C, half of the specimens were subjected to mechanical fatigue aging for 1,200,000 cycles (F = Fatigue) in a chewing simulator (SD Mechatronik Chewing Simulator, Willytec, Munich, Germany). The specimens were kept in distilled water, and a 6.0-mm diameter stainless-steel ball-shaped stylus was positioned in the center of each occlusal surface. A 50-N load was applied at an angle of 45° to the long axis of each tooth at a frequency of 1.6 Hz (Figure 1). The other half of the specimens were not submitted to mechanical fatigue (C = Control); teeth were stored in distilled water at 37°C for one week. After chewing simulation, all specimens were examined with an exploratory probe under a stereomicroscope with 3.5x magnification for clinical signs of failure such as crown and/or post dislodgment, marginal gap formation, and tooth and/or core fracture. Then, all specimens were sectioned perpendicularly to the long axis of the roots using a water-cooled low-speed diamond saw (Isomet 1000, Buehler). The first section was made at 5.0 mm from the apex, and the root apex was discarded. Then, two 1.0-mm-thick root slices were obtained from each third (coronal, middle, and apical). Specimens were examined under a stereomicroscope with 3.5x magnification to evaluate if the slices contained defects caused by sectioning. Each slice was positioned with its coronal aspect directed downwards on a push-out jig attached to a universal testing machine (Instron 4444, Instron, Canton, MA, USA). After positioning a cylindrical plunger on the center of the fiber post without any contact with surrounding dentin walls, a 0.5-min/mm force was applied in an apical-coronal direction until failure. PBS values were calculated by using the formula R = L/A, where L was the maximum load at failure (N) and A the bonded area (mm^2), which was determined by using a formula to calculate the lateral area of a circular straight cone with parallel bases: $A = \pi \times g \times (R1 + R2)$, where $\pi = 3.14$, g = inclination, R1 = smaller base radius, and R2 = larger base radius. The inclination was calculated by using the formula $g = h^2 + (R2 - R1)^2$, where h = section height, measured with a digital caliper (Starrett 727, Starrett, Itu, Brazil), while R1 and R2 were obtained by measuring the internal diameters of the smaller and larger bases with an X-Y multipurpose modular measuring microscope equipped with a digital readout (Leitz VRZ-U, Wetzlar, Germany). The PBS data were analyzed for each root third separately. The Shapiro-Wilk test was used to check for data normal distribution (α=0.05), upon which the statistical software program SPSS 21.0 (IBM, Chicago, IL, USA) was employed to detect statistical differences using two-way analysis of variance (ANOVA) (dentin ferrule × mechanical fatigue), followed by applying Tukey's HSD *post-hoc* test (α=0.05).

The failure mode of each specimen was assessed using a stereomicroscope with 3.5x magnification. Failures were classified as adhesive between composite cement and dentin, adhesive between composite cement and glass-fiber post, cohesive fracture of the glass-fiber post, cohesive fracture of dentin, cohesive fracture of the composite cement, or mixed in case of a combination of at least two failure modes. The frequency distribution of failure modes among the experimental groups was statistically analyzed using the Person Chi-squared test (a=0.05) and *post-hoc* comparisons with Bonferroni. Representative specimens of the most frequent failures were observed under SEM (JSM-6610LV, JEOL, Tokyo, Japan).

RESULTS

No pre-test failures were recorded for all experimental groups tested. The PBS data for each root third and their respective pairwise comparisons are detailed in Table 1 and Figure 2. Both the factors Dentin Ferrule and Fatigue, and their interaction were significant for all root thirds (p<0.05). Irrespective of the root third, specimens not subjected to mechanical fatigue presented significantly higher PBS (RDF_C and WDF_C) (p<0.001) than specimens subjected to

Table 1: *Push-out Bond Strength (MPa) and Failure-mode Distribution (%) at Each Root Third (mean ± SD) (n=48)*[a]

Group	PBS (MPa)	Failure mode (%)		
Coronal				
		C/D	C/P	M
RDF_F	10.4 ± 2.7[b]	79	6	15
WDF_F	7.6 ± 1.6[c]	60	13	27
RDF_C	14.8 ± 3.7[a]	90	6	4
WDF_C	14.2 ± 3.3[a]	90	4	6
Middle				
Group	PBS (MPa)	Failure mode (%)		
		C/D	C/P	M
RDF_F	9.9 ± 1.6[b]	88	4	8
WDF_F	7.1 ± 1.9[c]	69	10	21
RDF_C	14.4 ± 2.5[a]	90	6	4
WDF_C	14.1 ± 3.2[a]	92	6	2
Apical				
Group	PBS (MPa)	Failure mode (%)		
		C/D	C/P	M
RDF_F	10.8 ± 4.5[b]	84	4	12
WDF_F	5.9 ± 1.7[c]	67	12	21
RDF_C	14.4 ± 1.8[a]	88	8	4
WDF_C	14.3 ± 2.3[a]	94	4	2

Abbreviations: C/D = adhesive failure at composite cement/dentin interface; C/P = adhesive failure at composite-cement/glass-fiber post interface; M = mixed failure; PBS = push-out bond strength; RDF_C = remaining dentin ferrule without (control); RDF_F = remaining dentin ferrule + fatigue; WDF_C = without dentin ferrule (control); WDF_F = without dentin ferrule + fatigue.

[a]*For each root third, different lowercase letters in the same column indicate significant difference (p<0.05).*

mechanical fatigue (RDF_F and WDF_F). For the experimental groups that were aged by mechanical fatigue, significantly lower PBS ($p<0.05$) was registered when there was no ferrule (WDF_F), as compared to when a dentin ferrule was remaining (RDF_F).

A similar failure-mode distribution was observed for all root thirds. Cohesive failures limited to the glass-fiber post, dentin, or composite cement were not observed. Most failures were adhesive between composite cement and dentin (Figure 3), followed by mixed failures (Figure 4) (Table 1). All observed mixed failures combined an adhesive failure at the composite cement/dentin interface and a cohesive fracture within root-canal dentin. The Pearson chi-square test revealed significant differences in failure modes among the experimental groups for all root thirds (p=0.006 coronal; p=0.022 middle; p=0.013 apical). A significant decrease of adhesive failures at the composite cement/dentin interface and an increase of mixed failures were found for WDF_F ($p<0.001$) concerning all root thirds.

DISCUSSION

The present research aimed to verify the 2.0-mm dentin remaining ferrule effect on glass-fiber post PBS to root dentin. A significant influence of the ferrule effect on PBS was only observed for the specimens that were subjected to mechanical fatigue aging. Thus, the first null hypothesis partially failed to be accepted. After chewing simulation, the presence of 2.0-mm remaining coronal dentin was not able to maintain the PBS to

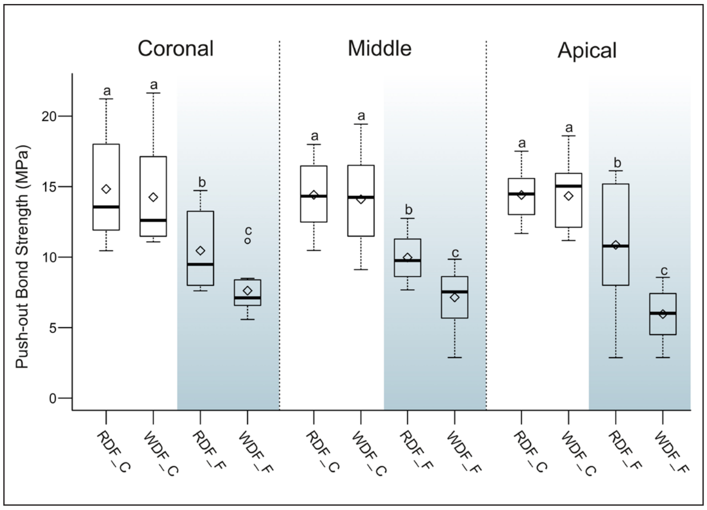

Figure 2. *Box plots of the push-out bond-strength results for each root third. The box represents the spreading of the data between the first and third quartile. The central horizontal line and the diamond symbol represents the median and mean, respectively. The whiskers extend to the minimum and maximum values measured, with the exception of the outliers that are represented with open dots. Abbreviations: RDF_C = remaining dentin ferrule (control); RDF_F = remaining dentin ferrule + mechanical fatigue; WDF_C = without dentin ferrule (control); WDF_F = without dentin ferrule + mechanical fatigue).*

root-canal dentin in comparison to the specimens that were not subjected to mechanical aging. Moreover, the absence of 2.0-mm remaining coronal dentin resulted in even significantly lower results. These results corroborate with previous FEA findings that observed a reduction in tensile stress at both the glass-fiber post/cement and the cement/crown interface when a ferrule was present.[6,17] Scientific literature shows that preservation of a dentin ferrule with sufficient height (1.5 to 2.0 mm) and thickness (1.0 mm) resulted in reduction of the wedging force of the glass-fiber post against the root structure. It consequently decreased stress at the adhesive interface, reducing the risk of failure during mastication.[3,16,19,20,25-27]

Regardless of the presence of ferrule, the present research showed that a significant lower PBS was only found for the specimens that were subjected to mechanical fatigue aging. Thus, the second null hypothesis failed to be accepted. These results indicate that mechanical fatigue aging of the specimens plays an important role when applying a PBS-test protocol and should be applied to specimens whenever possible. Although no glass-fiber post de-bonding was recorded for both aged groups, the significantly lower PBS recorded for the non-ferrule group (WDF_F) may be related to large micromovement of the glass-fiber post during chewing, thereby probably also increasing microleakage.[28] Chang and others[29] observed a dramatic increase in microleakage extension up to the glass-fiber post space after only 120,000 cycles of mechanical fatigue aging. This effect may be regarded as preceding PBS decrease and possible future glass-fiber post de-bonding. A six-year randomized controlled clinical trial performed by Ferrari and others[21] pointed out that preservation of dentin ferrule significantly reduced the failure risk of restored pulpless premolars. A possible explanation for the results reported by Ferrari and others[21] may concern the lower microleakage observed for those restored teeth presenting dentin ferrule and reduced post de-bonding and/or endodontic effects. A recent systematic review and meta-analysis[27] found that restorations exhibiting dentin ferrule showed a higher survival rate (88.4%) compared to those without dentin ferrule (78.1%). Nevertheless, no statistically significant difference was noted regarding general post failures and root fractures, although a higher number of failures were associated with non-ferrule restorations.[27]

The 45-degree oblique loading applied in the present study aimed to simulate the worst-case scenario, in which non-axial forces may induce bending moments and non-uniform stress distribution.[30] In addition, single-root and endodontically treated upper premolars have been shown to be more prone to root fractures, which is the justification for the selection of these teeth in this study.[1]

The predominance of adhesive failures between composite cement and root-canal dentin confirmed that this interface remains the weakest link of teeth restored with post systems.[31,32] The WDF_F group showed a significant increase in mixed failures that involved adhesive failure at the composite cement/dentin interface and cohesive fracture within root-canal dentin. Thus, repetitive forces exerted by the glass-fiber post towards the root-canal dentin during mechanical fatigue aging may cause minor dentin cracks that more easily propagated during testing, having resulted in lower PBS. On the other hand, the presence of dentin ferrule seems to attenuate, to a certain extent, crack initiation and propagation, since a lower percentage of mixed failures was observed for the RDF_F group. The fewer failures between composite cement and glass-fiber post indicated that silanization was able to provide

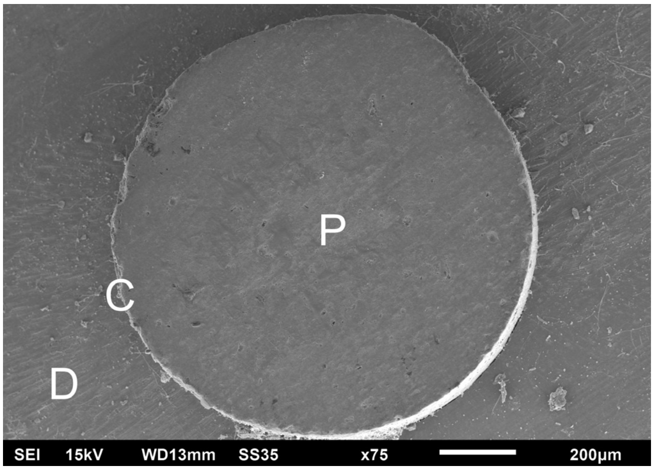

Figure 3. *Representative SEM photomicrograph of the most predominant failure mode for all groups (adhesive failure at the composite cement/dentin interface). Abbreviations: C, composite cement; D, dentin; P, glass-fiber post.*

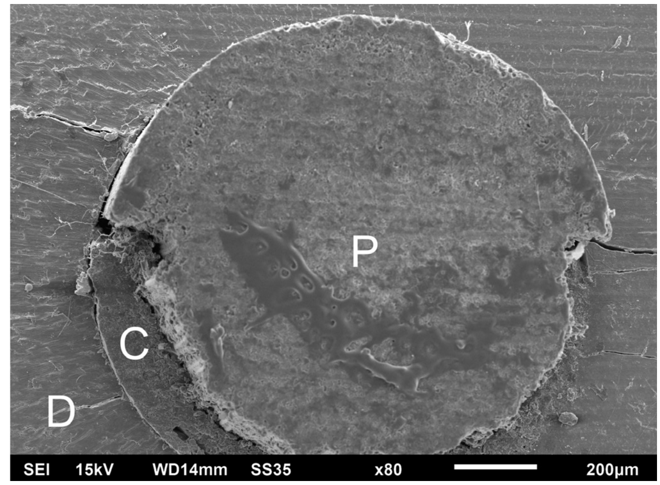

Figure 4. *Representative SEM photomicrograph of a mixed failure. Note the crack propagation within adjacent dentin. Note the crack propagation within adjacent dentin Abbreviations: C, composite cement; D, dentin; P, glass-fiber post.*

adequate chemical bonding and superior bond strength in comparison to the strength of the composite cement/dentin interface within the root canal. Nevertheless, even this type of cement/post failure can be reduced if additional surface pre-treatment of the post would have been conducted, such as hydrogen peroxide cleaning, air-abrasion with 30-mm (silica-coated) aluminum oxide particles.[33,34] Future research should address such additional fiber-post surface pre-treatments in order to evaluate their influence on PBS.

Since glass-fiber posts have a weak mechanical retention to root-canal dentin, their dislodgment resistance relies on the quality of adhesion of the composite cement to root-canal dentin.[27,35] A recent systematic review[23] showed that self-adhesive composite cements can provide adequate root-canal dentin bond strength, and that self-adhesive composite cements are less influenced by other variables, such as the composite-cement application method, operator experience, and fiber-post pre-treatment. When compared to multi-step resin-based luting systems, the single-step self-adhesive composite cement used in the present study is less technique-sensitive,[36] which may explain the similar PBS values recorded among the root thirds.[37] In principle, self-adhesive composite cements bond less effectively to dentin than adhesive-assisted composite cements. Because the root canal surface area to bond to is relatively large, the lower bonding potential is perhaps compensated for by the larger area. A recent multicenter randomized controlled 6-year clinical trial compared two glass-fiber post cementation strategies, namely using a two-step etch-and-rinse adhesive-assisted composite cement versus using a self-adhesive composite cement.[38] The survival rate of glass-fiber posts was not influenced by the cementation strategies.[38]

There still exists no consensus regarding the contribution of ferrule effect on survival of teeth restored with a glass-fiber post.[27,39] More clinical trials are still needed to determine the influence of remaining coronal dentin on survival of teeth restored with a glass-fiber post. Moreover, well-designed clinical trials to detect differences in survival, for example considering the variables "prefabricated post system" or "presence of post," are difficult to be executed, as the research design may require a sample size of over 500 per experimental group.[40] *In vitro* studies are simpler and more convenient and are thus useful in obtaining meaningful results. Further *in vitro* studies should, for instance, also investigate whether absence of ferrule has an influence on PBS when composite cements are used with different adhesive strategies (etch-and-rinse versus self-etch).

CONCLUSION

Absence of 2.0-mm dentin remaining ferrule in premolars restored with glass-fiber posts resulted in a higher reduction of the push-out bond strength to root-canal dentin after mechanical fatigue aging. PBS did not differ depending on the root third. The interface of composite cement with root-canal dentin appears to be the weakest link of glass-fiber post systems cemented with self-adhesive composite cement.

Regulatory Statement

This study was conducted in accordance with all the provisions of the human subjects oversight committee guidelines and policies of the Federal University of Santa Catarina Ethics Committee for Human Research. The approval code issued for this study is #1.342.024.

Conflicts of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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