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# Effect of Mechanical Cycling on the Push-out Bond Strength of Fiber Posts Adhesively Bonded to Human Root Dentin

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## Clinical Relevance

When adhesively cemented, tested fiber posts are fatigue resistant and appear to have no affect on bond strength to root dentin. Thus, the retention strength of these fiber posts could be maintained for an extended period; however, further studies should be conducted.

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## SUMMARY

**This study evaluated the effect of mechanical cycling on the bond strength of fiber posts bonded to root dentin. The hypotheses examined were that bond strength is not changed after fatigue testing and bond strength does not present vast variations according to the type of fiber post. Sixty crownless, single-rooted human teeth were endodontically treated, with the space prepared at 12 mm. Thirty specimens received a quartz fiber post (Q-FRC) (DT Light-Post), and the remaining 30 specimens received a glass fiber post (G-FRC) (FRC Postec Plus). All the posts were resin luted (All Bond+Duolink), and each specimen was embedded in a cylinder with epoxy resin. The specimens were divided into six groups: G1- Q-FRC+no cycling; G2- Q-FRC+20,000 cycles (load: 50N; angle of 45°; frequency: 8Hz); G3- Q-FRC+2,000,000 cycles; G4- G-FRC+no cycling; G5- G-FRC+20,000 cycles; G6- G-FRC+2,000,000 cycles. The specimens were cut perpendicular to their long axis, forming 2-mm thick disc-samples, which were submitted to the push-out test. ANOVA ($\alpha$=.05) revealed that: (a) Q-FRC (7.1±2.2MPa) and G-FRC (6.9±2.1MPa) were statistically similar (*p*=0.665); (b) the "no cycling" groups (7.0±2.4MPa), "20,000 cycles" groups**

**(7.0±2.1MPa) and "2,000,000 cycles" groups (7.0±2.0MPa) were statistically similar (*p*=0.996). It concluded that mechanical cycling did not affect the bond strength of two fiber posts bonded to dentin.**

## INTRODUCTION

The technique of root anchorage using prefabricated fiber posts that are adhesively luted (passive) follows the minimal intervention procedures of restorative dentistry,[1] with the purpose of: 1) preserving tooth structure (*minimal intervention*); 2) reducing the risk of root fracture by providing sufficient alveolar bone support,[2] a long post length[3] and adhesive systems and posts with a modulus of elasticity (E) similar to dentin;[4-12] 3) increasing the retention of the build-up material. Adhesive luting (adhesive systems + resin cements) is fundamental in this technique, since it increases the bond strength of the post,[13-14] reduces marginal microleakage[15-16] and optimizes the homogeneous distribution of stresses to the remaining tooth structure.[17]

Fiber-reinforced composite posts (FRC) have an E similar to that of dentin (post ≅ 40 GPa; dentin ≅ 18 GPa). This characteristic allows for the absorption and homogeneous distribution of stress to the remaining root structure, instead of concentrating it. Concentration of stress has been reported for cast posts (either metallic or ceramic) and zirconia oxide-based metallic and ceramic prefabricated posts, because their E is higher than that of dentin (E of materials: stainless steel ≅ 200 GPa; titanium alloy ≅ 110 GPa; gold alloy ≅ 80 GPa; zirconia oxide ≅ 150 GPa), increasing the risk of root fracture.[17-23]

However, either the post diameter or the type of post fiber may influence the value of stiffness.[18,24-25] According to Aird,[26] "Mathematically, the stiffness varies with the cube of the thickness, so, if we double the thickness, we get eight times the resistance to buckling." Asmussen and others[18] demonstrated that an increase in diameter usually increases the value of stiffness, while also showing that the type of fiber and resin employed for post fabrication may change stiffness. Thus, it is possible that different fiber posts may perform differently from a mechanical standpoint by changing the pattern of stress distribution. The percentage of fibers may also influence the value of stiffness for fiber posts.[27]

*In vivo* studies have reported success rates ranging from 95% to 99% for teeth reconstructed with FRC adhesively luted to root dentin (no root fracture), with the main reason for failure being debonding of the cement-post-reconstruction assembly (failure between the adhesive system and root dentin).[5-7,10-11] *In vitro* studies on fracture resistance reveal that fractures are less harmful when teeth are restored with FRC; whereas, teeth restored with rigid posts (metallic or ceramic) display catastrophic or irreversible root fracture.[4,9,12]

Despite the limitations of *in vitro* studies, mechanical fatigue tests conducted in a humid environment seem to be the best method for predicting the clinical performance of different materials and restorative techniques.[28-34] A mechanical fatigue test may lead to fracture of a structure after a repeated load. The fracture may be explained as the result of the spread of microscopic cracks from areas of force concentration, usually in areas presenting with macroscopic or molecular structural defects.[28-34] Normally, fatigue tests are conducted in a humid environment, contributing to degradation of the physical and mechanical properties of the restoration materials.[24,31,34-36] Pontius and Hutter[37] described 1,200,000 cycles in a mechanical fatigue test as corresponding to approximately five years of clinical function.

Therefore, considering that different fiber posts may perform in different ways under a dynamic mechanical load, this study: 1) investigated the fatigue resistance of teeth restored with two types of fiber posts, 2) evaluated the bond strengths between post and root dentin for the different fiber posts and mechanical cycling regimens, 3) tested the null hypotheses that bond strength is not changed after the fatigue test and that bond strength does not present sizeable variations according to the type of fiber post.

## METHODS AND MATERIALS

Sixty single-rooted human teeth (maxillary central incisors, canines and mandibular premolars) were selected. The specimens comprised only teeth not previously submitted to endodontic treatment. The teeth were cleaned with periodontal curettes, stored in 1.23% chlorhexidine for two hours for disinfection and stored in $H_2O$ at 37°C until used in this study. The crowns of all the teeth were sectioned using a diamond disc under cooling, standardizing the length of specimens at 16 mm. The mean diameter ($Ø_\mu$) of the root canal at the coronal portion of all roots was measured with a light microscope (Leica M-10 Wild, Heerbrugg, Switzerland), considering that $Ø_\mu = (Ø_{bucco\text{-}lingual} + Ø_{mesio\text{-}distal})/2$. If one diameter considered for calculation was larger than the estimated post diameter at this region (approximately 1.7 mm), the specimen was discarded and replaced. The specimens were arranged in decreasing order of diameter dimension and placed into 10 sets of six specimens, based on the coronal diameter of the root canal. Then, each of the six study groups received one specimen of each set (n=10), so that all groups had samples with a similar average root canal diameter.

The root canals were mechanically instrumented with NiTi instruments, followed by irrigation with Dakin solution (10 mL). Then, the root apices were sealed with an adhesive system (One Step Plus, BISCO, Schaumburg, IL, USA) and a resin composite (W3D Master, Wilcos, Petrópolis, Brazil) to avoid overflowing of the adhesive systems and resin cements during the experimental procedures.

Specimens were prepared at 12 mm, using the preparation burs of each post system: 1) Q-FRC: 30 specimens were prepared for the quartz fiber post DT. Light-Post #2 (BISCO). These fiber posts are double-tapered (mean diameter = 1.5 mm; Flexural modulus = 18 GPa) and are composed of epoxy resin and quartz fibers (70%). 2) G-FRC: 30 specimens were prepared for the glass fiber post FRC Postec Plus #3 (Ivoclar-Vivadent AG, Schaan, Liechtenstein). These fiber posts are tapered (mean diameter = 1.5 mm; Flexural modulus = 21 GPa) and are composed of dimethacrylates and glass fibers (70%).

**Post Luting**

The following procedures were performed for the luting of the two post types:

A) *post surface conditioning*: air abrasion (Dento-Prep, RØNVIG A/S, Daugaard, Denmark) with 30 µm $Al_2O_3$ particles modified with $SiO_x$ (CoJet-Sand, 3M ESPE, Seefeld, Germany), rotating the post manually until its surface appeared matte under visual inspection (air-particle protocol: pressure = 2.8 bars; distance = 10 mm; perpendicular to the post surface; time = 20 seconds). Thereafter, the ESPE-Sil silane was applied and allowed to dry for five minutes.[38]

B) *root canal dentin conditioning*: a multiple-bottle total-etch adhesive system (All Bond 2 system, BISCO) was used, as described: 1) etching with 32% phosphoric acid for 30 seconds; 2) washing with 10 mL of water using a disposable syringe; 3) removal of excess water with #80 absorbent paper points; 4) mixing Primer A and Primer B (All Bond 2 system), applying the mixture and removing the excess material with the Cavi-tip brush (Svenska Dental Instrument AB, Upplands Värby, Sweden); 5) application of Pre-Bond resin (All Bond 2 system) and removal of the excess material with a brush.

C) *post cementation*: 1) the A and B pastes of the resin cement Duolink (BISCO) were measured and mixed. The cement was applied to the post and root canal with a Lentulo #40 spiral (Maillefer); 2) light-curing through the incisal surface for 40 seconds, using the XL 3000 unit (3M ESPE) at a light intensity of 450 mW/cm².

Taking into account the post-luting length (12 mm) and the length of both G- and Q-FRC (20 mm), 8 mm of the FRC remained out of the root canal in the coronal portion.

**Adequacy of the Specimens for Mechanical Cycling**

For mechanical cycling, the specimens were embedded in epoxy resin (285, Schaller, Florence, Italy), using a support with a 16 mm diameter specific for each post (Figure 1A), with a central orifice slightly larger than the coronal diameter of the post. This allowed the specimen to be as perpendicular as possible to the ground (Figure 1A). A 10 ml surgical plastic syringe was sectioned in a mechanical lathe so that the surface of this section was parallel to the ground (Ø = 12 mm; h = 40 mm). Thus, when the support-specimen set was positioned in the syringe, the specimen was embedded as perpendicular as possible to the ground (Figure 1B). Following this procedure, the epoxy resin was prepared and poured into the syringe. The support with the coupled specimen was positioned into the syringe so that the root was embedded 3 mm in the apical direction (Figure 1C).

**Fatigue Test**

The fatigue test was carried out in a machine designed and produced by Baldissara.[34] The specimens were placed in a metallic base at a 45° angle, so that a point with a 1.6 mm diameter at the upper rod of the cycling machine could induce load pulses from 0 N to 50 N at a frequency of 8 Hz directly onto the post (Figure 2). During cycling, the specimens were irrigated with water at 37°C ± 1°C, as regulated by a thermostat.[28-34] Ten specimens from each FRC were not cycled, 10 specimens from each FRC were submitted to 20,000 cycles and 10 specimens from each FRC were cycled 2,000,000 times.

Considering the two factors studied in this study ("type of fiber post" in two levels and "mechanical cycling regimens" in three levels), six groups were

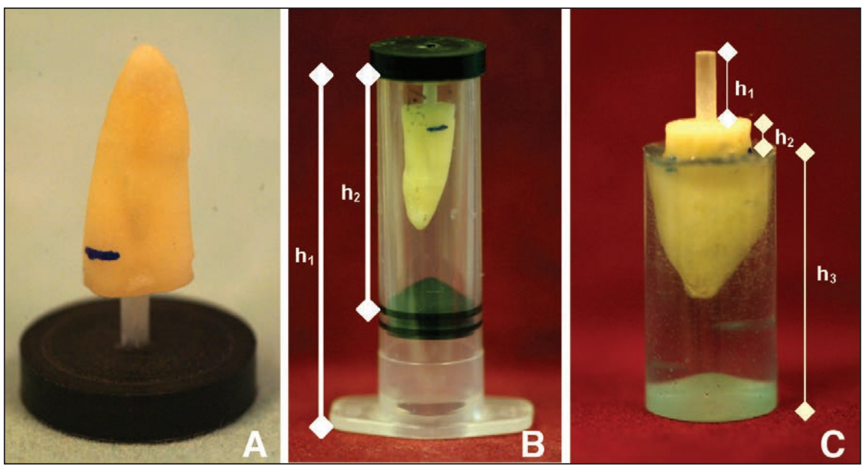


Figure 1: *Adequacy of specimen: A) specimens positioned on the support for embedding. The post was introduced into a guide orifice and kept perpendicular to the ground; B) support and specimen positioned in the embedding syringe ($h_1$=40 mm; $h_2$=30 mm); C) specimen embedded into epoxy resin ($h_1$=8 mm; $h_2$=3 mm; $h_3$=30 mm).*

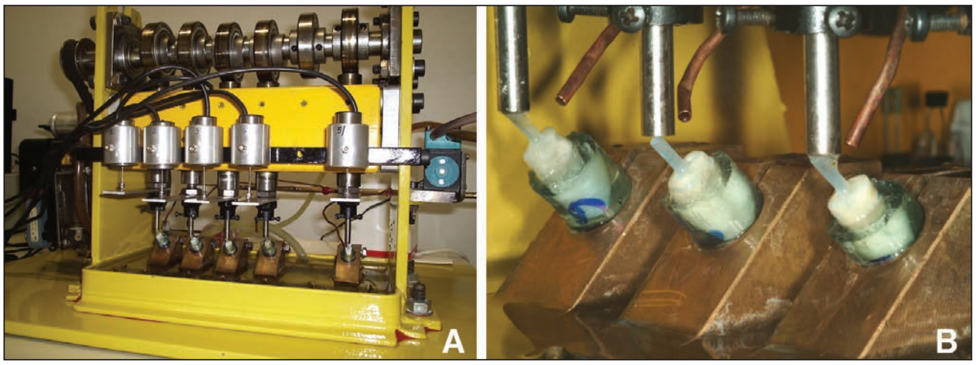


Figure 2: *A) Fatigue tester, having five stations for cycling; B) Specimens placed in an angle of 45°.*

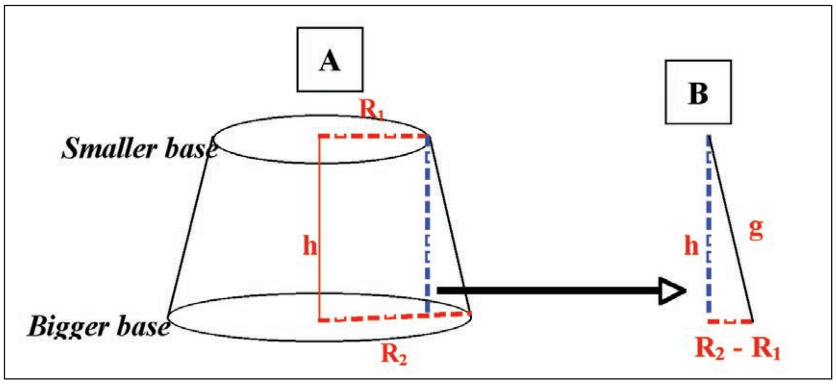


Figure 3: *A) schematic drawing that corresponds with the internal section of the specimen (root walls)—geometric figure of a circular straight cone trunk of parallel bases; B) geometric figure for calculation of the cone trunk.*

examined (n=10): (G1) Q-FRC + no cycling; (G2) Q-FRC + 20,000 cycles; (G3) Q-FRC + 2,000,000 cycles; (G4) G-FRC + no cycling; (G5) G-FRC + 20,000 cycles; (G6) G-FRC + 2,000,000 cycles.

To standardize the water storage period and eliminate a variable storage period, all specimens were kept in distilled water (37°C ± 2°C) for the same period, regardless of mechanical cycling. The storage period was defined according to the time required for cycling of G3 and G6 (groups with the highest number of cycles).

## Push-out Strength Test

Each specimen was fixed on a metallic base of a sectioning machine (LabCut 1010, Extec Corp, Enfield, CT, USA), which enabled the preparation of approximately 2-mm slices by using perpendicular sectioning along the root axis, using a diamond disc under cooling spray. The first cervical slice (approximately 1 mm) was discarded, given that the excess cement in that region could influence adhesive resistance. Four to five other sections per specimen were sectioned (50 per group).

Each specimen was positioned on a metallic device with a central opening (Ø=3 mm) larger than the canal diameter. The most coronal portion of the specimen was placed downward. For push-out testing, a metallic cylinder ($Ø_{extremity}$ = 0.85 mm) induced a load in the apical to coronal direction on the post without applying any pressure to the cement and/or dentin. Considering that the specimens were embedded into the epoxy resin parallel to the root axis (Figure 1) and that the specimens were sectioned perpendicular to that axis, the post was submitted to parallel pressure to the greatest extent in relation to the root axis. The test was performed in a universal testing machine (EMIC, São José dos Pinhais, Brazil) at a speed of 1 mm/minute.

The bond strength (σ) in MPa was obtained with the formula $\sigma=\mathbf{F}/\mathbf{A}$, where **F** = load for specimen rupture (N) and **A** = bonded area ($mm^2$). To determine the area (Figure 3A), the formula to calculate the lateral area of a circular straight cone with parallel bases was used. The formula used is: $\mathbf{A}=\pi * g * (R_1 + R_2)$, where π=3.14, **g**= slant height, $\mathbf{R_1}$= smaller base radius, $\mathbf{R_2}$= larger base radius. To determine the slant height, the following was used (Figure 3B): $g = (h^2 + [R_2-R_1]^2)^{1/2}$, where **h**= section height. $\mathbf{R_1}$ and $\mathbf{R_2}$ were obtained by measuring the internal diameters of the smaller and larger base, respectively, which corresponded to the internal diameter between the root canal walls. These diameters were measured using a light microscope (Leica M-10 Wild), while **h** was measured with a digital caliper (Starrett 727, Starrett, Itu, Brazil).

## Statistical Analysis

The mean bond strength value for each specimen was initially calculated from its respective disk specimens. Considering that each group was composed of 10 specimens, 10 mean bond strength values from each group (n=10) were used for statistical analysis (two-way analysis of variance, α≤0.05).

## Evaluation of the Type of Failure

All specimens tested were initially analyzed under a light microscope (Leica M-10 Wild), up to 98x magnification, to observe the area of failure: (Adhes DC) adhesive failure between dentin and adhesive system; (Adhes PC) adhesive failure between post and cement; (Cohes P) cohesive failure of the post; (Cohes D) cohesive failure of dentin; (M) mixed adhesive/cohesive failure and (Cohes C) cohesive failure of the cement at the DC or PC interface.

Specimens from the six groups were selected for analysis in a scanning electron microscope (SEM) (JEOL–JSM–5400, Jeol Ltd, Tokyo, Japan) (35x to 5,000x magnification). For SEM analysis, the selected specimens were initially fixated on an aluminum support with double-face carbon adhesive tape (SPI, West Chester, PA, USA) and sputter-coated with a gold-palladium alloy in a sputter coater (Polaron SC 7620 Sputter Coater, Quorum Technologies, Newhaven, UK) (time: 130 seconds, current 10-15 mA, vacuum 130 mTorr, sputter coating rate: 3.5 nm/minute, approximate layer of Pd-Au of 80 Å).

Table 1: *Means (± standard deviation) of the Bond Strength Data (MPa)*

| Mechanical Cycling | Fiber Post | | Total |
|---|---|---|---|
| | Q-FRC (DT) | G-FRC (FRC) | |
| 0 | 7.1 ± 2.8 | 6.8 ± 2.2 | 7.0 ± 2.4 |
| 20,000x | 7.1 ± 1.8 | 6.9 ± 2.4 | 7.0 ± 2.1 |
| 2,000,000x | 7.1 ± 2.8 | 6.9 ± 1.9 | 7.0 ± 2.0 |
| Total | 7.1 ± 2.2 | 6.9 ± 2.1 | |

Table 2: *Two-way Analysis of Variance of the Bond Strength Data*

| Source | *df* | SS | MS | F | *P* |
|---|---|---|---|---|---|
| Post | 1 | 0.948 | 0.94753 | 0.19 | 0.665 ns |
| Mechanical Cycling | 2 | 0.039 | 0.01926 | 0.00 | 0.996 ns |
| Between | 2 | 0.004 | 0.00216 | 0.00 | 1.000 ns |
| Within | 54 | 270.367 | 5.00679 | | |
| Total | 59 | 271.357 | | | |

*ns: not significant.*

## RESULTS

For both types of fiber posts that were investigated, there was no root, post fracture or loss of retention after the mechanical fatigue test (20,000 or 2,000,000 cycles).

The bond strength data are presented in Table 1. The mean values for the Q-FRC (DT Light Post) and G-FRC (FRC Postec Plus) posts are very similar at all cycling levels. The result of the ANOVA test (Table 2) revealed that the factor "*fiber post*" was not statistically significant (the null hypothesis was accepted, $p$=0.665). The bond strength values achieved for the fiber post Q-FRC (DT) (7.1 ± 2.2 MPa) and the fiber post G-FRC (FRC) (6.9 ± 2.1 MPa) were statistically similar to each other. The factor "*mechanical cycling*" was not statistically significant (the null hypothesis was accepted, $p$=0.996). The values obtained for the condition without cycling (7.0 ± 2.4 MPa) were statistically similar to those obtained at the 20,000 (7.0 ± 2.1 MPa) and 2,000,000 (7.0 ± 2.0 MPa) conditions. The interaction effect was not statistically significant ($p$=1.000). This indicates that the six experimental groups were statistically similar to each other.

The fracture types of the specimens of each experimental group are graphically presented in Figure 4. Twenty-six percent and 0.4% of the specimens presented cohesive fracture of the post (Figures 5A, 5B, 5C and 5D) and mixed fracture, respectively; whereas, 78% of the pushed-out specimens presented adhesive fracture between the dentin and adhesive system (Figures 6A, 6B, 6C and 6D). Considering the types of fracture of each fiber post, the percentage of Adhes DC fracture was higher for the Q-FRC post (82%) than for the G-FRC post (73%); whereas, the percentage of cohesive fractures of the post was higher for the G-FRC post (27%) compared to the Q-FRC post (17%). There was no adhesive fracture between post and cement.

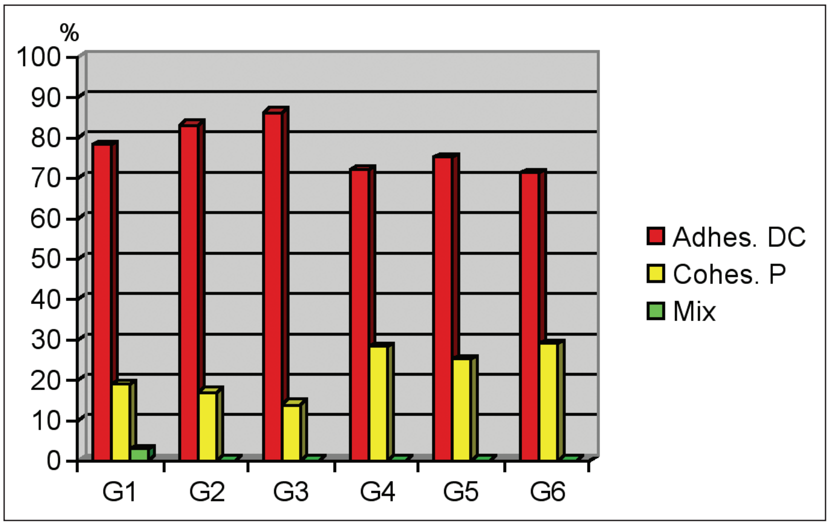


Figure 4: *Graphic representation of percentages of the type of fractures occurring in specimens submitted to the push-out test (**Adhes DC** = adhesive fracture between dentin and cement; **Cohes P** = cohesive fracture of the post; **Mixed** = adhesive fracture between post-cement and cohesive fracture of the post).*

## DISCUSSION

The minimally invasive approach of associating adhesive techniques and posts with similar mechanical characteristics to dentin seems to contribute to a better clinical prognosis of endodontically-treated teeth. However, one of the main problems with this approach

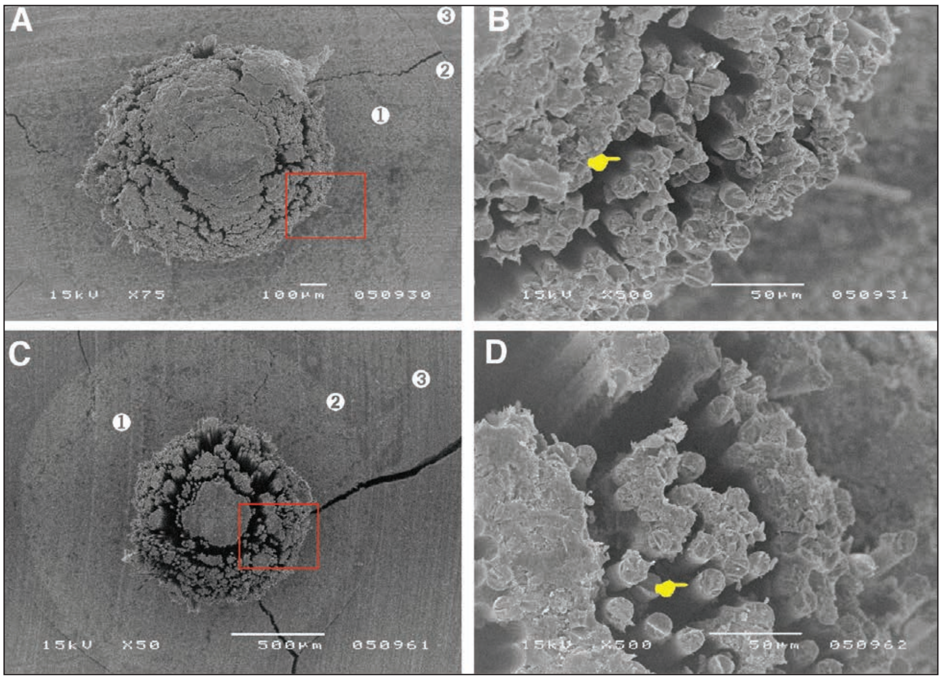


Figure 5: *A-B Micrograph representing a cohesive fracture of the quartz fiber post (DT Light-Post). The square in A (75x) is magnified in B (500x). In A, ❶ = fiber post, ❷ = resin cement and ❸ = dentin. The signal (☛) in B indicates some fibers loosened from the filling resin. C-D Micrograph representing a cohesive fracture of the glass fiber post (FRC Postec Plus). The square in C (75x) is magnified in D (500x). In C, ❶ = fiber post, ❷ = resin cement and ❸ = dentin. The signal (☛) in D indicates some fibers loosened from the filling resin.*

is that clinicians are concerned with factors affecting the retention of root posts instead of being concerned with the preservation of tooth structure and factors that may protect the tooth from catastrophic failure under masticatory load. Clinical studies have demonstrated that preservation of the remaining tooth structure significantly influences retention of the post-reconstruction-crown assembly, while also reducing the risk of root fracture.[5-8,10-11]

The current study observed that mechanical cycling did not reduce the bond strength for two types of fiber posts. This result may corroborate studies of stress distribution analysis, since the stresses yielded during the fatigue test were most likely distributed equally along the post-cement-root dentin interface; therefore, a greater dentin area supported the applied load.[17-23] These results uphold the findings of two recent studies,[39-40] which also revealed that mechanical cycling ($10^6$ cycles) did not affect bond strength between root dentin and adhesively luted fiber posts.

In opposition to the current study, Galhano and others,[41] employing a similar methodology, demonstrated that the push-out bond strength between a zirconia oxide post and the root dentin was significantly reduced after the dynamic fatigue test ($2x10^6$ cycles). This reduction is probably related to the potential of stress concentration in the root dentin when rigid zirconia oxide posts are used,[19] which may have affected adhesion between the post and dentin. Thus, it seems that posts with values of E similar to dentin probably affect the adhesion to root dentin less due to the more homogeneous stress distribution, compared with posts with a higher value of E than that of dentin.[17-23] In this way, the report from all *in vivo* studies of no root fracture probably is related to the issue discussed above.[5-8,10-11,42]

In the current study, the fatigue test ($2x10^6$) was performed over a few days, representing nearly 10 years of clinical function.[37] This versatility is the main advantage of fatigue tests, since they may predict, within a short period of time, the long-term clinical performance of dental techniques and materials. However, even though no "macroscopically visible" failure was observed during or after the fatigue test, it should be noted that, in a real clinical situation, there may be marginal leakage at one interface during the actual 10 years of clinical functioning. This microleakage could lead to degradation of the cement or adhesive interface and the occurrence of caries,[43] neither of which were considered in this study. Within this context, Baldissara[34] commented that, even though specimens restored with a fiber post can be resistant to fatigue, different degrees of leakage at the dentin-resin composite interface may arise, especially at the lingual, as opposed to the buccal, aspect of teeth[44-45] due to the tensile stresses yielded during the test. The authors also mentioned that, despite fatigue resistance, there might be failures at the interface without an occurrence of macroscopically observable catastrophic failures. Thus, the fatigue-resistance or bond-strength test in isolation should not be considered a parameter for the good performance of this technique. Other tests, including microleakage tests and microscopic evaluation of the interface integrity, should be conducted to complement the results observed in a fatigue study.

Analysis of Table 2 reveals that the main effect "fiber post" was not significant, and thus the quartz fiber posts (DT Light-Post) and glass fiber posts (FRC Postec Plus) presented statistically similar bond strengths. Regardless of the similar bonding strengths, it is important to consider that the posts were resistant to fatigue, which is fundamental from a clinical standpoint. Quartz and glass fiber posts present similar compositional features and mechanical properties, respectively:[35] a) the quantities of quartz and glass fibers (70%) and resin matrix (30%); b) flexural modulus (18 and 21 GPa); c) conical (5°); d) density of fibers (32 and 25 fibers/mm$^2$); e) average diameter of the post (1.5 mm). This may have contributed to similar performance in this *in vitro* fatigue study; however, no controlled clinical trial has been conducted to compare these two fiber posts.

The 21% mode of fracture of the pushed-out specimens was cohesive in the fiber post. These cohesive fractures (Figure 5A, 5B, 5C and 5D) may be explained by the exposure of FRC to water and its effect on the organic matrix of the post and on the fiber-organic matrix interface. It should be noted that, after the completion of post-luting, the specimens were immediately stored in water (37°C) and always kept in contact with water from that moment until the push-out test, totaling approximately three months of contact with water. Some authors have observed a reduction in the mechanical properties of FRC after storage in water,[24,32,36,46] due to water sorption of the organic matrix of FRC increasing the matrix volume and also stress on the matrix-fiber interface.[46-47]

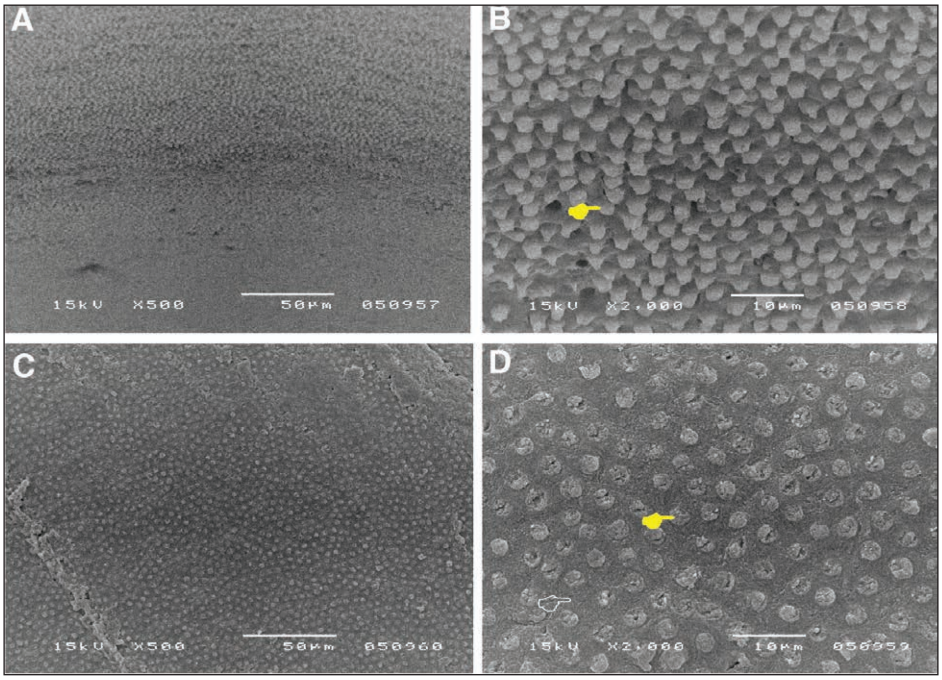


Figure 6: *Micrograph representing an adhesive fracture between the dentin and adhesive system, with cohesive fracture of the resin tags (post DT Light-Post). A (500x) and B (2000x) are images of the dentin surface, indicating adhesive rupture. In B, the resin tags that were fractured on their base can be observed (☛), slightly extruded by the shear stress applied during the push-out test. C (500x) and D (2000x) are images of the surface of the cement that was kept adhered to the post, confirming the adhesive fracture. In D, the tags that were fractured on their base can be observed (☛) and the post surface was kept covered by cement and/or by the adhesive system (☞).*

Still, with regard to the cohesive fracture of the post, utilization of a compression cylinder with a rounded end and a 0.85 mm diameter in the push-out test may have contributed to the extrusion of one part of the fibers and epoxy resin from the post. Utilization of a cylinder with a flat base might reduce the number of cohesive failures of the post. There was no adhesive fracture between the post and resin cement, which is probably related to the post-surface treatment (tribochemical silica coating method), which significantly increases bond strength of the resin cement.[38,48]

Considering that debonding of the cement-post-buildup is the main *in vivo* failure,[5-7,10-11] some clinical procedures may optimize adhesion to root dentin and post retention: a) utilization of multi-bottle adhesive systems with dual or chemical curing associated with chemical- or dual-resin cements;[49-51] b) utilization of size compatible brushes to the root canal to apply the adhesive system;[52-55] c) utilization of Lentulo burs to insert the resin cement.[50,56] Though often contraindicated by some manufacturers, the Lentulo burs were used in this study, and analysis of the failure modes of the specimens did not reveal visible bubbles in the resin cement at the tooth-post interface when examining the magnifications employed in SEM.

With regard to the methodology of bond strength testing, it is important to bear in mind that the current study observed 21.6% cohesive failures in the fiber post, which may be considered a limitation of the push-out test for fiber posts, since cohesive failures in the post underestimate the real bond strength, as previously discussed. Goracci and others[57] considered the push-out test to be better indicated to evaluate the bond strength between fiber posts and root dentin when compared to the microtensile test, because many specimens in the last test (nearly 22%) fractured during preparation; whereas, no specimen was lost in the push-out test. Therefore, it should be considered that both tests presented limitations for bonding evaluation between these substrates. Discussing the validity of the single push-out test for bone-fixed implants, An and Draughn[58] stated that it is known that most push-out tests do not measure pure shear strength but report a value that is a combination of various fixation principles, such as friction, mechanical interlocking and chemical bonding. The authors say that researchers should use strictly designed and detailed protocols that, although they do not make studies comparable, allow for comparisons within a single study.

Even though the current study demonstrated that teeth restored with quartz fiber posts or glass fiber posts were resistant to fatigue, and *in vitro* (fatigue tests, mechanical resistance and FEA) and *in vivo* (prospective and retrospective) studies demonstrate favorable outcomes when using fiber posts, no controlled clinical study (*randomized controlled study*) has actually demonstrated the longitudinal performance of the root anchorage technique with fiber-reinforced fiber posts.[59] Further longitudinal clinical evaluations should be performed.[60]

## CONCLUSIONS

Considering the results, the following can be concluded: 1) all specimens restored with fiber posts were resistant to fatigue; 2) the bond strength of fiber post to root dentin was not affected by the fatigue test; 3) fiber posts presented significantly similar bond strengths to root dentin.

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### References

1. Degrange M & Roulet JF (1997) *Minimally Invasive Restorations with Bonding* Quintessence Publishing Berlin.
2. Naumann M, Rosentritt M, Preuss A & Dietrich T (2006) The effect of alveolar bone loss on the load capability of restored endodontically treated teeth: A comparative *in vitro* study *Journal of Dentistry* **34(10)** 790-795.
3. Nakamura T, Ohyama T, Waki T, Kinuta S, Wakabayashi K, Mutobe Y, Takano N & Yatani H (2006) Stress analysis of endodontically treated anterior teeth restored with different types of post material *Dental Materials* **25(1)** 145-150.
4. Martinez-Insua A, Silva L, Rilo B & Santana U (1998) Comparison of fracture resistances of pulpless teeth restored with a cast post and core or carbon-fiber post with a composite core *Journal of Prosthetic Dentistry* **80(5)** 527-532.
5. Ferrari M, Vichi A, Mannocci F & Mason PN (2000) Retrospective study of the clinical performance of fiber posts *American Journal of Dentistry* **13(Special Issue)** 9B-13B.
6. Ferrari M, Vichi A & García-Godoy F (2000) Clinical evaluation of fiber-reinforced epoxy resin posts and cast post and cores *American Journal of Dentistry* **13(Special Issue)** 15B-18B.
7. Glazer B (2000) Restoration of endodontically treated teeth with carbon fiber posts *Journal of Canadian Dental Association* **66(11)** 613-618.
8. Hedlund SO, Johansson NG & Sjögren G (2003) A retrospective study of prefabricated carbon fibre root canal posts *Journal of Oral Rehabilitation* **30(10)** 1036-1040.
9. Maccari PC, Conceição EN & Nunes MF (2003) Fracture resistance of endodontically treated teeth with three different prefabricated esthetic posts *Journal of Esthetic and Restorative Dentistry* **15(1)** 25-31.
10. Malferrari S, Monaco C & Scotti R (2003) Clinical evaluation of teeth restored with quartz fiber-reinforced epoxy resin posts *International Journal of Prosthodontics* **16(1)** 39-44.
11. Monticelli F, Grandini S, Goracci C & Ferrari M (2003) Clinical behavior of translucent-fiber posts: A 2-year prospective study *International Journal of Prosthodontics* **16(6)** 593-596.
12. Newman MP, Yaman P, Dennison J, Rafter M & Billy E (2003) Fracture resistance of endodontically treated teeth restored with composite posts *Journal of Prosthetic Dentistry* **89(4)** 360-367.
13. Utter JD, Wong BH & Miller BH (1997) The effect of cementing procedures on retention of prefabricated metal posts *Journal of the American Dental Association* **128(8)** 1123-1127.
14. Schmage P, Sohn J, Nergiz I & Ozcan M (2004) Various conditioning methods for root canals influencing the tensile strength of titanium posts *Journal of Oral Rehabilitation* **31(9)** 890-894.
15. Bachicha WS, DiFiori PM, Miller DA, Lautenschlager EP & Pashley DH (1998) Microleakage of endodontically treated teeth restored with posts *Journal of Endodontics* **24(11)** 703-708.
16. Mannocci F, Ferrari M & Watson TF (2001) Microleakage of endodontically treated teeth restored with fiber posts and composite cores after cyclic loading: A confocal microscopic study *Journal of Prosthetic Dentistry* **85(3)** 284-291.
17. Lanza A, Aversa R, Rengo S, Apicella D & Apicella A (2005) 3D FEA of cemented steel, glass and carbon posts in a maxillary incisor *Dental Materials* **21(8)** 709-715.
18. Asmussen E, Peutzfeldt A & Heitmann T (1999) Stiffness, elastic limit, and strength of newer types of endodontic posts *Journal of Dentistry* **27(4)** 275-278.
19. Rengo S (1999) Behavior of RTD fiber posts in finite element analysis (FEM) on three-dimensional models 20-27 In: Proceedings from 3rd International Symposium Adhesion and Reconstruction in Modern Dentistry Mason Milan.
20. Ukon S, Moroi H, Okimoto K, Fujita M, Ishikawa M, Terada Y & Satoh H (2000) Influence of different elastic moduli of dowel and core on stress distribution in root *Dental Materials Journal* **19(1)** 50-64.
21. Pegoretti A, Fambri L, Zappini G & Bianchetti M (2002) Finite element analysis of a glass fiber reinforced composite endodontic post *Biomaterials* **23(13)** 2667-2682.
22. Pierrisnard L, Bohin F, Renault P & Barquins M (2002) Corono-radicular reconstruction of pulpless teeth: A mechanical study using finite element analysis *Journal of Prosthetic Dentistry* **88(4)** 442-448.

23. Castro-Albuquerque R, Abreu-Polletto LT, Fontana RHBTS & Cimini CA Jr (2003) Stress analysis of an upper central incisor restored with different posts *Journal of Oral Rehabilitation* **30(9)** 936-943.

24. Lassila LVJ, Tanner J, Le Bell A-M, Narva K & Vallittu PK (2004) Flexural properties of fiber reinforced root canal posts *Dental Materials* **20(1)** 29-36.

25. Galhano G, Valandro LF, Melo RM, Scotti R & Bottino MA (2005) Evaluation of the flexural strength of carbon fiber-, quartz fiber-, and glass fiber-based posts *Journal of Endodontics* **31(3)** 209-211.

26. Aird F (1996) Molds In: *Fiberglass and Composite Materials* HPBooks New York.

27. Viquie G, Malquarti G, Vincent B & Bourgeois D (1994) Epoxy/carbon composite resins in dentistry: Mechanical properties related to fiber reinforcements *Journal of Prosthetic Dentistry* **72(3)** 245-249.

28. Wiskott HW, Nicholls JI & Belser UC (1995) Stress fatigue: Basic principles and prosthodontic implications *International Journal of Prosthodontics* **8(2)** 105-116.

29. Isidor F, Ödman P & Brondum K (1996) Intermittent loading of teeth restored using prefabricated carbon fiber posts *International Journal of Prosthodontics* **9(2)** 131-136.

30. Dietschi D, Romelli M & Goretti A (1997) Adaptation of adhesive posts and cores to dentin after fatigue testing *International Journal of Prosthodontics* **10(6)** 498-507.

31. Mannocci F, Ferrari M & Watson TF (1999) Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber and zirconium dioxide ceramic root canal posts *Journal of Adhesive Dentistry* **1(2)** 153-158.

32. Drummond JL & Bapna M (2003) Static and cyclic loading and fiber-reinforced dental resin *Dental Materials* **19(3)** 226-231.

33. Itinoche MK, Oyafuso DK, Miyashita E, Araujo MAM & Bottino MA (2004) Evaluation of influence of cyclic mechanical in flexural strength of ceramic *Brazilian Dental Science* **7(2)** 47-54.

34. Baldissara P (2003) Mechanical properties and *in vitro* studies In: Ferrari M, Scotti R *Fiber Posts Theoretical Considerations and Clinical Applications* Masson Milan.

35. Grandini S, Goracci C, Monticelli F, Tay FR & Ferrari M (2005) Fatigue resistance and structural characteristics of fiber posts: Three-point bending test and SEM evaluation *Dental Materials* **21(2)** 75-82.

36. Mannocci F, Sherriff M & Watson TF (2001) Three-point bending test of fiber posts *Journal of Endodontics* **27(12)** 758-761.

37. Pontius O & Hutter JW (2002) Survival rate and fracture strength of incisors restored with different post and core systems and endodontically treated incisors without coronoradicular reinforcement *Journal of Endodontics* **28(10)** 710-715.

38. Valandro LF, Özcan M, Melo RM, Galhano G, Baldissara P, Scotti R & Bottino MA (2006) Effect of silica coating on flexural strength of fiber posts *International Journal of Prosthodontics* **19(1)** 74-76.

39. Bolhuis P, de Gee AJ & Feilzer AJ (2004) Influence of fatigue loading on four post-and-core systems in maxillary premolars *Quintessence International* **35(8)** 657-667.

40. Bolhuis P, de Gee AJ & Feilzer AJ (2005) The influence of fatigue loading on the quality of the cement layer and retention strength of carbon fiber post-resin composite core restorations *Operative Dentistry* **30(2)** 220-227.

41. Galhano GAP, Melo RM, Barbosa SH, Valandro LF & Bottino MA (2005) Adhesive luting of zirconium post: Evaluation of the effect of the mechanical cycling *Brazilian Oral Research* **19 (Special Issue)** Abstract #Pb196 p 181.

42. Fredriksson M, Astback J, Pamenius M & Arvidson KA (1998) A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts *Journal of Prosthetic Dentistry* **80(2)** 151-157.

43. Mannocci F, Qualtrough AJ, Worthington HV, Watson TF & Pitt Ford TR (2005) Randomized clinical comparison of endodontically treated teeth restored with amalgam or with fiber posts and resin composite: Five-year results *Operative Dentistry* **30(1)** 9-15.

44. Goto Y, Nicholls JI, Phillips KM & Junge T (2005) Fatigue resistance of endodontically treated teeth restored with three dowel-and-core systems *Journal of Prosthetic Dentistry* **93(1)** 45-50.

45. Baldissara P, Di Grazia V, Palano A & Ciocca L (2006) Fatigue resistance of restored endodontically treated teeth: A multi parametric analysis *International Journal of Prosthodontics* **19(1)** 25-27.

46. Torbjorner A, Karlsson S, Syverud M & Hensten-Pettersen A (1996) Carbon fiber reinforced root canal posts *European Journal of Oral Science* **104(5-6)** 605-611.

47. Miettinen VM, Narva KK & Vallittu PK (1999) Water sorption, solubility and effect of post-curing of glass fibre reinforced polymers *Biomaterials* **20(13)** 1187-1194.

48. Valandro LF, Yoshiga S, Melo RM, Galhano GAP, Mallmann A, Marinho CP & Bottino MA (2006) Microtensile bond strength between a quartz fiber post and a resin cement: Effect of post surface conditioning *Journal of Adhesive Dentistry* **8(2)** 105-111.

49. Mallmann A, Jacques L, Valandro LF, Muench A & Mathias P (2005) Microtensile bond strength of light- and self-cured adhesive systems to intraradicular dentin using a translucent fiber post *Operative Dentistry* **30(4)** 500-506.

50. Giachetti L, Scaminaci Russo D & Bertini F (2003) [Utilizzo di adesivi e composite fotopolimerizzanti nella cementazione di perni translucenti: Analisi al SEM e Pull-out test] *Minerva Stomatologica* **42(4)** 133-144.

51. Valandro LF, Filho OD, Valera MC & Araujo MAM (2005) The effect of adhesive systems on the pull-out strength of a fiber glass-reinforced composite post system in bovine teeth *Journal of Adhesive Dentistry* **7(4)** 331-336.

52. Ferrari M, Mannocci F, Vichi A, Cagidiaco MC & Mjör IA (2000) Bonding to root canal: Structural characteristics of the substrate *American Journal of Dentistry* **13(5)** 255-260.

53. Ferrari M, Grandini S, Simonetti M, Monticelli F & Goracci C (2002) Influence of a microbrush on bonding fiber post into root canals under clinical conditions *Oral Surgery Oral Medicine Oral Pathology Oral Radiology & Endodontics* **94(5)** 627-631.

54. Ferrari M, Vichi A, Grandini S, Goracci C & Geppi S (2002) Influence of microbrush on efficacy of bonding into root canals *American Journal of Dentistry* **15(4)** 227-231.

55. Vichi A, Grandini S, Davidson CL & Ferrari M (2002) An SEM evaluation of several adhesive systems used for bonding fiber posts under clinical conditions *Dental Materials* **18(7)** 494-502.

56. Fernandes AS & Dessai GS (2001) Factors affecting the fracture resistance of post-core reconstructed teeth: A review *International Journal of Prosthodontics* **14(4)** 355-363.

57. Goracci C, Tavares AU, Fabianelli A, Monticelli F, Raffaelli O, Cardoso PC, Tay FR & Ferrari M (2004) The adhesion between fiber posts and root canal walls: Comparison between microtensile and push-out bond strength measurements *European Journal of Oral Science* **112(4)** 353-361.

58. An YH & Draughn RA (1999) The validity of a single push-out test. Mechanical testing of bone and bone-implant interface *CRC Press* Florida

59. Heydecke G & Peters MC (2002) The restoration of endodontically treated, single-rooted teeth with cast or direct posts and cores *Journal of Prosthetic Dentistry* **87(4)** 380-386.

60. Sutherland SU (2001) Evidence-based dentistry: Part IV. Research design and levels of evidence *Journal of the Canadian Dental Association* **67(7)** 375-378.