Effects of Mechanical Cycling on the Bonding of Zirconia and Fiber Posts to Human Root Dentin

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Purpose: To evaluate the effect of cyclical mechanical loading on the bond strength of a fiber and a zirconia post bonded to root dentin.

Materials and Methods: Forty single-rooted human teeth (maxillary incisors and canines) were sectioned, and the root canals were prepared at 12 mm. Twenty randomly selected specimens received a quartz fiber post (FRC) (D.T. Light-Post) and 20 others received a zirconia post (Zr) (Cosmopost). The posts were resin luted (All Bond 2 + resin cement Duo-Link) and each specimen was embedded in epoxy resin inside a PVC cylinder. Ten specimens with FRC post and 10 specimens with Zr post were submitted to fatigue testing (2,000,000 cycles; load: 50 N; angle of 45 degrees; frequency: 8 Hz), while the other 20 specimens were not fatigued. Thus, 4 groups were formed: G1: FRC+0 cycles; G2: FRC+2,000,000 cycles; G3: ZR+0 cycles; G4: ZR+2,000,000 cycles. Later, the specimens were cut perpendicular to their long axis to form 2-mm-thick disk-shaped samples (4 sections/specimen), which were submitted to the push-out test (1 mm/min). The mean bond strength values (MPa) were calculated for each tooth (n = 10) and data were submitted to statistical analysis (α = 0.05).

Results: Two-way ANOVA revealed that the bond strength was significantly affected by mechanical cycling (p = 0.0014) and root post (p = 0.0325). The interaction was also statistically significant (p = 0.0010). Tukey's test showed that the mechanical cycling did not affect the bonding of FRC to root dentin, while fatigue impaired the bonding of zirconium to root dentin.

Conclusion: (1) The bond strength of the FRC post to root dentin was not reduced after fatigue testing, whereas the bonding of the zirconia post was significantly affected by the fatigue. (2) Cyclical mechanical loading appears to damage the bond strength of the rigid post only.

Keywords: mechanical cycling, fiber post, zirconia post, adhesive cementation, push-out test, fatigue test, clinical study.

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Endodontically treated teeth often require placement of root canal posts for anchorage and retention of the crown reconstruction. Considering the principles of minimally invasive dentistry, adhesively luted, prefabricated root canal posts seem better able to meet the requirements of minimal intervention. Fiber-reinforced composite posts (FRC) present a modulus of elasticity (E) close to that of dentin (E_post = 40 GPa; E_dentin = 16 GPa), allowing more uniform absorption and distribution of stresses to the remaining root structure, instead of concentrating the stresses. Stress concentration has been related to cast posts (metallic or ceramic) and metallic and zirconium oxide (E_post = 200 GPa) prefabricated posts, since they possess a higher E than dentin. The integrity of the resin cement employed for post luting may be affected by the different modulus of elasticity between post and cement due to the unequal distribution of
Table 1. Composition of the groups

<table>
<thead>
<tr>
<th>Post</th>
<th>Adhesive system</th>
<th>Mechanical cycling</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRC</td>
<td>All Bond 2</td>
<td>0</td>
<td>G1</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>2,000,000 cycles</td>
<td>G2</td>
</tr>
<tr>
<td>ZR</td>
<td>DuroLink</td>
<td>0</td>
<td>G3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2,000,000 cycles</td>
<td>G4</td>
</tr>
</tbody>
</table>

stresses on the adhesive system when a mechanical load is applied.\textsuperscript{5,9,17} Utilization of rigid root canal posts leads to stress concentration at the apical portion of the post,\textsuperscript{5,9,17} which may affect the bond strength. On the other hand, posts with a low modulus of elasticity present higher flexure, which produces higher stresses at the cervical region and may also affect the bonding to dentin.\textsuperscript{5,9,17}

Even though some finite element and in vitro studies have demonstrated the risks of using ceramic posts,\textsuperscript{5,9,17} no clinical studies are available to validate the laboratory findings. Similarly, no investigation has addressed the possible effects of mechanical cycling on the bond strength between dentin and fiber or dentin and zirconia posts, simulating 10 years of clinical function.\textsuperscript{18,21}

Thus, this study evaluated by push-out testing the effect of mechanical cycling on the bond strength between the root dentin and adhesively luted fiber and zirconia posts. The null hypothesis was that mechanical cycling does not affect the bond strength to the fiber post, but it damages the bond to the zirconia post.

MATERIALS AND METHODS

Forty single-rooted human teeth (maxillary incisors and canines) were cleaned with pericoronal curettes and stored in distilled water. The coronal and cervical portions of the root were sectioned to standardize the size of the specimens at 16 mm. Thereafter, the coronal diameters of the canals were measured with a digital caliper (Starrett 727, Starrett, Itu, Brazil) and specimens presenting diameters much larger than the diameter of the post (1.6 mm) were discarded and replaced by other specimens that met this requirement. The canals were sequentially instrumented and irrigated with 0.5% sodium hypochlorite.

Twelve millimeters of the root canal were first prepared with large drills #2. The 40 teeth were randomly divided into 2 groups for canal preparation as follows: 20 teeth were prepared with custom burs #3 of the double-tapered quartz fiber-reinforced composite post system (FRC) (D.T. Light-Post, Bisso, Schaumburg, IL, USA) (Ωpost = 1.5 mm; elastic modulus = 20 to 30 GPa). The other 20 teeth were prepared with calibration burs #3 of the tapered zirconium dioxide (zirconia) post system (ZR) (Cosmopost, Ivoclar-Vivadent; Schaan, Liechtenstein) (Ωpost = 1.5 mm; elastic modulus = 200 GPa).

The same procedures were used to lute the 2 types of post.

Post Surface Conditioning

Post surfaces were conditioned by air abrasion with 30 μm Al₂O₃ particles modified with SiOx (CoJet-Sand, ESPE; Seefeld, Germany), employing a blasting protocol of 2.8 bars pressure, 10 mm distance, perpendicular to the post surface, for 20 s. Thereafter, ESPE-Sil silane was applied and allowed to dry for 5 min.

Root Canal Deninm Conditioning

A multiple-bottle total-etch adhesive system (All Bond 2, Bisso) was used. First, dentin was etched with 32% phosphoric acid for 30 s, followed by washing with 10 ml of water from a disposable syringe. Excess water was removed with # 8 absorbent paper points (Dentsply/Maillerfer; Petropolis, Brazil). Then Primer A and Primer B were mixed and applied; excess material was removed with the Cavi-tip brush (3D). Finally, Pre-Bond resin was applied and excesses removed with a brush.
Post Cemenation
The A and B pastes of the resin cement Duclink (Elasco) were measured and mixed. The cement was brought into the root canal with a Lentulo # 40 spiral (Maillefer; Genf, Switzerland) and also with the post. Light curing was conducted through the incisal surface for 40 s with the XL 3000 unit (3M ESPE; St Paul, MN, USA) at a light intensity of 450 mW/cm².

After cemenation, each specimen was embedded in a PVC cylinder (height: 25 mm, diameter: 12 mm) filled with epoxy resin (resin 285, Schaller; Florence, Italy) up to 3 mm of the most coronal portion of the specimens. The long axis of the specimens was embedded perpendicular to the ground. The specimens were then stored in distilled water at 37 °C for 24 h until fatigue testing.

Fatigue Testing
Ten specimens with fiber posts and ten with zirconia posts were submitted to fatigue testing (Fig 1). They were placed in a metallic base at a 45-degree angle, so that a point with 1.6 mm diameter at the upper rod of the cycling machine could induce load pulses of 50 N, at a frequency of 6 Hz, directly on the post. During cycling, the specimens were irrigated with water at 37 ± 1°C, as regulated by a thermostat. Two million cycles were executed, simulating approximately 10 years of clinical service.

Considering the two factors examined in this study – the kind of post (zirconia and fiber) and mechanical cycling regimens (0 and 2 million cycles) – 4 groups were formed (n=10) (Table 1).

For standardization of the water storage period, all specimens were kept in distilled water (37 ± 2°C) for the same period, regardless of whether mechanical loading was performed or not. The storage period was defined according to the time required for cycling of G2 and G4 (about 3 months).

Push-out Strength Test and Statistical Analyses
Each specimen was fixed on a metallic base on the cutting machine, which enabled perpendicular sectioning into ca 2-mm-thick slices along the root axis with a diamond disk under water-spray cooling spray. The first cervical slice (approx 1 mm) was discarded, given that the excess of cement in that region could influence the result of the adhesive strength. For five to other disk-shaped samples were produced per specimen.

Each sample was positioned on a metallic device with a central opening larger than the canal diameter. The most coronary sample portion had previously been placed downwards. For push-out testing, a metallic cylinder (diameter 0.85 mm) induced load from apical to coronal on the post without being applied to the cement and/or dentin. Considering that the posts were cemenated parallel to the root canal axis and the specimens were sectioned perpendicular to that axis, the post underwent parallel pressure to the highest possible extent in relation to the root axis. The test was performed in a universal testing machine (EMIC; São José dos Pinhais, Brazil) at a crosshead speed of 1 mm/min.

The bond strength (σ) in MPa was obtained by means of the formula σ = F/A, where F = load for sample rupture (N) and A = bonded area (mm²). For area calculations (Fig 2), a formula was applied to calculate the lateral area of the geometric figure circular straight cone trunk of parallel bases: A = π · g · h · (R₁ + R₂), where π = 3.14, g = trunk generatrix, R₁ = smaller base radius, R₂ = larger base radius. For conic trunk generatrix calculation g(Fig 2, B), the Pythagorean theorem was used (g² = h² + (R₂ - R₁)²) with terms defined as above and h = section height. R₁ and R₂ were obtained by measuring the internal diameters of the smaller and larger base, respectively, corresponding to the internal diameter between the sample canal walls. These diameters and the height h of the sample were measured after the test with digital calipers (Starrett 727, Starrett).

The bond strength data were submitted to two-way ANOVA and the post-hoc Tukey test (α = 0.05).

RESULTS
All 10 specimens of each post system survived the fatigue test. No root post fracture and no loss of retention of the posts were observed.
The results of two-way ANOVA of the push-out bond strength data are given in Table 2. They show that the bond strength was significantly affected by mechanical cycling (p = 0.0014) and root post (p = 0.0325). The interaction was also statistically significant (p = 0.0010).

The post-hoc Tukey test (Table 3) showed that the mechanical cycling did not affect the bonding of FRC to root dentin, while the fatigue impaired the bonding of the zirconia post to root dentin (Fig 3). The null hypothesis was confirmed, since bonding to the fiber post was not affected, while bonding to the zirconia post was impaired.

**DISCUSSION**

The present study observed that mechanical cycling did not alter the bond strength for the quartz fiber post investigated (0 cycles = 6.8 ± 2.2 MPa; 2,000,000 cycles = 6.9 ± 1.9 MPa), while the bond strength to the zirconia post was reduced by the fatigue test (0 cycles = 7.7 ± 1.3 MPa; 2,000,000 cycles = 3.3 ± 2.3 MPa). Studies of analysis of stress distribution may explain this result, since the stresses produced during the fatigue test were probably uniformly distributed along the fiber post/cement/root dentin interface, and thus a larger dentin area supported the load applied. In contrast, for the zirconia posts, the stress concentrated in a restricted zone, reducing the bond strength. These results corroborate the findings of two recent studies, which also revealed that mechanical cycling (10^6 cycles) did not affect the bond strength between the root dentin and adhesively luted fiber posts.

Adhesively luted fiber posts have a greater ability to absorb stress and a more homogeneous redistribution of stresses to the remaining tooth structure, since their modulus of elasticity (E) is similar to that of dentin. Stress concentration has also been found with cast posts (metallic or ceramic) and prefabricated metallic posts (titanium and stainless steel) and ceramic posts (zirconia), since their E is considerably higher than that of dentin.

Based on these studies of stress distribution, the effect of stress concentration on the root canal walls associated with posts having high E seems to be significant, which may perhaps facilitate the degradation of adhesion, since a smaller area of the structure supports more stress. However, posts with an elasticity modulus similar to that of dentin allow more uniform stress distribution in the root, thus reducing the risk of fracture of the remaining tooth structure.

Some authors have observed a reduction in the mechanical properties of FRC after storage in water, Torbjörner et al. stored FRC in water (37°C) for four months and observed a reduction in flexural strength. They explained that the organic matrix of FRC allows water sorption, and this increased matrix volume exerts stresses on the matrix-fiber interface, which affects the mechanical properties. Miettinen et al. observed high values of water sorption by organic matrices constituting fiber-reinforced polymers. They mentioned that sorption depends on the type, homogeneity, and degree of conversion of the organic matrix, and may affect the hydrolytic stability of fiber-reinforced polymers. Lassila et al. evaluated the effect of storage (two weeks) and thermal cycling (12,000x) on the flexural strength of different fiber posts and observed that this property was reduced by approximately 16%. Obviously, in the present study, besides the effect of water, the mechanical fatigue may have increased the effects of degradation of the organic matrix and the fiber/matrix Interface. In the current study, the time from post luting until the fatigue test (2 x 10^6) was approximately 3 months, during which the fiber and zirconia posts were in contact with water. They were nonetheless resistant to fatigue.

The scope of this study did not include coronal buildup of endodontically treated teeth. Other investigations must be conducted to evaluate the performance of endodontically treated teeth restored with crowns retained by root posts in order to better simulate the clinical conditions.

Although the current study demonstrated more encouraging results for the fiber post, the adhesive Interfaces may degrade during 10 years of clinical service, potentially leading to restoration failure. Thus, further randomized clinical studies must be conducted to more comprehensively compare this post system to others.
CONCLUSIONS

(1) The bond strength of FRC to root dentin was not reduced after the mechanical fatigue test, whereas the bonding of the zirconia post was significantly affected by fatigue.

(2) Mechanical cycling appears to damage the bond strength of the rigid post only, probably due to stress concentrations arising from of the high modulus of elasticity of this type of post.

REFERENCES


Clinical relevance: The resin bond to fiber posts seems to bear the impact from mechanical fatigue better than the resin bond to rigid zirconium posts.