

Effect of Cyclic Loading on Bond Strength of Fiber Posts to Root Canal Dentin

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Abstract

Objective: The aim of this study was to evaluate the effect of cyclic loading on the bond strength of quartz fiber posts to root canal dentin after different surface treatments of different regions of root canal dentin.

Materials and Methods: Forty-eight single-rooted human teeth were selected. Post spaces were prepared and then the teeth were divided into four groups: G1: no treatment (control); G2: irrigation with a chemical solvent; G3: etching with 37% phosphoric acid; G4: treatment with ultrasonic file. The fiber posts were cemented using dual-cured resin cement. Half of the specimens were load-cycled (10000 cycles, 3 cycles/s) and the others did not undergo any load cycling. From each root, two slides measuring 1 mm in thickness were obtained from the apical and cervical regions. The push-out bond strength test was performed for each slice. Data were analyzed by using 3-way ANOVA and Tukey HSD tests. The fracture modes were evaluated under a stereomicroscope at $\times 20$.

Results: The effect of load cycling and surface treatment as the main factors and the interaction of main factors were not significant ($P=0.734$, $P=0.180$, and $P=0.539$, respectively). The most frequent failure mode under the stereomicroscope was adhesive.

Conclusion: It appears that load cycling and surface treatment methods had no effect on the bond strength of fiber posts to root canal dentin, but it depended on the region of the root canal dentin.

Key Words: Resin Cements; Post and Core Technique; Root Canal Preparation; Dual Cure Resin Cement, Acid Etching

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INTRODUCTION

Restoration of endodontically treated teeth is one of the problems in dentistry. When there are no sufficient tooth tissues and retention of the core is questionable, posts would be indicated [1,2].

Nowadays, fiber posts as an acceptable alternative for metal posts are routinely used [3,4]. Some advantages of fiber posts over metal posts are improvement of esthetics, bonding to dentin, resistance to corrosion and minimizing the root fracture risk [5,6].

Previous studies have reported that the weakest surface is the dentin–resin interface [7,8]. Preparing the post space results in a thick smear layer. This layer and residual gutta-percha and sealer may decrease the bond strength between the cement resin and intraradicular dentin [9]. It has been shown that removal of the smear layer and diffusion of resin within the dentin affect the efficacy of the dentin adhesive [10].

Various methods have been introduced for post space treatment, such as application of H₂O₂, NaOCl, chlorhexidine, 17% EDTA, etching with acids and using ultrasonic files in the root canal [11-13]. Demiryürek [7] showed that treatment of root dentin with Sikko Tim, 37% orthophosphoric acid and 10% citric acid considerably increased the bond strength to dentin. Zhang et al.¹⁴ reported that application of 35% phosphoric acid and EDTA/NaOCl irrigation with ultrasonic file improved adhesion between resin and dentin.

Serafino [9] demonstrated that using ultrasound agitation in combination with etching removed the smear layer from the root canal surface. Another study revealed that EDTA cleaned root canal walls and subsequently increased bond strength at different regions of the roots.

Recent studies have measured bond strength under an immediate load [7,15,16]. Since teeth usually withstand the forces during mastication and parafunctional habits [17], performing in vitro studies which simulate situations similar to the oral environment provide relevant results. Albaladejo reported that microtensile bond strength decreased when the specimens underwent load cycling, [18] while Bolhuis reported that fatigue loading had no effect on the retention strength of carbon fiber post to composite core [19].

To our knowledge, only limited data are available on the effect of cyclic loading on the bond strength of fiber posts to root canal dentin after different post space treatments. Therefore, the aim of this study was to evaluate the

influence of cyclic loading on the bond strength of quartz fiber posts to different regions of root canal dentin after different surface treatments of the canal dentin.

The null hypothesis stated that load cycling and regions of the root had no effect on the bond strength of fiber posts to treated root canal dentin.

MATERIALS AND METHODS

Forty-eight straight, single-rooted, human maxillary central incisors and canines were selected for this study. Freshly extracted teeth were cleaned with periodontal curette and stored in 10% formalin. The teeth were placed in 1.23% chlorhexidine for 2 hours and then stored in 0.9% saline solution at room temperature until use. All the teeth underwent radiographic examination to evaluate root integrity. The roots did not display cracks, caries, resorption, or canal calcification and had closed apices. All the teeth used in this study had similar root shape and size.

The crowns of the teeth were cut at the cemento-enamel junction using a low-speed water-cooled diamond disc (910 D; Diatech; Goldene AG, Altstätten, Switzerland). To standardize the root canal diameter, the mean diameter ($\bar{\mu}$) of the root canal at the coronal portion of all roots was measured under a light microscope (Leica M – 10 Wild, Heerbrugg, Switzerland), considering $\bar{\mu} = (\bar{\mu}_{\text{buccolingual}} + \bar{\mu}_{\text{mesio-distal}})/2$. Specimens with a larger diameter than the estimated post diameter were replaced. After endodontic access, the root canals were instrumented with K-files (Mani Inc, Tochigi, Japan) using the step-back technique.

The apical portion was prepared to a #40 master file. The coronal portion of each canal was enlarged with #2 to #4 Gates-Glidden drills (Mani Inc., Tochigi, Japan). The root canals were irrigated with normal saline and then dried with absorbent paper points (Maillefer–Dentsply, Ballaigues, Switzerland). The canals were obturated with gutta-percha points (Dia-

dent Group Int., Seoul, Korea) and AH-plus sealer (AH-plus; Dentsply De Trey GmbH, Konstanz, Germany) using the lateral condensation technique. Temporary filling material (Cavit G, 3M Espe, Seefeld, Germany) was used to seal the coronal cavity.

After storage in distilled water for 1 week at room temperature, the sealing material was removed with a #2 Peeso reamer (Mani Inc, Tochigi, Japan). Then, gutta-percha was removed with a low-speed #3 drill from the DT light-post system (Bisco, Schaumburg, IL, USA) to a depth of 9 mm. The roots were divided into four groups (n=12) according to the surface treatment used:

Group 1: No canal treatment (control group).

Group 2: The canals were treated with a synthetic chemical solvent in organic chemistry laboratory with compositions of acetone, 33%; ethanol, 33%; and ethyl acetate, 34%, for 15 seconds.

Group 3: The canals were etched with 37% phosphoric acid (Total Etch, Ivoclar Vivadent, USA) for 15 seconds.

Group 4: The canals were treated with a #15 ultrasound file (Piezon Master 400; EMS, Nyon, Switzerland) using 10 mL of normal saline as irrigant.

In this study, quartz fiber posts #2 (RTD, St. Egeven, France) were used. Post spaces were dried with absorbent paper points (Maillefer, Dentsply, Ballaigues, Switzerland). For the application of adhesive resin cement (Panavia F2.0, Kuraray Co. Ltd, Osaka, Japan), one drop of each of ED primer liquid A and B were mixed for 5 seconds in a mixing well of a dappen dish. Then, the mixture was applied to post space walls with a microbrush for 10 seconds. Excess primer solution was removed with paper points, and the primer was then gently air-dried. Equal amounts of a dual-polymerized resin-luting agent paste base and catalyst (Panavia F 2.0; Kuraray Co. Ltd, Osaka, Japan) were mixed and applied to the post space according to the manufacturers' instructions. The posts were then seated to full depth

in the prepared spaces using finger pressure and excess luting agent was removed with a sponge pellet. Subsequently, the bonding margins were light polymerized with a light-curing unit (Hilux LED 550; Benlioglu Dental, Ankara, Turkey) for 20 seconds. The tip of the polymerization unit was placed in direct contact with the coronal end of the posts and the specimens were irradiated. Core was built up around the fiber post with a light-cured composite resin (Filtek P60, 3M ESPE, USA) to a height of 4 mm. The specimens were stored in water at room temperature for 24 hours. Then, the specimens were subjected to 2500 thermal cycles between 55°C and 5°C using a digital thermocycling machine (Willytec/SD, Mechatronik GmbH, Munich, Germany), with a dwell time of 60 seconds and a transition time of 15 seconds. For cyclic loading procedure, in each group, half of the prepared teeth (n=6) were mounted in acrylic blocks at an angle of 45° and were placed in a universal testing machine (Zwickroll, Z050, Zwick GmbH, Ulm, Germany) for mechanical cycling. The upper rod of the cycling machine could apply load pulses from 15 N to 45 N at a frequency of 3 Hz onto the core buildup. During cycling, the teeth were irrigated with water at 37°C, as regulated by a thermostat. The specimens were cycled 100000 times at a crosshead speed of 1 mm/min. The other teeth from each group, which were not subjected to cyclic loading, were stored in distilled water until load cycling was completed. Each root was sectioned perpendicular to its long axis from the coronal to the apical direction under water cooling using a high-speed machine (Meccatom T201A; Persi Co., France). Two slices, each 1-mm thick, were obtained from the root apical and cervical regions and 4 slices were finally prepared from each root. The thickness of each slice was measured by a digital gauge (Mitutoyo CD15, Mitutoyo Co., Kawasaki, Japan). For each final slice, push-out bond strength was performed using a universal testing machine (Zwickroll, Z050, Ulm, Germa-

ny) at a crosshead speed of 0.5 mm/min until failure occurred. The point of bond failure was recorded in Newton (N).

Push-out bond strength values were calculated in MPa by dividing this force by the bonded interface of the post segment, which was calculated with the following formula:

$$A = N / 2\pi rh$$

Where π is 3.14, r is the post radius, and h is the thickness of the slice in mm.

After the push-out test, failure modes of the samples were assessed using a stereomicroscope (Nikon Eclips E600, Tokyo, Japan) at $\times 20$ and recorded as follows:

- 1) Cohesive, if the fracture occurred in the post or dentin
- 2) Adhesive, if the fracture occurred at post–dentin interface
- 3) Mixed, when a combination of adhesive and cohesive failure occurred

Data were analyzed using statistical software (SPSS 13.0, SPSS Inc., Chicago, IL). Means of bond strength values were compared by three-way ANOVA.

Then, the Tukey HSD test was used for paired comparisons. Statistical significance was set at the 5% level.

RESULTS

Mean and standard deviation of the studied groups for push-out bond strength are presented in Table 1.

Results of three-way ANOVA indicated that bond strength of fiber post to root dentin was not affected by the factors of "mechanical cycling" ($P=0.549$), "surface treatment of root canal dentin" ($P=0.279$) and their interactions ($P=0.774$); whereas, "region of the root canal" as the main factor showed significant differences ($P=0.004$). Push-out bond strength for cervical regions was higher in comparison with the apical regions ($P=0.004$). The interactions of mechanical cycling and region of the root canal and also surface treatment and region of the root canal was not significant ($P>.05$). Stereomicroscopic assessment is summarized in Tables 2 and 3. The results showed that the adhesive failure was the most predominant mode of failure (Fig 1).

Table 1. Mean & Standard Deviation of the Studied Groups

Group	Mean (MPa) \pm SD	N	Min (MPa)	Max (MPa)
Control	25.41 \pm 8.75	48	7.06	42.75
Chemical Solvent	27.92 \pm 9.36	48	8.20	51.39
Phosphoric Acid 37%	28.90 \pm 10.54	48	9.46	49.05
Ultrasonic File	26.58 \pm 8.60	48	7.38	42.46
With Load Cycling	26.80 \pm 9.42	96	7.06	48.69
Without Load Cycling	27.61 \pm 9.37	96	7.38	51.39
Cervical Region	29.19 \pm 8.22	96	10.88	51.39
Apical region	25.22 \pm 10.06	96	7.06	49.05

Table 2. Distribution of fracture modes in the apical region

Surface Treatments	Without Mechanical Cycling			With Mechanical Cycling		
	Adhesive	Cohesive	Mixed	Adhesive	Cohesive	Mixed
Control	12	0	0	12	0	0
Chemical solvent	12	0	0	12	0	0
Phosphoric acid	10	0	2	11	0	1
Ultrasound file	12	0	0	11	0	1



Fig 1. Stereomicroscopic view of the fractured surface in the chemical solvent group in the apical region without mechanical cycling, showing adhesive failure

Stereomicroscopic assessment is summarized in Tables 2 and 3. The results showed that the adhesive failure was the most predominant mode of failure (Fig 1).

DISCUSSION

In order to increase retention of fiber posts in the root canal, it is necessary to improve their clinical performance and long-term service.

In vitro studies that simulate the clinical situations might be useful in this respect. To focus on these issues, the aim of the present study was to evaluate the effect of cyclic loading on the bond strength of quartz fiber posts to different regions of the root canal dentin after different surface treatments of the root canal dentin.

The results indicated that mechanical cycling did not decrease the bond strength of quartz fiber posts to root canal dentin significantly, consistent with the results of studies focusing on stress distribution [19-21].

This finding might be attributed to the better stress distribution of fiber posts due to similarity of their elastic modulus to root dentin. Valandro et al. concluded that mechanical loading has no adverse effects on the adhesion between two fiber posts and root dentin [22]. In contrast, the results of a study by Galhano revealed that the bond strength of zirconium post to root dentin is compromised when specimens are subjected to cyclic loading. Rigidity and high modulus of elasticity of zirconia posts concentrate stresses at the post-dentin interface [23].

Table 3. Distribution of Fracture Modes in the Cervical Region

Surface Treatments	Without Mechanical Cycling			With Mechanical Cycling		
	Adhesive	Cohesive	Mixed	Adhesive	Cohesive	Mixed
Control	11	0	1	12	0	0
Chemical Solvent	12	0	0	12	0	0
Phosphoric Acid	12	0	0	11	0	1
Ultrasound File	11	0	1	11	0	1

Bottino et al. reported that flexibility of the post plays an important role in the bond strength of the post to root dentin after load cycling [24].

The results of this study showed that chemical solvent application, phosphoric acid etching and treatment with ultrasound file did not significantly increase the bond strength of fiber posts to root dentin. Pretreatment of root dentin with acid removes the smear layer and smear plug, opens dentinal tubules, demineralizes intertubular and peritubular dentin and exposes the collagen fibers. Inter-diffusion zone forms on the etched dentin substrate by penetration of adhesive resins [25]. However, the present study demonstrated that the bond strength did not significantly increase after treatment with phosphoric acid. Contrary to the results of this study, Zhang et al. [14] demonstrated that application of phosphoric acid could significantly increase bond strength. An explanation could be that the applied bonding system and resin cement used in their study was different. Application of a chemical solvent did not significantly increase the bond strength of fiber posts. Conversely, Demiryurek [7] et al. showed that the bond strength of fiber posts significantly increased after treatment with Sikko Tim (chemical solvent). The chemical solvent removes the remnants of resin sealer and gutta-percha and increases the bond strength between the resin cement and dentin. In this study, treatment with ultrasound file did not significantly improve the bond strength. Zang et al. demonstrated that ultrasonic agitation in combination with EDTA/NaOCl irrigation improved the push-out strength of the fiber post. [14] In their study, a chemical irrigant was applied in combination with ultrasonic agitation and this may explain the negative results.

In addition, a previous study reported that treatment with ultrasound file increased the bond strength of fiber posts. A combination of etching and ultrasound file was applied in that study, while we used only ultrasound files.

This might explain the controversy. The results of push-out bond strength for different root regions in this study revealed that the bond strength was significantly affected by the region of the root canal. Push-out bond strength for the cervical segments in this study was higher than that for the apical segments. An explanation for this could be low-density tubules and orientation of tubules in the apical regions of the root canal. Another reason might be insufficient polymerization in apical regions due to difficult accessibility. A favorable handling in the cervical rather than the apical region leads to better achievements and higher bond strength. The results of the present study were consistent with the studies conducted by Ohlmann et al. [15] and Kalkan et al. [16]. The debonded specimens were assessed under a stereomicroscope. It was found that adhesive fracture was the most common mode of failure, confirming that the weakest area was the post-dentin interface.

In this study, the specimens were loaded 100000 cycles under 15-45 N, representing the recorded occlusal forces during mastication and swallowing [19].

In the present study, the push-out test was used for measuring the bond strength of the cemented fiber posts. Application of the thin-slice design of specimens in this test provides uniform distribution of the stresses. In addition, measurement of retention strength in different regions is possible [14]. Goracci et al. concluded that a push-out test is more accurate than a microtensile technique and there is a narrow spread for data distribution. Moreover, in measuring the bond strength with the microtensile test, more premature failures occurred compared with the push-out test [20]. It is necessary to carry out further studies to reinforce bond in post-cement-dentin interfaces. In this study, only various treatments on dentin surface with an adhesive system and a luting cement were evaluated; it is recommended to assess different adhesive systems and luting cements.

CONCLUSION

Based on the results presented in this research, push-out bond strength for the cervical region was higher than that for the apical region. It was shown that the bond strength of fiber post to root dentin was not affected by the mechanical cycling and different surface treatments of root canal dentin.

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