The effect of environmental pressure and resin cements on the push-out bond strength of a quartz fiber post to teeth root canals

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ABSTRACT

Aim: To evaluate the effect of environmental pressure changes on the bond strength between a fiber post and one of three resin cements using different mixing methods and modes of application.

Methodology: Sixty single-canal human teeth were divided into three groups (n=20) and endodontically treated. Post spaces were prepared, and a quartz fiber post was secured with either a self-adhesive machine-mixed cement (RelyX Unicem, Aplicap), a self-adhesive hand-mixed cement (RelyX Unicem), or a self-etching dual-cured resin cement (Panavia F2). Half of each group was subjected to 24 pressure cycles from 0 to 5 atmospheres. The mean push-out bond strength of the posts was calculated and statistically analyzed using ANOVA and Tukey tests (α = 0.05).

Results: Regardless of the pressure, Unicem Aplicap achieved the highest bond strength (P<0.05). The bond strengths of all groups were significantly lower after they were subjected to the pressure cycles (P < 0.003), and they were lower in the apical regions.

Conclusion: Bond strengths between the fiber post and root canal can be affected by environmental pressure while the type of resin cements, their mixing methods and modes of application incorporated lower porosity, achieving higher bond strength.

INTRODUCTION

Use of fiber posts in restoring root canal-treated (RCT) teeth has become a common practice. This is because it has become evident that this type of post carries a lower risk of root fracture compared to more rigid types of posts, such as those constructed from metal and ceramic [1,2]. This desirable quality is attributed to the modulus of elasticity, averaging 30 gigapascals (GPa), which is close to that of dentin, which averages 15 GPa. This promotes better stress distribution in the root canal space [3]. It was argued that the stress is concentrated along the cement interface of a bonded fiber post, whereas it shifts to the apical portion in a metal post. The latter can promote the risk of root fracture [4].

The stress pattern in an RCT tooth restored with a fiber post and adhesive cement can be similar to that in an intact tooth, provided that the bonded interface is flawless and continuous [5]. In practice, achieving a perfect, cohesive, bonded interface is unlikely because of the challenges in the root canal environment, such as the anatomical and histological characteristics of root dentin [6], limited visibility and control [7], limited light exposure and limited depth of curing, particularly in the apical third [8,9], and a high configuration factor [10].

It is suggested that the configuration factor is the main reason for high shrinkage stress when resin cement sets, and it could be high enough that debonding along the dentin/cement/post interface can occur before or after thermomechanical loading [11-13]. Several studies showed that mechanical or/and thermal stresses could increase the stress in the cement layer, lowering the bond strength between the resin and the dentin and/or

KEYWORDS: environmental pressure, push-out test, quartz fiber post, resin cement
These findings are supported by clinical studies that showed debonding was the most frequent mode of failure when fiber posts were used [2,16].

Unlike thermal and mechanical conditions that impact restorations intermittently, environmental pressure typically has a relatively constant effect in the oral cavity. However, there are situations that introduce temporary barometric changes on the body, such as high-altitude flights, diving, and working in hyperbaric pressures [17,18]. The increasing number of people who are exposed to these circumstances calls for provision of prevention and treatment of the side effects that those activities can introduce in the oral cavity and to dentition.

In the 1940s, it was evident that exposure to air pressure alterations could cause pain and other discomforts among pilots and air crew, occasionally leading to sudden incapacitation. The phenomenon of barometric-induced pain in the orofacial region was originally called barodontalgia [18]. Dental barotrauma is the term for barometric-induced tooth fracture, restoration loss, and displacement. With the growing use of the self-contained underwater breathing apparatus (scuba) in the middle of the 20th century, in-flight oral manifestations of barometric change have been reported among divers as well [19].

It was suggested that barodontalgia and barotrauma could be seen at altitudes as low as 3,000 meters and in water as shallow as 10 meters [17]. Seven cases of barotrauma and barodontalgia were reported that occurred during commercial flights and flight training sessions [20]. In a survey [21], it was estimated that 1% of recreational scuba divers experienced barotrauma. The effect of pressure on the retention of full cast crowns has been evaluated in two studies showing that pressure change could impair the retention of crowns cemented with zinc phosphate but did not affect crowns placed with resin cements [22,23]. The effect of pressure changes on the bond strength of fiber posts has not yet been investigated.

Few studies addressed the effect of mixing methods on the porosity of the cement and their correlations to the strength of the cement [24-27]. However, while the results were not consistent, the bond strength between fiber posts and resin cements was found higher when the mode of application incorporated fewer voids and air inclusions [14,24]. On the contrary, in another study, mixing mode and application revealed no effect on the bond strengths of fiber posts cemented with self-adhesive cements [25].

Therefore, the aim of this study was to examine the effect of environmental pressure changes on the bond strength between fiber posts and resin cements mixed and applied in various ways. The null hypothesis was that neither pressure alteration cycles nor the resin cements have influences on the push-out bond strength between fiber posts and root canal dentine.

MATERIALS AND METHODS

Sixty single-rooted, single-canal human teeth which were recently (within three months) extracted because of periodontal or orthodontic treatments were included in this study. Informed consent was received from all patients according to the Clinical Research Ethics Board at Tehran University of Medical Sciences protocol. The teeth were cleaned of tissue tags and debris using a hand instrument and air stream, followed by an ultrasonic scaler, then stored in 1% chloramine for one week and then normal saline until use. Teeth were required to be free of caries, previous fillings, cracks and excessive wear, with nearly straight roots, 15mm in length.

Teeth were decoronated from the most coronal portion of the cementoenamel junction on the buccal side using a diamond disc in a rotary handpiece tool under cool running water. Each tooth was instrumented at a working length where a #10 K-file tip (Mani Inc., Kiohara Industrial Park, Tochigi, Japan) passed the apical foramen. Canals were prepared to a master file size of 40 to 45 using a step-back technique, and then irrigated with 1ml of 2.5% sodium hypochlorite. Files were replaced after use in four canals. Root canals were finally irrigated with distilled water, dried with absorbent paper points (Meta Biomed Co. Ltd., Cheongju City, Cungbuk, Korea) and obturated with gutta-percha (Meta Biomed Co. Ltd., Cheongju City, Cungbuk, Korea) and a eugenol-free sealer (AH26, DeTrey Dentsply, Konstanz, Germany) using a lateral-condensation technique. The coronal portion was sealed using a glass ionomer cement (GC Fuji II, GC America, Alsip, Illinois, U.S.) and stored in 100% humidity and 37°C for seven days.
The post space was prepared by removing the filling material and enlarging it with a low-speed universal drill (D.T. Light-Post Illusion kit, Bisco, Inc., Schaumburg, Illinois, U.S.) followed by drills #1 and #2 for canine and central teeth and #1 for premolars to create a 9mm-long post space. For the sake of apical sealing, 4mm to 5mm of the apical filling was maintained.

Post spaces were examined radiographically with mesiodistal and buccolingual exposures to ensure that no filling material was left. All canals were cleaned of the smear layer using 17% ethylene-diamine-tetraacetic acid (EDTA) (MD-Cleanser, Meta Biomed, Co. Ltd., Cheongju City, Chungbuk, Korea) and normal saline thereafter.

Teeth were divided into three groups of 20 using a stratified random allocation method to ensure that the types of teeth were similar in each group. A translucent, tapered quartz-fiber post (D.T. Light-Post Illusion X-RO, Bisco, Inc.) was employed and cemented with a different resin cement in each group. In the first group (n=20) – the Unicem Hand-mix group (UNH) – the posts were cemented using a self-adhesive resin cement (RelyX Unicem, 3M/ESPE, Seefeld, Germany). Equal amounts of the two pastes were mixed manually and placed in the post space with the aid of a lentulo drill (Dentsply Maillefer, Ballaigues, Switzerland). Posts were inserted and held in place with finger pressure for one minute, then cured with a light unit (Coltolux 75, Coltene/Whaledent, Cuyahoga Falls, Ohio, U.S.) for 40 seconds on each side at 600 mW/cm² and a distance of 1.0mm. In second group (n=20) – Unicem Automix group (UNA) – a machine-mixed self-adhesive resin cement (RelyX Unicem Aplicap, 3M/ESPE) was used. The activated capsule was inserted into the mixing device (Roto Mix Capsule Mixing Unit, 3M/ESPE) and mixed for 10 seconds. It was then inserted into the applicator gun (Applier, 3M/ESPE) and dispensed into the post space through the nozzle. The post was inserted into the canal, and the remainder of the procedure was the same. All specimens were stored in distilled water for 24 hours to achieve complete setting of the cements.

To test the effect of pressure cycling, each group was divided into two subgroups of 10, one of which was the control group. Each tooth in the test group was secured in a stainless steel split mold with the aid of self-polymerized acrylic resin (Major Tray, Major Prodotti Dentari S.p.A., Moncalieri, Italy). The pressure chamber was made in-house (Sadaf Recompression Chamber, Sea Industrial Organization, Isfahan Iran) to electronically change the pressure and control it to an accuracy of 0.5 atmospheres absolute (atm abs) (Figure 1). The pressure cycle regimen consisted of 24 pressure cycles over a range of 0 to 5 atm abs. Pressure was increased at a rate of 1 atm abs/minute, and once the maximum pressure of 5 atm abs was reached, it was maintained for five minutes before the decompression phase began, which was also at a rate of 1 atm abs/minute [28].

**Push-out test**

Each tooth was sectioned perpendicular to the long axis of the root into three 2mm-thick slices using a low-speed diamond saw (Dorsa Boresh, Dorsa Pazhohesh Inc., Karaj, Iran) under cool running water, resulting in 30 slices per group. Using a universal testing machine
(Zwick Roell Z050, Ulm, Germany) at a crosshead speed of 1mm/minute, a load was applied until the post was dislodged (Figure 2). The punch pin used was 1.3mm for the coronal sections, 1mm for the middle sections, and 0.7mm for the apical sections. It was positioned on the post from the apical aspect of each slice to facilitate post removal. The bond strength in MPa was calculated by dividing the failure force in N by the surface area of the bonded interface using the following formula:

\[ A = \pi (r+R) \sqrt{h^2 + (R-r^2)} \]

where \( A \) is the interfacial surface, \( R \) is the radius of the larger end of the post, \( r \) is the radius of the smaller end of the post, and \( h \) is the thickness of the slice. All measurements were performed using a digital caliper (Series 500 Caliper, Mitutoyo, Tokyo, Japan) with an accuracy of 0.01mm.

Because the obtained data were normally distributed, as shown by Kolmogorov-Smirnov test, the mean bond strength of each group was statistically analyzed using two-way ANOVA and Tukey’s test post hoc at \( \alpha = 0.05 \). The middle sections were also examined for the mode of failure using a stereomicroscope (Zeiss OPM1, Carl Zeiss, Oberkochen, Germany) at 30× magnification. The failure mode was classified as adhesive in dentin, adhesive in post, or cohesive in cement.

RESULTS

Descriptive data of the push-out bond strengths from the three segments are summarized in Table 1. The push-out bond strength was significantly affected by the resin cement (P<0.001) and pressure variation (P<0.003), though the interaction between the two factors was not significant (P>0.05). Regardless of the cement and pressure, a descending trend was observed in the bond strength from coronal to apical segments. Because the effect of cement type was independent of the application of the pressure alteration, all data were pooled. The differences between the three cements were significant in the coronal sections (P<0.023; Table 2), where UNA achieved the highest bond strength. Among the middle sections, UNA and UNH were similar and among the apical sections only UNA and PAN showed significant differences (P=0.018). The failure mode in all specimens was adhesive between the cement and dentine (Figure 3).

DISCUSSION

Our results showed that environmental pressure alteration and the type of resin cement and application mode could affect push-out bond strength between a quartz fiber post and root canal dentin. Therefore, the null hypothesis of the study was rejected. Unicem Aplicap achieved the highest bond strength, both in normal pressure and in variable pressures. The UNH group and the PAN group followed. Self-adhesive cements, including Unicem, have gained popularity in adhesive dentistry, mainly because of their simplicity of use, removing the separate steps of etching and priming. Using one-step adhesive cement reduces the challenges of moisture control and controlling the application of primer and/or adhesive in root canals [29].

The bond strength between RelyX Unicem and fiber posts was found to be higher than that of Panavia in other studies [6,13,30,31], and our study found the same under normal pressure.

According to data provided by the manufacturer, during the setting of Unicem, water is produced from acid-base reactions between phosphoric acid methacrylate, basic filler and hydroxyapatite (HA) [29]. Therefore, the cement is said to be more tolerant of moisture; this could circumvent the moisture control problem in root canals and consequently result in
higher bond strength than other cements that we tested. Moreover, because of the relatively mild acidity of the functional monomer in Unicem, the depth of acid infiltration through the dentin would be decreased when a thick smear layer has built up as a result of RCT [32,33]. We removed the smear layer using EDTA during post-space preparation to improve the bond strength of Unicem. It was demonstrated that application of EDTA improved the bond strength of Unicem and a translucent fiber post [9].

Panavia F2 is a self-etching dual-cured resin cement that employs a self-etching primer. It contains an acidic functional monomer, 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP), which partially demineralizes the dentinal tubules and chemically bonds to the dentinal HA. It was shown that the calcium salt produced by the chemical reaction between this monomer and HA was the most stable among tested self-etching primers [34].

Thus far, both cements have been found to be mildly acidic and stable in humid conditions. These features can justify the comparable bond strengths found in these two cements in other studies [7,10]. Hence, the difference observed in our study can be explained by the methods of mixing and application. The Unicem Aplicap is machine-mixed and dispensed into the canal using the applicator tip. It was previously shown that machine-mixing introduced fewer air bubbles and lower porosity [26] in the set cement. Air inclusion and porosity are believed to impair the cement’s interfacial integrity. In general, stresses concentrate in the defects and flaws in the cement layer, and encourage crack propagation, accelerating debonding [12,14].

We applied the hand-mixed RelyX Unicem into the post space with the aid of lentulo. Using a lentulo spiral for the application of cement has been recommended and proven to be effective in enhancing the bond strength of self-adhesive cements in a recent study [24].

| Table 1: The bond strength data obtained from test groups |
|---------------------------------|-----------------|-----------------|
| **SECTION** | **CEMENT** | **CONSTANT PRESSURE** | **CYCLIC PRESSURE** |
| SITE | **minimum (MPa)** | **maximum (MPa)** | **mean±SD (MPa)** | **minimum (MPa)** | **maximum (MPa)** | **mean±SD (MPa)** |
| coronal | PAN | 5.89 | 8.81 | 7.45±0.91 | 5.74 | 8.41 | 7.21±0.84 |
| | UNH | 7.82 | 10.71 | 9.35±0.90 | 6.46 | 9.55 | 8.24±1.72 |
| | UHA | 8.53 | 11.50 | 10.32±1.02 | 7.24 | 11.31 | 9.09±1.91 |
| middle | PAN | 5.45 | 8.38 | 7.12±0.82 | 5.17 | 7.80 | 6.71±0.83 |
| | UNH | 6.43 | 9.52 | 8.23±1.11 | 5.42 | 8.61 | 7.52±1.04 |
| | UHA | 6.87 | 11.00 | 9.27±1.16 | 6.59 | 9.11 | 7.69±0.93 |
| apical | PAN | 4.94 | 7.91 | 6.63±0.86 | 4.93 | 7.34 | 6.30±0.74 |
| | UNH | 5.86 | 8.85 | 7.62±0.94 | 5.20 | 7.72 | 6.38±0.74 |
| | UHA | 5.91 | 9.34 | 7.86±1.10 | 5.22 | 8.35 | 6.67±0.92 |

| Table 2: Result of multiple comparisons of regional bond strength among test groups |
|---------------------------------|-----------------|-----------------|
| **cement** | **coronal** | **middle** | **apical** |
| PAN | a | a | a |
| UNH | b | b | ab |
| UHA | c | b | b |

Cements in a column with different letters are significantly different by Tukey’s test at the 95% significance level.
Using lentulo or any early application of Panavia mixed cement to the post space is discouraged by the manufacturer to avoid premature setting of the cement before insertion of the post. Therefore, it was suggested that the method of applying Panavia F2 to the post and post space could produce more porosity in the cement layer and gaps in the existing bonded surface. It was also found that cements achieved superior bond strength when injected into the canal or applied with a lentulo spiral compared with applying the cement onto the post first [24].

On the other hand, in another study, the bond strengths between a fiber post and three self-adhesive cements were evaluated, and hand-mixing vs. auto-mixing and applying with an applicator or syringe vs. lentulo were examined [25]. They found that auto-mixing and use of an application tip decreased the bond strength in one of the cements tested. They assumed that auto-mixing could result in incomplete mixing, compromising the bond strength, which might be material-dependent. Hence, the difference between their results and ours can be attributed to the different materials used.

The micro push-out test has been popular for evaluating the bond strength between fiber posts and dentin. To produce a more homogenous interfacial stress, the root is cut cross-sectionally into slices of small thickness. In addition, the different sites are examined separately. To concentrate the applied load on the bonded surface, careful attention should be paid to positioning the punch tip on the post to avoid stressing the surrounding dentinal walls [11]. Therefore, we used three punch tip sizes corresponding to the three sections of root. Compared with the micro-tensile test, the push-out test is associated with less premature debonding and loss of specimens, allowing multiple specimens to be obtained from smaller sample sizes. Therefore, push-out test was used in our study.

A diving situation was simulated in our study, because the pressure changes are rather rapid compared to other situations in which barometric changes are involved, such as flying. A diver experiences pressure changes of 1 atmosphere for every 10-meter increase in depth, whereas in flight, an altitude of 3,000 meters reduces the pressure to 0.75 atm [17].

In one study, the effect of environmental pressure on three cements was evaluated [23]. The authors reported a higher retentive force in Panavia 21, followed by a glass ionomer, and zinc phosphate. Pressure did not affect the retention of crowns cemented with Panavia 21. Crowns were subjected to pressure cycles of 0 to 3 atm abs for 15 cycles, which corresponds to amateur recreational diving at 30 meters for two weeks. Our study employed 24 pressure cycles from 0 to 5 atm abs, which corresponds to professional diving 50 to 70 meters deep twice a week [28] for three months. Because the occurrence of barotrauma is time-dependent [19], more detrimental effects would be expected with longer periods of cyclic pressure changes, and this could explain the difference between our results and those of the aforementioned study. However, direct comparison of our results with theirs is not possible because of differences in test design and materials used.

According to Boyle’s law, any air bubbles and porosities in the cement layer or interfacial surfaces could be affected during increasing and recovery of the ambient pressure. Unlike some parts of the body, such as blood vessels, in a root canal there is no compensating mechanism to dissipate the compression/expansion of an enclosed gas. Therefore, in the case of diving, stress is introduced when air contained in cavities such as porosities in the cement layer attempt to compress. When returning to the surface, the enclosed gas experiences expansion. The accumulated stress of compression-expansion cycles can cause cracks and/or propagation of existing cracks and flaws inside the cement layer and/or along the interfacial surface [23]. The effects of pressure are expected to be less when porosity or air inclusion is lower. This may explain our findings that machine-mixed Unicem obtained a significantly higher bond strength than its hand-mixed counterpart. Panavia F2 was the weakest, as previously discussed.

In our study, the bond strength was weaker toward the apical region in both normal and cyclic pressure alteration conditions, and this agrees with other studies [6,8,11]. Also, the cement behavior was slightly different in each section. Unfavorable histological factors such as dentinal tubule densities, poor quality of dentin in the apical third, difficulty in moisture control, and light attenuation compromising the degree of conversion of the resin cement, have been found to be factors that could affect the bonding quality and performance in the apical third.
LIMITATIONS
One limitation of our study is that only two cements and one type of fiber post were investigated. Nevertheless, it was shown that the bond strength between resin cements and fiber posts could be material-dependent [3]. Therefore, new materials deserve for further investigation. Moreover, actual restorations are subjected to combined thermo-mechanical loading, and this was not simulated. Unless further clinical trials are conducted, the results of this in vitro study should be interpreted cautiously.

CONCLUSION
Within the limitation of the present study it may be concluded that barometric changes during scuba diving may have an adverse effect on the retention of a quartz fiber post. The impact may be enhanced when the mixing method and/or the mode of application of resin cement facilitate air inclusions.

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Conflict of interest statement
The authors declared that we have no conflict of interest, affiliations, funding sources or financial holdings that could raise questions about possible sources of bias.

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