Effects of different surface treatments on the bond strength of glass fiber-reinforced composite root canal posts to composite core material

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Final revision received 6 September 2011; accepted 6 December 2011
Available online 19 February 2012

KEYWORDS
acid etching; airborne-particle abrasion; bond strength; core material; Er:YAG laser; FRC post

Abstract  Background/purpose: The purpose of this study was to investigate the effects of different surface treatments on the bond strength of glass fiber-reinforced composite (FRC) posts to composite core material.

Materials and methods: A total of 18 FRC posts were randomly divided into six groups (n = 3), one of which was the untreated control group. Surface treatment of other groups were as follows: airborne particle abrasion with 50-μm Al₂O₃ powder at 60 psi for 10 seconds through an ozzled distance of 10 mm; etching with 4% hydrofluoric (HF) acid; and surface preparation with an Er:YAG laser under three different power settings (of 300, 400, and 500 mJ, at 2 Hz and 100 μs). A cylindrical Teflon mold was used to surround the treated posts, and the mold was filled with dual-cure composite core material. All samples were light-cured for 60 seconds through the top of the mold. After 24 hours of storage in water, specimens were sectioned perpendicular to the bonded interface under water cooling to obtain 2-mm thick post-and-core specimens. Each group consisted of 12 specimens. Push-out tests were performed at a cross-head speed of 0.5 mm/minute using a universal testing machine. Data were analyzed by one-way analysis of variance followed by Tukey’s honestly significant difference test (α = 0.05).

Results: The lowest bond strength was observed in the Er:YAG 500-mJ group (6.14 ± 0.94 MPa). The acid-etched group revealed a higher bond strength (15.08 ± 0.92 MPa) than the control group. The highest bond strength was observed in the airborne-particle abrasion group [18.89 ± 0.83 MPa (P < 0.05)].

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doi:10.1016/j.jds.2012.01.003
Introduction

Endodontically treated teeth are often severely damaged by decay, excessive wear, or previous restorations, resulting in a lack of coronal tooth structure. The longitudinal success of restorative or prosthetic rehabilitations of an endodontically treated tooth depends on the quality of the restoration, on its clinical adaptation, and on the health of the supporting tissue. Most clinical failures involving endodontically treated teeth reconstructed with posts are due to cementation failure of the posts, whereas root fractures are the most serious type of failure.

Prefabricated glass fiber-reinforced composite (FRC) posts have been used since the beginning of the 1990s with the introduction of carbon-fiber posts. Other types of FRC posts were developed in an attempt to improve aesthetics, thanks to the development of glass or white-quartz fibers and translucent resinous matrices. FRC posts are essentially composite materials composed of fibers of silica surrounded by a matrix of polymer resin, usually an epoxy resin. FRC posts are translucent and therefore have aesthetic advantages. Currently, a wide variety of FRC posts are available with different sizes, tapers, and shapes. FRC posts also more closely match the modulus of elasticity of sound root dentin, and numerous in vitro studies showed that the posts distribute occlusal stresses more evenly in the root dentin, usually leading to fewer and less-catastrophic root fractures, which are often repairable.

Generally, retention is affected by the post type, the properties of the cement, and the cement bond to the post and root canal dentin. FRC post placement involves the formation of two equally important interfaces, i.e., at the dentin/resin composite and resin composite/fiber level, where a failure can eventually occur. In published research on luting fiber posts to hybridized root canals, 60% of failures during push-out testing occurred between the fiber post and cement. The durability of a composite resin core restoration depends on the formation of a strong bond between the core material and residual dentin, as well as between the core and post material, enabling the interface to transfer stresses under functional loading.

A number of studies particularly focused on the possibility of improving adhesion at the fiber post-composite interface through various treatments of the post surface. In an attempt to maximize resin bonding to FRC posts, several surface treatments were recently suggested. These procedures can be divided into three categories: (1) silanization and/or adhesive application, (2) acid etching, sandblasting, and silica coating, and (3) alternative etching techniques (i.e., treatments that combine both a micromechanical and chemical component). Due to improvements in lasers used in dentistry, erbium: yttrium-aluminum-garnet (Er:YAG) laser treatment is considered an alternative method to other surface treatment methods because of its optical penetration depth. As far as laser treatment on FRC posts, no experimental research has been undertaken to date.

The purpose of this study was to investigate the effects of different surface treatment procedures on the bond strength of FRC root canal posts to composite core material. It was hypothesized that the bond strength achieved at the post-core interface would be affected by sandblasting, acid-etching, and the Er:YAG laser under different power settings.

Materials and methods

A total of 18 FRC root canal posts (FRC Postec Plus, size 3, Ivoclar Vivadent, Schaan, Liechtenstein) were randomly divided into six groups (n = 3), with one being a control group to which no surface treatment was applied. Surface treatment of the other groups were as follows: airborne particle abrasion with 50-µm aluminum oxide (Korox 50, Bego, Bremen, Germany) at 60 psi for 10 seconds through a nozzle distance of 10 mm; etching with 4% hydrofluoric (HF) acid (Porcelain Etchant, Bisco, Schaumburg, IL USA) for 60 seconds; and surface preparation using an Er:YAG laser (Fotona AT Fidelis, Ljubljana, Slovenia) under three different power settings (of 300, 400, and 500 mJ, at 2 Hz and 100 µs) for 10 seconds. The specimens were treated with an Er:YAG laser working at 2940 nm. A 90°-angled dental hand-piece (R14-C) was used with a cylindrical sapphire (1.3 × 12 mm) fiber-optic tip. The tip was used at an incidence angle of 45° under water irrigation. The air and water pressure was set to two bars. The application tip was moved from the bottom to the top and maintained in slight contact with the FRC post surface.

The FRC Postec Plus post system is parallel in the coronal part and tapered in the apical part of its design. A Teflon mold was prepared to eliminate the tapered part of the posts (Fig. 1A). The tapered section was placed into the Teflon mold, and the parallel section was used for the core foundation to simplify calculation of the surface area. Only the upper cylindrical portion of the FRC posts (10-mm long) with the larger diameter of 2 mm was used. It is desirable that the post diameter be constant throughout the post length. A cylindrical Teflon mold was placed around the root dentin. A Teflon mold was prepared to eliminate the tapered part of the FRC post surface.
each side for 20 seconds for a total exposure of 60 seconds. After 24 h of storage in water, specimens were attached to the arm of a low-speed saw (IsoMet; Buehler, Lake Bluff, IL, USA) and sectioned perpendicular to the bonded interface into 2-mm-thick post and core segments under water cooling. Four segments were obtained from each post-and-core specimen, and therefore, each group of 12 post and core specimens provided a total of 72 post and core segments. The exact thickness of each post-and-core segment was measured using a digital micrometer (Mitutoyo, Tokyo, Japan) with 0.01-mm accuracy. The total bonding area of each FRC post segment was calculated using the formula: 
\[
A = \frac{2\pi r \times h}{2}
\]
where \(r\) is the post radius, \(P\) is the constant 3.14, and \(h\) is the thickness of each post section. Because parallel-sided coronal sections were used for the core foundations, the bonding area was equal for all post segments and calculated to be 
\[
A = 2 \times 3.14 \times 1 \times 2 = 12.56 \text{ mm}^2.
\]

Push-out tests were performed at a cross-head speed of 0.5-mm/minute using a universal testing machine (Lloyd LRX, Lloyd Instruments, Fareham, UK). After attaching the specimens to a loading installment, the FRC post was loaded with a 1.5-mm-diameter cylindrical stainless-steel plunger. The tip of the equipment was positioned such that it only contacted the FRC post without contacting the composite core (Fig. 2). The peak force, at the point of extrusion of the post segment from the test specimen, was taken as the point of bond failure and recorded in Newtons (N). Push-out bond strength values in MPa were then calculated by dividing this force by the bonded area of the post segment.

One-way analysis of variance (ANOVA) in statistical software (SPSS for Windows, version 12.0.1; SPSS, Chicago, IL, USA) was used to evaluate the effects of surface treatment procedures on the bond strength between FRC posts and composite core material. The means were then compared using Tukey’s honestly significant difference (HSD) test \((\alpha = 0.05)\).

In addition, one FRC post specimen from each group was prepared and evaluated by scanning electron microscopy (SEM) (JSM 6335-F, Jeol, Tokyo, Japan). Specimens were observed for surface irregularities under SEM at magnifications of \(\times 250\) and \(\times 1000\).

Results

Bond strengths were shown to significantly differ by one-way ANOVA \((P < 0.001)\). The mean bond strengths, standard deviations, and group differences for the six different surface-treatment groups are shown in Table 1.

In the study groups, the lowest bond strength was observed for the Er:YAG laser at 500 mJ (6.14 MPa). No statistically significant difference was observed between the Er:YAG laser at 400 (7.81 MPa) and 300 mJ (7.93 MPa \((P = 0.752)\)), and these groups demonstrated higher bond strengths compared with the Er:YAG laser at 500 mJ \((P < 0.05)\). The control group demonstrated a statistically significantly higher bond strength value (11.67 MPa).
compared with the above-mentioned groups (P < 0.05). The acid-etched group showed a higher bond strength (15.08 MPa) than the control group. The highest bond strength in this study was observed in the airborne-particle abrasion group (18.89 MPa (P < 0.05)). Differences among groups are listed in Table 1.

The SEM studies revealed that the surface irregularities of the FRC root canal post corresponded to the results of the bond-strength study (Fig. 3).

Discussion

Within the limitations of the present study, it was concluded that our hypothesis was confirmed, i.e., bond strengths of core build-up material to FRC posts were significantly affected by the investigated surface treatments. A number of studies particularly focused on the possibility of improving adhesion at the fiber post-composite interface through various treatments of the post surface.14-17,20,21

Laser applications for dental practice have been a research interest for the past 35 years. By varying a number of parameters (pulse mode, irradiation time, frequency, and energy outputs), several types of lasers [neodymium: yttrium-aluminum: garnet (Nd:YAG), carbon dioxide (CO2), Er:YAG, and semiconductor diode lasers] were indicated for dental treatments.22-24 The wavelength of the Nd:YAG laser penetrates into water to a depth of 60 mm, and the energy is scattered in soft tissues rather than being absorbed on the tissue surface. It is highly absorbed by black color; therefore, this laser is commonly used for cutting and coagulation of oral soft tissues with good hemostasis. However, due to its scattering effect, it is difficult to judge the depth of penetration of this laser.25 Characteristics of the Er:YAG laser completely differ from those of the Nd:YAG laser. It is also applicable to both hard and soft tissues without carbonization.26 The wavelength of the Er:YAG laser lies near the boundary of the invisible near- and midinfrared portion of the spectrum. The coherent and collimated light of this laser with a wavelength of 2940 nm is highly absorbed by water. Theoretically, its absorption coefficient by water is 10 times higher than that of the CO2 laser (at a wavelength of 10,600 nm) and 15,000~20,000-times higher than that of the Nd:YAG laser (at a wavelength of 1064 nm).27 Due to its high absorption by water, less tissue degeneration with a very thin surface interaction occurs with Er:YAG laser irradiation. Also, the temperature rise is minimal in the presence of water irrigation, which makes hard substrate preparations, caries removal, and scaling treatment possible with this laser, with no carbonization.26,28 Various reports confirmed the safety and efficacy of CO2 and Nd:YAG lasers, which are the most commonly used lasers for soft-tissue applications.29 However, when these lasers are applied to dental hard tissues, thermal adverse events can be a major problem. The thermal effect of the laser beam is based on the absorption of radiation by tissue and subsequent transformation of laser energy into heat.30 Heat generation during laser irradiation often causes carbonization, and melting and cracking of the tooth structure. However, the Er:YAG laser showed satisfactory results for hard-tissue ablation, due to its characteristic wavelength that is well absorbed by water. So, Er:YAG laser treatment was selected due to the reasons mentioned above. The use of water spray minimizes the heat generated by cooling the irradiated area and absorbing excessive laser energy.27,31,32 Water irrigation effectively prevented thermal damage and any major compositional or chemically deleterious changes due to the irradiation.33

Murray and colleagues34 indicated that laser treatment may be a suitable alternative to airborne-particle abrasion or other surface pretreatment techniques for enhancing the bond strength of dental materials to metal surfaces. As for laser treatment of FRC posts, no experimental research was undertaken to date. Zhang and others35 reported that cavity surfaces irradiated at 10 Hz with energies of 200 and 300 mJ were similar, but those irradiated at 10 Hz with an energy of 400 mJ showed cracks and melting of the dentin, indicating that the use of 4 W may damage the dentin. Gökce and colleagues36 reported that the shear bond strength after laser treatment at 300 mJ was higher than that after treatment at 600~900 mJ. According to them, the reason for the low bond strengths observed at high power settings may have been related to the observed heat-damaged layer.36 The current investigation focused on evaluating the effects of different surface treatment procedures, including Er:YAG laser under three different power settings [300 (0.6 W), 400 (0.8 W), and 500 mJ (1 W); 2 Hz for 100 μs] on the bond strength of FRC root canal posts.

<table>
<thead>
<tr>
<th>Control</th>
<th>HF Acid-etched</th>
<th>Airborne particle abrasion</th>
<th>Er:YAG 300 mJ</th>
<th>Er:YAG 400 mJ</th>
<th>Er:YAG 500 mJ</th>
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Figure 3 Scanning electron microscopy images of treated fiber post specimens at magnifications of ×250 and ×1000.
to composite core material. Therefore, the posts were inserted into a Teflon mold with an artificially created post space. It was thought that if the posts were luted into extracted teeth, bonding to dentin might have influenced the bond strengths.

Flowable and hybrid composites were reported to have good adaptation at the post surface of FRC posts. The mechanical properties of flowable composites are generally inferior compared with conventional composites. However, a dual-cure composite core material (MultiCore Flow) that is also recommended as a adhesive luting agent and core built-up material by the manufacturer was used in the present study.

According to results of the present study, although the Er:YAG 400- (7.81 MPa) and 300-mJ (7.93 MPa) groups demonstrated higher bond strengths compared with the Er:YAG 500-mJ group, all groups treated with the Er:YAG laser showed lower bond strengths than the control group. The use of Er:YAG laser treatment resulted in exposure of the composite matrix and damage to fibers at the surface of the FRC posts (Fig. 3). Based on the results of the present study, these procedures cannot be recommended for clinical use due to possible weakening effects on the stability and integrity of the posts. Although laser treatment was indicated to be a promising technology in dentistry, there is still need for more research to determine appropriate parameters of laser treatment for application of this technology to dental materials.

Studies focusing on silane application to FRC posts revealed controversial results, and two studies reported an increasing effect of silanization compared with the untreated controls, whereas other studies detected no difference between silanated and untreated control posts. Chemical adhesion after silane coupling to FRC post surfaces can only be established between luting agents and exposed fibers or filler particles of the post. Due to differences in chemistry, no bonding can be expected between the methacrylate-based resin of the luting agents and the epoxy resin matrix of prefabricated FRC posts.

Ceramic etching with HF acid is able to create a rough surface that allows micromechanical interlocking with the resinous cement. This methodology was recently proposed for etching glass-fiber posts. The acid effect was time-dependent and was influenced by the post composition (type of the matrix, fibers, or both). The technique produced substantial damage to the glass fibers and affected the integrity of the post. FRC post conditioning using HF acid might attack both the fiber and matrix, while other chemical conditioning methods only affect the glass fibers. This is due to the corrosive effect of HF acid on the glass phase of the ceramic matrix. These findings were confirmed by Vano and colleagues when HF acid was used for conditioning methacrylate-based fiber posts. Despite the improvement in post-to-composite bond strengths, noteworthy surface alterations ranging from microcracks to longitudinal fractures of the fiber layer were detected. On the contrary, the HF acid-etched group showed a higher bond strength (15.08 MPa) than the control group in the present study. In addition, the SEM analysis revealed significant morphological roughness of acid-etched posts with no damage to fibers (Fig. 3). These differences may be assumed to be due to differences in the surface texture of other types of FRC posts, etching time, and concentration of the HF acid solution. In the present study, an etching time of 60 seconds was selected to avoid massive substance loss of the FRC surface. Previous investigators advised similar etching times and HF acid concentrations.

It is well accepted that sandblasting with alumina particles results in increased surface roughness and surface area. The highest bond strength in this study was observed in the airborne-particle abrasion group [18.89 MPa (P < 0.05)]. This was supported by the SEM observations, which revealed more micromechanical retention after airborne-particle abrasion. This result is consistent with those of previous studies that reported that airborne-particle abrasion with alumina particles increased the surface area and enhanced the mechanical interlocking between the cement and roughened surface of a post. The mechanical action of blasting probably determines the removal of the superficial layer of the resinous matrix, creating micromechanical spaces on the post surface. Mechanical pretreatment of FRC posts with airborne-particle abrasion roughens the FRC surface; yet, in addition to the matrix being removed, the fibers might also be damaged, depending on the particle size and abrasion time.

The current study was limited to one FRC post and core build-up material. Nevertheless, these findings allow for a better understanding of the effects of different surface treatments including an Er:YAG laser on the bond strength of core build-up material to FRC posts. However, future studies evaluating the effects of different post and core materials that utilize artificial aging methods are recommended.

Conclusions

Within the limits of the present study, it was concluded that different surface treatments and the type of laser treatment significantly influenced the push-out bond strength between the composite core build-up material and treated FRC posts (P < 0.05). For FRC posts, Er:YAG laser treatments significantly decreased the bond strengths compared with the control group. Thus, the Er:YAG laser treatments tested cannot be recommended for clinical use due to possible weakening effects on the stability and integrity of FRC posts. Although the acid-etched group showed higher bond strengths than the control group, the highest bond strength in this study was observed in the airborne-particle abrasion group (P < 0.05). Additionally, airborne-particle abrasion may produce an increased bond strength to FRC posts.

References


