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ORIGINAL ARTICLE

Effects of dentin surface treatments including Er,Cr:YSGG laser irradiation with different intensities on the push-out bond strength of the glass fiber posts to root dentin

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Abstract

Objective. Intra-canal post systems are commonly used to restore root-filled teeth. Bond strengths of the posts can be affected by various surface treatments of the post or the dentin. The aim of this study was to evaluate the effects of dentin surface treatments including erbium-chromium; yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser irradiation with different intensities on the push-out bond strength of the glass fiber posts to root dentin. ***Materials and methods.*** Forty single-rooted human maxillary incisors were filled and post spaces were prepared. After these procedures, the specimens were divided randomly into four groups according to the dentin surface treatments, as follows: (i) untreated surface (control), (ii) 1W Er,Cr:YSGG laser application, (iii) 2W Er,Cr:YSGG laser application and (iv) 3W Er,Cr:YSGG laser application. Then the posts were cemented into the root canals using dual-cured resin cement. Bonded specimens were cut into 1-mm-thick slices and push-out tests were performed using a universal testing device. All specimens were loaded until fracture and the failure modes were evaluated with a stereomicroscope at 32× magnification. Representative specimens were analyzed by scanning electron microscopy. Data were analyzed using a one-way ANOVA, Tukey and Wilcoxon tests. ***Results.*** The bond strength values ranged from 3.22–4.68 MPa. There were no statistically significant differences among the groups, regardless of the different levels. The coronal and middle levels of the post space had significantly higher bond strength values compared with the apical level ($p < 0.05$). ***Conclusion.*** Er,Cr:YSGG laser irradiation with different intensities did not increase the bond strength of the fiber posts to the root canal dentin walls.

Key Words: *bond strength, fiber posts, root dentin, push-out test, Er,Cr:YSGG laser*

Introduction

An intra-canal post is commonly used to restore a root-filled tooth that has suffered excessively lost tooth structure because of caries, previous restorations and fractures [1]. The loss of retention and root fractures are the main reasons for long-term clinical failures of post-endodontic restorations [2]. In recent years, fiber-reinforced composite (FRC) posts have been slated for the restoration of root-filled teeth as a viable alternative to posts fabricated from metal and ceramic [2,3]. These FRC posts, which consist of reinforcing carbon, quartz or glass fibers embedded in epoxy or a methacrylate resin-polymerized matrix, are advantageous in restoring root canal treated teeth [4]. It is well documented that the main advantage of FRC posts is that their modulus of elasticity is similar to dentin, reducing stress transmission to root canal walls and the risk of vertical root fracture [4]. Moreover, FRC posts provide superior biocompatibility, mechanical strength, corrosion resistance, easier removal, single-visit placement and esthetics compared to other types of posts [5].

FRC post retention depends on the strength of the chemical and micromechanical interaction among the post, dentin and resin cement [6]. The failure of this type of post often occurs because of debonding at the adhesive resin–dentin or at the adhesive resin–post interface as a result of bond deficiencies [3,6]. Bond strength is affected by many factors, among which are the degree of dehydration of the root dentin, physical properties of resin cements used, unfavorable cavity

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configuration, adverse effects of sealers and anatomic features like decreasing numbers of dentinal tubules at different levels of the canal [1–6]. Therefore, in order to increase the bond strengths of FRC posts, several surface treatment procedures on posts or dentin have been performed [7–9]. Dentin surface treatment using various agents, ultrasonic/sonic techniques or laser irradiation can affect the structural properties of dentin, which can finally alter the microhardness, permeability and solubility of dentin in the positive or negative directions [9–11]. These dentin changes significantly affect the bond strength between the resin cement and the treated dentin [12]. For this reason, dentin surface treatment requires further research to choose the most appropriate method that does not jeopardize fiber post retention.

The use of laser technology has been shown to be relatively safe and proposed for different dental applications such as surface treatments of dental material or tissue, etching metals, reducing tooth sensitivity, removing caries, cavity preparation, disinfecting dental tissues and bleaching [13–17]. Among the various laser types, a erbium:yttrium-aluminum-garnet (Er:YAG) laser (λ = 2.940 nm) and a neodymium:yttrium-aluminum-garnet (Nd:YAG) laser (λ = 1.064 nm) were used for these applications. Also, an erbium-chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser (λ=2.780 nm) has been introduced to remove caries and to evaluate the morphological changes in human enamel and dentin [18]. In addition, current studies [19,20] have evaluated the effects of the Er,Cr:YSGG laser irradiation on shear bond strength of resin cement to ceramic restorations.

The aim of this study was to evaluate the effects of dentin surface treatments including Er,Cr:YSGG laser irradiation with different intensities on the push-out bond strength of the glass fiber posts to root dentin. The null hypothesis was that, compared with the control group, the bond strength values could be increased by the application of various laser irradiations to the dentin.

Materials and methods

Forty single-rooted human maxillary incisors with straight root canals that were extracted for periodontal and/or prosthetic reasons were used in this study. Crowns were removed under water using a low-speed diamond saw to obtain a root height of 15 mm (Isomet 1000, Buehler, Lake Bluff, IL). The teeth were stored in a 0.5% chloramine T solution until required.

Apical patencies were determined with a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) and the working length (WL) was established as 1 mm short of the apical foramen. All the root canals were instrumented using the ProTaper NiTi rotary system (Dentsply Maillefer) and an electric motor (X-Smart; Dentsply Maillefer) in a crown down technique. ProTaper SX and S1 files were used to flare the cervical and middle thirds of the canals. The middle and apical thirds were instrumented with S1 and S2 files until encountering slight resistance and the canals were then finished using F1, F2 and F3 files until the WL was reached. After each file was used and before proceeding to the next, canals were irrigated with 2 mL of 2.5% NaOCl. When instrumentation of the canals was completed, 2 mL of distilled water was used for the final irrigation. Prepared canals were then dried with paper points and filled with gutta percha cones and AH Plus sealer (Dentsply DeTrey, Konstanz, Germany) by using a lateral condensation technique. After root filling, the coronal 1 mm of the filling materials was removed from each specimen and the space in each was filled with a temporary filling material (Cavit; 3M ESPE, Seefeld, Germany). All teeth were stored in a humidor at 37°C and 100% humidity for 1 week to allow complete setting of the sealer.

Post procedure

Gutta percha was removed with a special drill provided by the manufacturer with a 1.5 mm tip diameter. Each canal length was prepared while maintaining a 4–5 mm apical seal for creating a standard post space of 10 mm from the coronal surface. After this, the root canals were cleaned with distilled water and dried with paper points.

After preparing the root canals, the specimens were randomly divided into four groups of 10 teeth, as follows:

- *Group 1 (Control group)*.: Untreated dentin surface.
- *Groups 2–4 (Laser irradiation groups)*: Er,Cr:YSGG laser (Millenium; Biolase Technology, San Clemente, CA) with a wavelength of 2780 nm was applied to the root walls (Figure 1A). The beam diameter at the focal area of the handpiece Z3 was 320 μm. This tip has a transmitting factor of 0.6 and is 28 mm long. The laser parameters were 20 Hz (pulses per second) and pulsed laser-powered hydrokinetics. The pulse duration ranges from 140–200 μs. However, the energy parameters at 1W (Group 2), 2W (Group 3) and 3W (Group 4), respectively, and water/air flows both of 50% were used continuously during the irradiation for 10 s.

Before cementation, each fiber post was cleaned with 70% alcohol and dried with oil-free air. Then, the fiber posts were also covered with a thin layer of a silane agent (Futura Bond, VOCO, Cuxhaven, Germany) according to the manufacturer's instructions. Size 15 fiber posts (Rebilda; VOCO) made of glass fiber-reinforced composite were cemented using a dual-cure resin cement (Grandio Core Dual Cure; VOCO) according to the manufacturer's instructions. The resin cement was applied to the root canal with a lentulo drill for obtaining a uniform cement layer and the fiber post was immediately inserted into the root canal. Excess cement was removed and light cured for 40 s at a light intensity of 600 mW/cm^2 from the coronal direction using a light curing unit (LITX 680A; Dentamerica, Bedford, CA). After the post luting procedures, the roots were stored at 37°C in distilled water for 7 days.

Push-out test

After 1 week, the samples were submitted to the push-out test. Each root was embedded in autopolymerizing acrylic resin (Meliodent, Bayer Dental Ltd., Newbury, UK) by using a metal mold (12 mm in diameter and 22 mm in height). Each specimen was then sectioned horizontally for obtaining 1 ± 0.1 mm thick post/dentin slices using a slow speed diamond blade (Isomet 1000, Buehler) under water cooling, thus obtaining six slices of each root, for a total of 240 slices (Figures 1B and C). The first two slices (from 8 and 9 mm) represented the coronal region, the next two (from 5 and 6 mm) represented the middle region and the final two (from 2 and 3 mm) represented the apical region of the post space. All slices were used for the evaluation of the push-out test. The actual length of the fiber post in each sample was measured using a digital caliper (Mitutoyo, Tokyo, Japan), rounded to the nearest 0.01 mm (Figure 1C). Each slice was fixed on the metallic plate in which the coronal surface would be in contact with the instrument and the post was centered over the hole of the metallic plate. The post segments were loaded with a cylindrical plunger 0.75 mm in diameter centered on the post segment; contact with the surrounding dentin surface was avoided. Compressive loads were applied using a universal testing device (Lloyd LF Plus; Ametek Inc., Lloyd Instruments, Leicester, UK) at a crosshead speed of 0.5 mm/min in an apical-to-cervical direction until the post was dislodged (Figure 1D). Push-out bond strengths were calculated for each specimen by using the formula: Debond stress = Debonding force (N)/A, where A is area of the post/dentin surface. Debond stress values were converted to megapascals (mPa). The diameter of the post in each slice of post/dentin was measured and the total bonding surface area was determined using the formula: $A = \pi\ (r_1 + r_2) \times \sqrt{(r_1 - r_2)^2 + h^2}$, in which r_1 is the radius of the cervical area, r_2 is radius of apical area and h is the thickness of each slice (h = 1 mm) [21].

Microscopy analysis

After the push-out test, each specimen was visually examined under a stereomicroscope (SMZ 800, Nikon, Tokyo, Japan) at 32× magnification to determine the failure mode. Four types of failure were classified: (1) adhesive failure between post and resin; (2) adhesive failure between dentin and resin; (3) cohesive failure inside the post; and (4) mixed failure (a combination of two of the above). Representative images of the root canal walls from two specimens in each group were obtained to evaluate the surface differences after the laser irradiations by using a scanning electron microscope (SEM). The slices were mounted on an aluminum stub and sputter-coated with a gold layer. SEM photomicrographs were taken using a SEM device (JSM-6060LV, Jeol, Tokyo, Japan) at 1000× magnification to evaluate the cleanliness of the canal walls. The open dentinal tubules were counted on each photomicrograph using Adobe Photoshop software (Adobe Systems, San Jose, CA).

Statistical analysis

All statistical analyses were performed with SPSS 15.0 (SPSS for Windows; SPSS Inc., Chigaco, IL). Data were statistically analyzed with one-way analysis of variance, Tukey HSD multiple comparisons and Wilcoxon tests. Statistical significance was defined as $p < 0.05$.

Results

The mean ± standard deviation of the push-out bond strength values for each group is shown in Table I

Figure 1. Experimental set-ups images. (A) laser application, (B) a post/dentin slice section process, (C) actual length measurement, (D) compressive load application.

Table I. Mean ± standard deviation of the bond strength values (MPa) in each experimental group and statistical differences.

	Groups			
Level	Control	1W laser	2W laser	3W laser
Coronal	$4.68 \pm 1.45^{A,a}$	$4.66 \pm 1.39^{A,a}$	$4.66 \pm 1.19^{A,a}$	$4.67 \pm 1.01^{A,a}$
Middle	$4.40 \pm 1.66^{A,a}$	$4.43 \pm 1.48^{A,a}$	$4.44 \pm 1.37^{A,a}$	$4.44 \pm 1.60^{A,a}$
Apical	$3.24 \pm 0.91^{B,a}$	$3.25 \pm 1.17^{B,a}$	$3.27 \pm 1.34^{B,a}$	$3.22 \pm 1.25^{B,a}$

In each column, groups with the same capital superscripts are not significantly different and in each row, groups with the same lower case superscripts are not significantly different ($p > 0.05$).

and Figure 2 shows representative SEM images taken from various levels of the canal walls in different groups. The bond strength values ranged from 3.22–4.68 MPa. Statistical analysis of data revealed no significant differences among the groups, regardless of the different levels ($p > 0.05$). For post space levels, the coronal and middle levels of the post space had significantly higher bond strength values compared with the apical level ($p < 0.05$). However, no significant difference was found between the coronal and middle levels ($p > 0.05$). The lowest values were observed in the apical level of the all groups.

All failures occurred at the dentin/resin interface in stereomicroscope analysis. SEM images of the control group as well as laser-treated groups showed a similar structure. Images showed small rare open tubules in all surface regions of the control group when compared to the others. Only, dentin surfaces of apical levels of control and 1W groups showed no opened dentinal tubules. Analysis revealed more open dentin tubules in the coronal and middle levels than in the apical level in all groups. In addition, laser-irradiated dentin surfaces showed some parts with melting and re-crystallization. This analyses were in agreement with the bond stregth values.

Discussion

After post space preparation, cleaning the root canal dentinal walls is a critical procedure for optimal post retention. Because several factors may impede this retention, such as the presence of fluid, the odontoblastic process within the tubules, dentin humidity and the smear layer formation [3,4,7,9,22]. Among these factors, the smear layer must be considered before post cementation, bearing in mind that there is little interaction between this layer and the close dentin and that it must be removed or modified with different methods (e.g. irrigation regimes, sonic/ultrasonic systems, lasers) [7,9,11,12,18]. Also, it contains gutta-percha and sealer remnants and dentin components. Removal of this layer before the post cementation has been advocated to allow better adhesive penetration into dentinal tubules and enhance the micromechanical adhesion of the resin cements [23,24]. Dentin surface treatment with the above-mentioned methods causes alterations in the chemical and structural composition of dentin; the permeability and solubility characteristics of dentin may change and, hence, affect the adhesion of resin cements to dentin surfaces. Therefore, dentin surface treatment requires further research to choose the most appropriate dentin conditioning

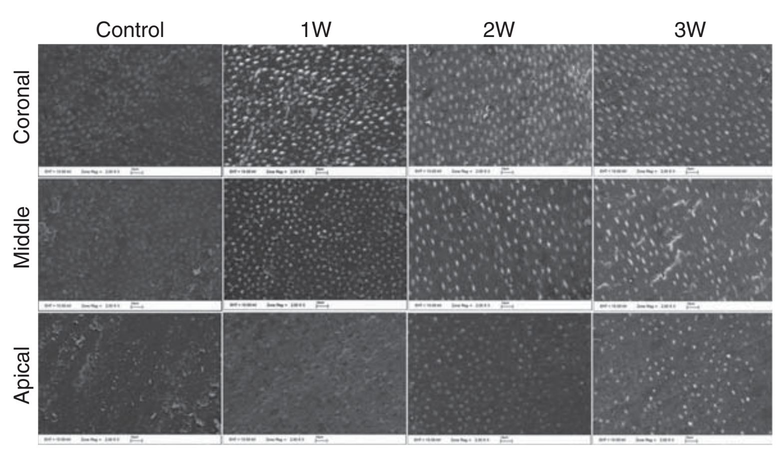

Figure 2. Representative SEM images showing selected samples from coronal, middle and apical segments representing the different groups (magnification ×1000).

method that does not jeopardize the FRC post retention.

To date, various types of the lasers (diod, Nd:YAG, and erbium lasers) have been used to increase the bond strength of FRC posts to the root canal dentin. Ghiggi et al. [25] stated that Nd:YAG and Er:YAG lasers changed the adhesive–dentin interface. Arslan et al. [26] found that Er:YAG laser irradiation with/without EDTA increased the bond strength of the fiber posts. According to Haragushiku et al. [27], they obtained the highest adhesion values when the dentin surface was treated with Er:YAG laser and EDTAC solution. Our study focused on evaluating the effects of different Er,Cr:YSGG laser protocols on the bond strength of glass fiber posts to the radicular dentin. Among the various laser types, the use of an Er,Cr:YSGG laser on the tooth structure is lately recommended [18]. Erbium lasers act on tissues by thermo-mechanical ablation and vaporize any water, causing an expansion followed by micro-explosions that eject both organic and inorganic tissue to provide a surface with open dentinal tubules and no smear layer. Yamazaki et al. [18] irradiated the dentin surface with Er,Cr:YSGG laser and recommended this laser for the removal of the smear layer and debris from root canals. According to the studies, researchers have reported different results about the effects of this laser on the radicular dentin. Mohammadi et al. [21] demonstrated that the bond strength values after Er,Cr:YSGG laser irradiation (0.5–2.5W) were significantly higher than those for the untreated group. Whereas Nagase et al. [28] found that the bond strength using a glass fiber post and total-etch adhesive system in combination with dual-cured resin cement was similar to that in the control group after Er,Cr:YSGG (0.75W) or Nd:YAG + Er,Cr:YSGG laser irradiation, the Nd:YAG (1.5W) laser alone was shown to negatively affect the post retention force. Other studies [29,30] showed the negative effect of Er,Cr:YSGG laser irradiation on the adhesion of resin to dentin with various adhesive systems; however, acid-etching [29] after laser irradiation increased the tensile strength of the bond to dentin. In the present study, there was no difference between the Er,Cr:YSGG laser irradiation (1W, 2W and 3W) groups and the untreated group, regardless of the different root levels. According to us, there are several reasons for these results. We have aimed to determine the effects of laser irradiation on dentin surface only. For this reason, effective root canal irrigation regimes (e.g. EDTA, NaOCl or acids) for the removal of the smear layer were discarded during the post space treatment. Only distilled water was used for cleaning. Besides, laser energy is delivered through a fiber-optic system to a sapphire tip terminal in the laser system used in this study. This condition can result in the limited penetration of laser beams to the lateral dentin surfaces and cause a thick smear layer. In addition, special-shaped drills were used to remove the gutta-percha and sealer. These instruments were able to perform effective post space debridement, but left more debris on dentinal walls.

FRC post adaptation and bond strength were significantly related to the post space region. Bond strength values decreased from the coronal to the apical level of the post space in previous studies [21,26,27]. The results of this study showed that the region of the root canal affected the bond strength. Higher bond strength values were observed in the coronal and middle levels and lower values were observed in the apical levels of the all groups. No significant difference was found between the coronal and middle levels. This finding could be due to several factors, such as regional differences in the number and density of the tubules toward the apical region of the canal, apical sclerosis, the high C-factor, the difficulty in visualization and access to the apical region, restrictions in the flow and distribution of the material and thick smear layer formation during the post space preparation [21,26,28,29,31].

Different output powers with or without water cooling were chosen in the studies. The average output varied from 0.1–8W [32]. For dentin irradiation, several researchers have recommended that irradiation outputs varying from 1.25–5W can be used [33]. High energy values have been related to more harmful thermal effects on dentin, especially when irradiation is not accompanied by cooling. In a study [18], dentin surfaces were irradiated by using a Er,Cr:YSGG laser at different output powers ranging from 1–6W and researchers observed carbonization and cracks in all samples irradiated without cooling, whereas there was little or no carbonization and smear layer in samples irradiated with cooling. Additionally, Hossain et al. [34] recommended that a Er,Cr:YSGG laser with the output powers below 3W and water cooling is a useful method for the removal of the smear layer and debris from the root canals. To avoid these negative effects of the laser, we used the 1W, 2W and 3W outputs with air/water flow continuously at 50%.

Bond strength of dental material with dentin is an important factor for the success of root canal treatment procedures. Consequently, mechanical testing of bonded interfaces can provide important insights into material selection and outcome prediction [35]. Several test methods are used to measure the adhesion of numerous materials including tensile, shear and push-out strength tests. One of them, the push-out test, has been frequently used in endodontics [35]. It has been suggested that the push-out test provides better evaluation results than the shear test because, using the push-out test, the fracture occurs parallel to the dentin-bonding interface, which makes it a true shear test for parallel-sided samples [32]. Besides, the tensile test is not appropriate for use with intra-canal fillings because of the high percentage of premature bond failures and the large variation in test results [36]. For these reasons, for FRC posts, the push-out test has been considered a more reliable test method.

Within the limitations of the present study, it may be concluded that dentin surface treatment by using Er,Cr:YSGG laser irradiation with different intensities did not improve the push-out bond strength of dentin. Thus, the null hypothesis of the study was rejected. Push-out bond strength was significantly lower in the apical level than in the coronal and middle levels, regardless of the experimental laser groups. Additional laboratory and clinical studies are still required for the futher evaluation of lasers when different application modes are used.

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