Influence of the ER,CR:YSGG laser and different irrigation methods on push-out bond strength of fiber post

Neslihan Çökük, Emine Kara, Devrim Kaki, Murat Aydoğdu & Serkan Sarıdağ

Published online: 03 Feb 2016.

Submit your article to this journal

Article views: 12

View related articles

View Crossmark data

Taylor & Francis
Taylor & Francis Group

Influence of the ER,CR:YSGG laser and different irrigation methods on push-out bond strength of fiber post

Neslihan Çökük[a], Emine Kara[b], Devrim Kaki[c], Murat Aydoğdu[a] and Serkan Sarıdağ[d]

[a]Faculty of Dentistry, Department of Prosthodontics, Yüzüncü Yıl University, Van, Turkey; [b]Faculty of Dentistry, Department of Restorative Dentistry, Yüzüncü Yıl University, Van, Turkey; [c]Faculty of Dentistry, Department of Endodontics, Yüzüncü Yıl University, Van, Turkey; [d]Faculty of Dentistry, Department of Prosthodontics, Kocaeli University, Kocaeli, Turkey

ABSTRACT

Er,Cr:YSGG lasers are currently being investigated for disinfecting the root canal treatment. The aim of this study was to compare the effects of various irrigation protocols on push-out bond strength of fiber posts. Fifty maxillary anterior teeth were divided into five groups ($n = 10$) according to the protocol that applied into the post space. Group-1: distilled water, Group-2: 5% NaOCl, Group-3: 2% CHX, Group-4: Er,Cr:YSGG laser (1.5 W, 20 Hz, 85 air, 75 water, 26.7 J/cm^2), Group-5: Er,Cr:YSGG laser (1.25 W, 50 Hz, 34 air, 24 water, 12.7 J/cm^2). Fiber posts were cemented with resin cement. The remaining part of the root, three slices were obtained from each specimen and push-out test was performed. One-way ANOVA and Duncan's test at a 5% level of significance were used for the statistical analysis. Post space irradiation with Er,Cr:YSGG laser (1.5 W 20 Hz, 85 air, 75 water, 26.7 J/cm^2) increases push-out bond strength of fiber post to root canal dentin. Further investigations are needed to establish and optimize ER,Cr:YSGG laser parameters to increase the push-out bond strength of fiber posts.

Introduction

Fiber-reinforced composite (FRC) posts are widely used to retain core material in endo-dontically treated teeth with extensive loss of coronal tooth structure.[1,2] FRC posts made from glass or quartz fiber improve esthetics in anterior regions.[3] FRC post systems have some advantages over metal posts. Their elasticity modulus is similar to that of dentin and they do not reflect dark color within the root and overlying gingival tissues.[4,5] Also, FRC post systems can be easily removed from the canal during root canal retreatment.[6] In previous clinical studies, the most common cause of FRC post failure was failure of adhesion between the post and the resin cement, or between the dentin and the resin cement.[1]

Fiber posts are passively retained inside the root canals, and resin-based luting agents are indicated for their retention.[7] Bond strength is affected by many factors among which

---

are the degree of dehydration of the root dentin, the physical properties of the resin cement used, inconvenient cavity configuration, adverse effects of sealers, and anatomic features such as different numbers of dentinal tubules at different levels of the canal.[8–10] Therefore, in order to increase the bond strength of FRC posts, several surface treatments have been performed on posts or dentin.[11,12] Successful bonding of posts to dentin can be compromised by various root canal disinfection pretreatments, which are necessary during chemomechanical instrumentation to prevent reinfection and to ensure a long-term positive outcome of the endodontic treatment.[13] Chemical irrigants such as sodium hypochlorite (NaOCl), ethylenediaminetetraacetic acid (EDTA),[14] chlorhexidine gluconate (CHX),[15] gaseous ozone [14], and high-energy light beams (lasers) are used for this purpose.[16]

The performance of the laser treatment depends upon absorption of laser energy by the target tissue. Among the high-power lasers that may be used on dental hard tissues, erbium-doped yttrium aluminum garnet (Er:YAG) laser (wavelength 2.94 μm) and erbium, chromium: yttrium–scandium–gallium–garnet (Er,Cr:YSGG) laser (wavelength 2.78 μm) are the best known and studied because of their large absorption by water and hydroxyapatite.[17] Various studies state that dental laser applications are employed for removal of pulp residues, removal of caries, morphological changes of enamel and dentin, and for revealing the dentinal tubules by removing the smear layer and debris on the root canal walls.[18,19] The energy of the high-power laser can be transmitted through the root canal by an optic fiber which is able to reach inaccessible areas of the root canal system, where endodontic instruments and chemical auxiliary substances cannot work effectively.[20]

The aim of this study was to evaluate the effects of dentin surface treatments including Er,Cr:YSGG laser irradiation of different intensities and different canal irrigation methods on the push-out bond strength of glass fiber posts to root dentin. The null hypothesis was that the push-out bond strength values of fiber posts would be increased by Er,Cr:YSGG laser pretreatment to root canal dentin.

Materials and methods

Specimen preparation

Fifty-five freshly extracted human maxillary central incisors were selected. The study was ethically approved by the institutional review board of the university. Periodontal ligaments and calculi were removed; teeth stored in 0.02% thymol solution at 1 month and then teeth were washed. Each tooth was decoronated below the cementoenamel junction, perpendicular to the longitudinal axis using a slow-speed, water-cooled diamond saw (Buehler Ltd., Lake Bluff, IL, USA) at low rotation. Root length was standardized to 14 mm measured from the apex of the tooth to the cementoenamel junction.

Pulp tissue and predentin were removed and root canals were enlarged to #40 file size (Dentsply Maillefer, Ballaigues, Switzerland). Roots were rinsed with 5 mL saline solution to remove remaining debris, dried with paper points, and filled with gutta-percha (Dentsply Maillefer, Ballaigues, Switzerland) by lateral condensation and MMSeal (MICRO-MEGA®, Besancon, USA). The specimens were kept at 37 °C and in 100% relative humidity for 7 days for full cement setting. One trained operator prepared all root canals.

Roots were embedded vertically with acrylic resin (Meliodent, Heraeus Kulzer, Hanau, Germany) using a prosthetic liner to ensure orientation in the long axis of the root. Filling
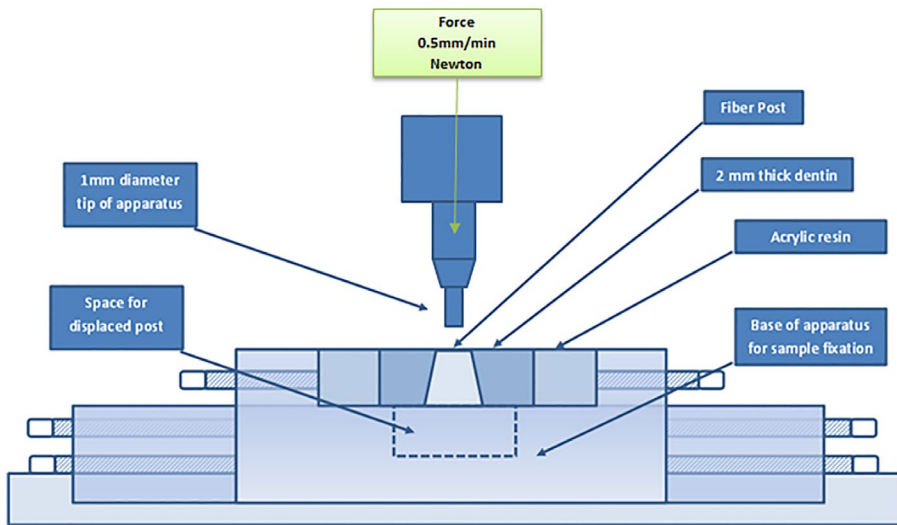
Figure 1. Magnified schematic diagram of the circled area.

material was then removed from the root canal using drill #2, leaving a remnant of 5 mm in the apex before applying the fiber glass post system (Exacto, Ângelus, Londrina, PR, Brazil).

The specimens were divided into five groups ($n = 10$) according to the irrigation solution used, as follows:

Group 1 specimens were irrigated with 2 mL distilled water only (control group) for 1 min.

Group 2 specimens were irrigated with 2 mL 5% NaOCl, for 1 min and then irrigated with 2 mL distilled water.

Group 3 specimens were irrigated with 2 mL 2% CHX, for 1 min and then irrigated with 2 mL distilled water.

Group 4 specimens received Er, Cr: YSGG laser (Waterlase MD, Biolase Technology Inc., San Clemente, CA, USA) irradiation (with 2780 nm wavelength), applied with a 14-mm MZ6 optical tip. The laser parameters used were output power of 1.5 W energy, pulse frequency of 20 Hz (pulses per second), 140–200 μs pulse duration range with continuous 85% air and (75%) water flow. The canals were continuously irradiated from most apical region at the post space area to the coronal area in slow, helicoidal movements for 7 s. This procedure was repeated four times per post space. Energy density was 26.7 J/cm^2.

Group 5 specimens received Er, Cr: YSGG laser (Waterlase MD, Biolase Technology Inc., San Clemente, CA, USA) irradiation (with 2780 nm wavelength), applied with a 14-mm RFPT5 optical tip. The laser parameters used were output power of 1.25 W energy, pulse frequency of 50 Hz (pulses per second), 140–200 μs pulse duration range with continuous air flow of 34%, and continuous water flow of 24%. The root canals were continuously irradiated from most apical region at the post space area to the coronal area in slow, helicoidal movements for 7 s. This procedure was repeated four times per post space. Energy density was 12.7 J/cm^2.

In all groups, the root canal walls were conditioned with an autopolymerizing primer (ED-primer, Kuraray Medical Inc., Tokyo, Japan) for 60 s. Then, the post spaces were

air dried and excess primer removed with paper points (Dentsply Maillefer, Ballaigues, Switzerland). In the cementation stage, equal amounts of base and catalyst pastes of an adhesive composite resin cement (Panavia F2.0, Kuraray Medical Inc., Tokyo, Japan) were mixed and applied to the prepared post surfaces and into the post spaces with a lentulo spiral instrument (Dentsply Maillefer, Ballaigues, Switzerland). The fiber posts were inserted into the root canals using gentle finger pressure. After removing excess cement from around the post, oxygen-inhibiting gel (Oxyguard II, Kuraray Medical Inc. Tokyo, Japan) was used to protect the remaining cement. The resin cement was light cured for 40 s. The specimens were kept at 37 °C and 100% humidity for 7 days.

For the bond strength test, both coronal 1 mm slice of root was sectioned due to the oxygen inhibition layer and apical 5 mm slice of root was sectioned due to gutta-percha. The remaining part of the roots was horizontally sectioned into three slices of 1.5 ± 0.1 mm thicknesses using a slow-speed saw (Buehler Ltd., Lake Bluff, IL) under continuous water cooling. Each slice represented one-third of the root thirds: cronal, middle, and apical. The diameter and perimeter of the canal were measured for calculation of the adhesive area using the following formula for the frustum of a cone:

$$A = \pi^{\times}(R + r)^{\times} \sqrt{\left((R - r)^2 + h^2\right)}$$

where π is the constant 3.14, R is the larger radius, r is the lower radius, and h is the thickness of the dental slice. The push-out bond test was performed using a universal test machine (Shimadzu Co., Kyoto, Japan) at crosshead speed of 0.5 mm/min. Each specimen was carefully positioned over a rigid base, with the apex facing the punch tip, and its diameter corresponding with the diameter of the set post/cement (Figure 1). The push-out bond strength of each specimen (MPa) was calculated as the force (N) of failure divided by the adhesive area (mm^2).

All statistical analyses were performed using SAS version 9.3. To obtain descriptive statistics and normality tests, results were expressed as Proc Means and Proc Univarite commands, respectively. One-way ANOVA was used to compare the means of the five groups to determine whether they differed significantly from one another ($p < 0.05$). Duncan's test was used for multiple comparisons at a 5% level of significance. One-way ANOVA and Duncan results were analyzed using Proc GLM in SAS.

Failure mode pattern

To analyze the fracture modes, slices were examined under a stereomicroscope (M320, Leica Microsystems, Heerbrugge, Switzerland) (40x magnification) to determine the mode of bond failure as follows:

(1) Adhesive failure between the resin cement and post (adhesive 1).
(2) Adhesive failure between the resin cement and dentin (adhesive 2).
(3) Mixed failure in both of the above and cohesive failure in dentin.

Analysis of SEM images

A total of five samples (one sample for each group) were examined alike root canal specimen preparation section. Apical 5 mm and coronal 1 mm slices of root were sectioned and

Table 1. Push-out bond strength values (MPa, ± SD) in each group of dentin surface treatments in each root region.

Groups	Coronal	Middle	Apical
Group 1 (Distilled Water)	$6.9112 \pm 0.05^{C,a}$	$7.0171 \pm 0.15^{B,a}$	$6.4432 \pm 0.09^{B-C,b}$
Group 2 (NaOCl)	$5.2663 \pm 0.02^{D,a}$	$5.3550 \pm 0,03^{D,a}$	$5.4741 \pm 0.01^{D,a}$
Group 3 (CHX)	$8.0424 \pm 0.19^{B,a}$	$7.3034 \pm 0.07^{A,b}$	$7.0109 \pm 0.17^{B,b}$
Group 4 (1.5 W)	$9.5597 \pm 0.25^{A,a}$	$7.4142 \pm 0.06^{A,b}$	$7.3967 \pm 0.15^{A,b}$
Group 5 (1.25 W)	$6.8297 \pm 0.05^{C,a}$	$6.6387 \pm 0.06^{C,a}$	$6.7893 \pm 0.12^{C,a}$

Means within each group with the same superscript letter are not significantly different (capital letter, column; small letter, row)
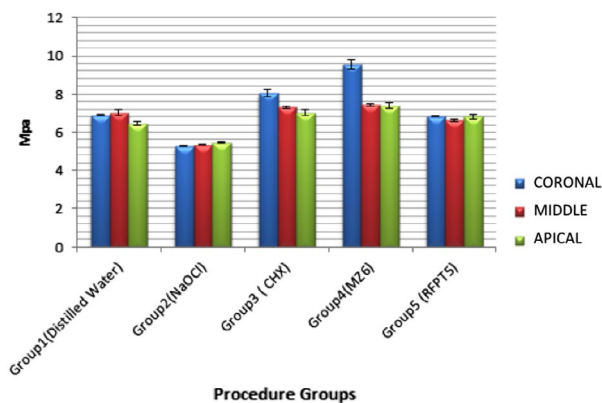

Figure 2. Push-out bond strengths (MPa) of dentin surface treatments in each root region.
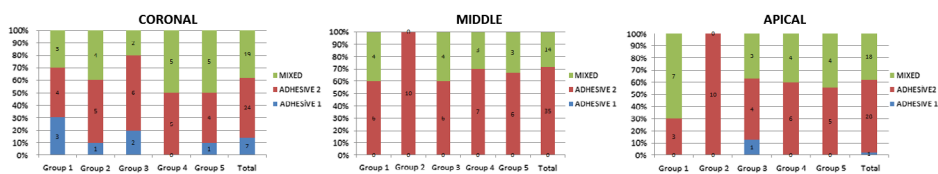
Figure 3. Failure mode distribution among groups tested (Group 1: Distilled water, Group 2: NaOCl, Group 3: CHX, Group 4: MZ6, Group 5: RFPT5).

then the remaining part of the roots were horizontally sectioned into three slices. For SEM analysis, each post space sectioned vertically before this slice was mounted Cressington Coater 108 (Ted Pella, Inc., Redding, Canada). Then, each specimen was examined by scanning electron microscope (Nova NanoSEM 650 Series; FEI Europe B.V., Netherlands) and photographs were taken.

Results

The mean and standard deviation values of the push-out test, indicating bond strength in each group, are shown in Table 1 and Figure 2. Among the coronal sections, group 4 performed the significantly highest bond strength. There was no significant difference between groups 5 and 1. Group 2 performed the lowest coronal bond strength values.
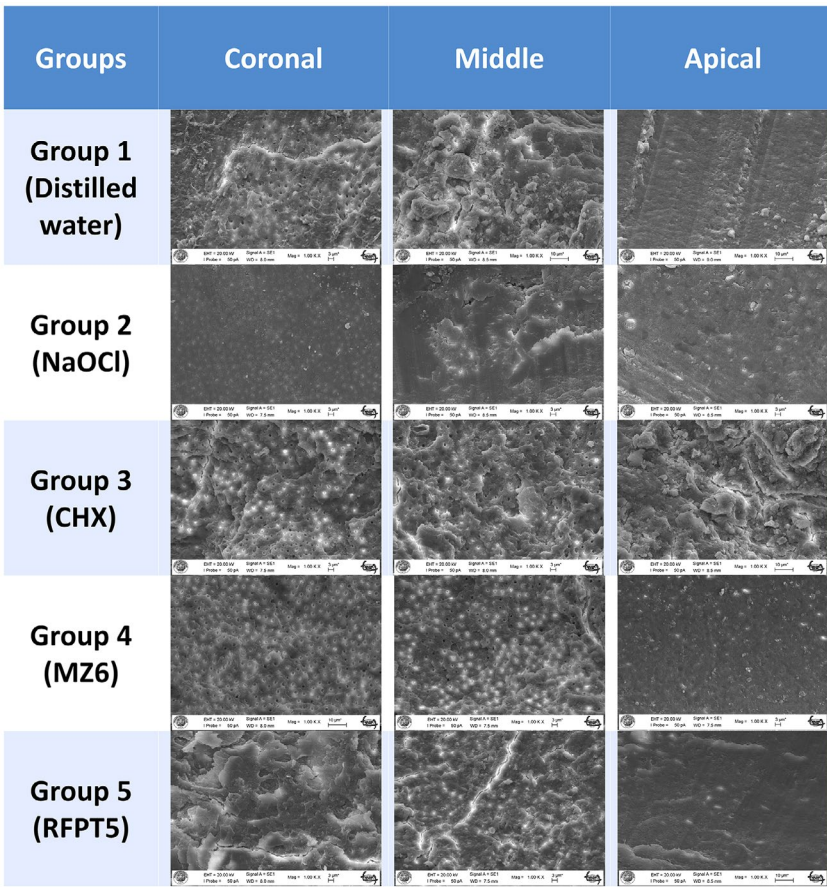
Figure 4. Representative SEM images showing each samples from coronal, middle, and apical third of root canal surfaces (magnification × 1000).

Among the middle sections, groups 3 and 4 were higher than the other groups and there was no statistically significant difference between groups. Group 2 performed the lowest middle bond strength values. Among the apical parts of the groups, group 4 had the significantly highest results. Although differences between groups 1 and 5 were not statistically significant ($p > 0.05$), group 3 was different to 5 ($p < 0.05$). Group 2 performed the lowest apical bond strength results.

A significant decrease in bond strength was observed after the use of 5% NaOCl in all root thirds ($p < 0.05$). Er,Cr:YSGG laser pretreatment (only 1.5 W) showed the highest results in all parts tested, and there was a significant difference between the coronal and apical parts ($p < 0.05$). The results of groups 3 and 4 coronal parts were statistically significantly higher than the other parts ($p < 0.05$).

Microscopic examination indicated that the predominant failure mode was adhesive failure between the resin cement and dentin. No cohesive failures were identified in dentin. The distribution of failure pattern among the groups tested is shown in Figure 3.

SEM images of the dentin surface of all groups at the apical thirds showed totally obliterating the dentin tubules; with the exception of the specimens irradiated by the Er,Cr:YSGG

laser with 1.5 W (group 4). The middle thirds of the CHX irrigated specimens (group 3) and group 4 showed obliterated dentinal tubules. In the coronal thirds, the surface texture of dentin that had been irradiated by the Er,Cr:YSGG laser with 1.5 W (group 4) was clearer than that of the dentin from the other irradiated group (group 5). While specimens in group 4 showed dentin tubules were open and clear. Specimens irradiated by the Er,Cr:YSGG laser with 1.25 W (group 5) showed that some parts of the obliterated dentinal tubules, wherein the fiber tip had not touched the canal walls. In addition, laser-irradiated root canal dentin showed some melting and recrystallization, resulting in a scaly and flaky structure (Figure 4). These findings were in agreement with the bond strength value results.

Discussion

In this study, the effect of different irrigation methods and different parameters of Er,Cr:YSGG laser for improvement of bonding strength of fiber posts were compared. For this purpose, push-out test was used to determine bond strength. This test was employed to determine bond strength of fiber posts in different sections of the root canal and to reduce the premature loss of samples during specimen manufacture.[21]

Traditionally, endodontic posts were individually cast metal posts but their higher elastic modulus caused teeth to be vulnerable to root fractures.[10] Contemporary fiber post systems have many advantages including high shear strength, dentin-like elastic modulus and reduced fracture rates with minimal stress transmission to root canals.[1] Additionally, characteristics such as esthetic appearance, no exposure of corrosion residues on the root surface and no gingival coloring are essential for anterior esthetics.[22]

Adhesive resin cements are recommended for cementation of fiber posts to enhance retention and for stress distribution throughout the post-dentin interface.[23] Self-etch systems are recommended to avoid the need for moisture for bonding in root canals.[24] In this study, a self-etch resin-based adhesive cement Panavia F2.0 was used. It contains 10-MDP (methacryloyloxydecyl dihydrogen phosphate) which is a phosphate-based functional monomer that bond chemically with the calcium in the hydroxyapatite crystals around collagen fibers.[25] It also forms micromechanical retention on demineralized dentin surface and bonds chemically with hydroxyapatite via the multifunctional phosphoric acid methacrylate group.[26]

Factors affecting adhesion in post space include the presence of tubular fluids in root canal dentin, odontoblastic extensions, remnants of gutta-percha and root canal filling paste, and moisture of root dentin and smear layer.[10–12] The smear layer has to be modified or removed by irrigation, ultrasonic or sonic devices, and dental lasers.[11,12,27,28] It has been reported that the removal of the smear layer prior to post cementation is necessary for the penetration of adhesive to dentinal tubules and for the formation of micromechanical retention.[28] Kirmali et al. compared the effects of dentin surface treatments on adhesion, using distilled water-treated teeth as controls.[29] In our study also, distilled water-treated group was used as control. We found that 5% NaOCl decreased the bond strength in all root thirds. Martinho et al. and several other groups report that various experimental concentrations of NaOCl lower the bond strength of resin cements.[30] This phenomenon can be explained by dentinal degradation causing the collapse of bonds between carbon atoms and the dissolving of collagens.[31] On the other hand, treatment with 2% CHX did not lower the bond strength significantly in our study. In a study by Lindblad et al., which was

investigating the effect of CHX on the adhesion of fiber-reinforced posts in root canals, 2% CHX was employed [15] because it reduced the bacterial accumulation in root canals during preparation,[32] it did not adversely affect the bonding values in pulp chamber,[30] it was frequently used in endodontic researches and as the final irrigant solution prior to root canal filling.[33] In our study, the choice of 2% CHX was similar to the mentioned study. Additionally, the CHX results of our study showed resemblance to the results of Lindblad et al. [15]. The usage of 2% CHX as post space irrigant did not adversely affect the bonding, although preserved bonding values after 12 months as shown by the study of Cecchin et al. [34].

Employment of dental lasers in endodontic treatments is a rising trend. Lasers such as diode, Nd:YAG (Neodymium doped with Yttrium–Aluminum–Garnet), Er:YAG, and Er,Cr:YSGG are frequently used for hard tissue removal, pulpectomy, and disinfection and shaping of root canals. Laser treatments are complementary to traditional root treatments. [16] Studies suggest that Er,Cr:YSGG laser irradiation successfully removes the smear layer and improves permeability by opening the dentinal tubules due to the affinity for hydroxyapatite and moisture.[18,19] In our study, Er,Cr:YSGG lasers with two kinds of different energy density were compared.

Er,Cr:YSGG laser (1.25 W) group showed results similar to those of the distilled water group in all three root sections and values were lower than those for the CHX group. Kirmali et al. reported no significant differences between the control group and groups irradiated with Er,Cr:YSGG laser (1 , 2 and 3 W).[29] We propose that our results are different because of the total energy density. And also, the energy density achieved with the RFPT5 fiber tip is used for post space cleaning and shaping. But the comparable bond strength values for all three root sections suggest that the laser beam equally distributes throughout the root. Considering all of the groups, Er,Cr:YSGG laser (1.5 W) group showed the highest bond values. Furthermore, Er,Cr:YSGG laser (1.5 W) group has significantly higher bond strength in the coronal third sections than in the middle and apical thirds, which showed similar values. We think that the reason for the highest bonding values in coronal third was higher power used and also the energy density achieved with the MZ6 fiber tip was used for etching and smear removal in the post space. Mohammadi et al. reported that application of Er,Cr:YSGG laser twice in the same root canal (0.5 W followed by 2.5 W) improves the bond strength of root dentin to a self-adhesive resin cement and there was no significant difference between different root sections.[35] Their results are consistent with our findings. Hossain et al. suggest that laser beam energy of maximum 3 W with water cooling is adequate for the removal of debris and smear layer from root canal surfaces.[36] In our study, we used 1.25 and 1.5 W laser radiation under water cooling to avoid negative effects such as carbonization and cracking. Therefore, the null hypothesis could be accepted because the highest bond values were observed in 1,5 W group of Er,Cr:YSGG laser but in 1.25 W group of laser group showed bonding values comparable to other irrigation methods.

Various studies have reported that bond strength of fiber posts is lower in apical sections than in coronal sections.[29,37,38] On the contrary, Mohammadi et al. found that Er,Cr:YSGG laser application enhanced bond strength in self-adhesive resin cements, with no significant difference between different root sections.[35] But in our study, the bond strength in the middle and apical thirds of root canals was not significantly different, but that in the coronal third was significantly higher. We propose that reasons for this difference may include smear layer remnants, penetration of root canal filling paste in dentinal tubules,

moisture after irrigation, limited visibility, and variation in the number and diameter of dentinal tubules toward the apical region. Further studies are needed to determine the laser parameters to increase bond strength value of apical and middle third of post space. And also, there are no previous studies on the different laser parameters with different fiber types of post space pretreatment with irradiation.

Mode and location of bond failure highlights the bonding characteristics between dentin and adhesive resin.[35] In our study, the most frequent mode of failure was adhesive failure between the resin and dentin and these results are consistent with previous studies.[38,39] Wrbas et al. found higher rates of resin-dentin and mixed failure and attributed this to silanization of post surface.[40] In our study, resin-post failure only occurred in coronal sections. This is thought to be due to higher resin-dentin bond strength in coronal sections.

When the SEM images of all groups were inspected, the results were parallel with the study of Kirmali et al. in which the dentinal tubules in apical thirds was completely plugged. [29] Bitter et al. reported that the tubules in laser-applicated root canal dentin was completely revealed, besides the surface was scaly and flaky structured because of melting and recrystallization.[27] In our study, Er,Cr:YSGG laser with 1.5 W group showed dentin tubules were open and clear. This was possibly due to the removal of smear layer by the Er,Cr:YSGG laser, which opened the dentinal tubules.[18,19]

Conclusions

Within the limitations of the present *in vitro* study, post space irradiation with Er,Cr:YSGG laser (1.5 W) increases push-out bond strength of fiber post to root canal dentin. However, Er,Cr:YSGG laser (1.25 W) and other surface treatment procedures showed lower push-out bond strength values than Er,Cr:YSGG laser (1.5 W) irradiation. Push-out strength values for CHX and Er,Cr:YSGG laser (1.5 W) were higher in the coronal region than in medium and apical regions, whereas the groups NaOCL and Er,Cr:YSGG laser (1.25 W) were equal on three thirds.

Disclosure statement

References

[1] Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J. Endod. 2004;30(5):289–301.

[2] Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. J. Prosthet. Dent. 1990;63:529–536.

[3] Akkayan B, Gülmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J. Prosthet. Dent. 2002;87:431–437.

[4] Qualtrough AJ, Mannocci F. Tooth-colored post systems: a review. Oper. Dent. 2003;28:86–91.

[5] Goracci C, Corciolani G, Vichi A, et al. Light-transmitting ability of marketed fiber posts. J. Dent. Res. 2008;87:1122–1126.

[6] Katalinic I, Glockner K, Anic I. Influence of several root canal disinfection methods on pushout bond strength of self-etch post and core systems. Int. Endod. J. 2014;47:140–147.

[7] Goracci C, Grandini S, Bossù M, et al. Laboratory assessment of the retentive potential of fiber posts: a review. J. Dent. 2007;35:827–835.

[8] Assif D, Gorfil C. Biomechanical considerations in restoring endodontically treated teeth. J. Prosthet. Dent. 1994;71:565–567.

[9] Ferrari M, Cagidiaco MC, Goracci C, et al. Long-term retrospective study of the clinical performance of fiber posts. Am. J. Dent. 2007;20:287–291.

[10] Asmussen E, Peutzfeldt A, Heitmann T. Stiffness, elastic limit, and strength of newer types of endodontic posts. J. Dent. 1999;27:275–278.

[11] Zicari F, De Munck J, Scotti R, et al. Factors affecting the cement–post interface. Dent. Mater. 2012;28:287–297.

[12] Khalighinejad N, Feiz A, Faghihian R, et al. Effect of dentin conditioning on bond strength of fiber posts and dentin morphology: a review. Am. J. Dent. 2014;27:3–6.

[13] Law A, Messer H. An evidence-based analysis of the antibacterial effectiveness of intracanal medicaments. J. Endod. 2004;30:689–694.

[14] Estrela C, Estrela CR, Decurcio DA, et al. Antimicrobial efficacy of ozonated water, gaseous ozone, sodium hypochlorite and chlorhexidine in infected human root canals. Int. Endod. J. 2007;40:85–93.

[15] Lindblad RM, Lassila LV, Salo V, et al. Effect of chlorhexidine on initial adhesion of fiber-reinforced post to root canal. J. Dent. 2010;38:796–801.

[16] Wang QQ, Zhang CF, Yin XZ. Evaluation of the bactericidal effect of Er,Cr:YSGG, and Nd:YAG lasers in experimentally infected root canals. J. Endod. 2007;33:830–832.

[17] Ramos TM, Ramos-Oliveira TM, Moretto SG, et al. Microtensile bond strength analysis of adhesive systems to Er:YAG and Er, Cr:YSGG laser-treated dentin. Lasers Med. Sci. 2014;29:565–573.

[18] Lee BS, Lin PY, Chen MH, et al. Tensile bond strength of Er, Cr:YSGG laser-irradiated human dentin and analysis of dentin–resin interface. Dent. Mater. 2007;23:570–578.

[19] Minas NH, Gutknecht N, Lampert F. In vitro investigation of intra-canal dentine-laser beam interaction aspects: II. Evaluation of ablation zone extent and morphology. Lasers Med. Sci. 2010;25:867–872.

[20] Dewsnup N, Pileggi R, Haddix J, et al. Comparison of bacterial reduction in straight and curved canals using Erbium, Chromium:Yttrium–Scandium–Gallium–Garnet laser treatment versus a traditional irrigation technique with sodium hypochlorite. J. Endod. 2010;36:725–728.

[21] Ebert J, Leyer A, Gunther O, et al. Bond strength of adhesive cements to root canal dentin tested with a novel pull-out approach. J. Endod. 2011;37:1558–1561.

[22] Solomon CS, Osman YI. Aesthetic restoration of the compromised root: a case report. SADJ. 2003;58:373–376.

[23] Toman M, Toksavul S, Sarıkanat M, et al. The evaluation of displacement resistance of glass FRC posts to root dentine using a thin slice push-out test. Int. Endod. J. 2009;42:802–810.

[24] Zhang L, Huang L, Xiong Y, et al. Effect of post-space treatment on retention of fiber posts in different root regions using two self-etching systems. Eur. J. Oral Sci. 2008;116:280–286.

[25] Fukegawa D, Hayakawa S, Yoshida Y, et al. Chemical interaction of phosphoric acid ester with hydroxyapatite. J. Dent. Res. 2006;85:941–944.

[26] Radovic I, Monticelli F, Goracci C, et al. Self-adhesive resin cements: a literature review. J Adhes. Dent. 2008;10:251–258.

[27] Bitter K, Noetzel J, Volk C, et al. Bond strength of fiber posts after the application of Erbium:Yttrium–Aluminum–Garnet laser treatment and gaseous ozone to the root canal. J. Endod. 2008;34:306–309.

[28] Celik D, Er K, Serper A, et al. Push-out bond strength of three calcium silicate cements to root canal dentine after two different irrigation regimes. Clin. Oral Invest. 2014;18:1141–1146.

[29] Kirmali O, Kustarci A, Kapdan A, et al. 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. Acta Odontol. Scand. 2015;73:1–7.

[30] Santos JN, Carrilho MR, De Goes MF, et al. Effect of chemical irrigants on the bond strength of a self-etching adhesive to pulp chamber dentin. J. Endod. 2006;32:1088–1090.

[31] Ari H, Erdemir A, Belli S. Evaluation of the effect of endodontic irrigation solutions on the microhardness and the roughness of root canal dentin. J. Endod. 2004;30:792–795.

[32] Zamany A, Safavi K, Spangberg L. The effect of chlorhexidine as an endodontic disinfectant. Oral Surg., Oral Med., Oral Pathol., Oral Radiol., Endod. 2003;96:578–581.

[33] Zehnder M. Root canal irrigants. J. Endod. 2006;32:389–398.

[34] Cecchin D, de Almeida JF, Gomes BP, et al. Influence of chlorhexidine and ethanol on the bond strength and durability of the adhesion of the fiber posts to root dentin using a total etching adhesive system. J. Endod. 2011;37:1310–1315.

[35] Mohammadi N, Oskoee SS, Kahnamoui MA, et al. Effect of Er,Cr:YSGG pretreatment on bond strength of fiber posts to root canal dentin using a self-adhesive resin cement. Lasers Med. Sci. 2013;28:65–69.

[36] Hossain M, Nakamura Y, Yamada Y, et al. Effects of Er,Cr:YSGG laser irradiation in human enamel and dentin: ablation and morphological studies. J. Clin. Laser Med. Surg. 1999;17:155–159.

[37] Chang H, Noh Y, Lee Y, et al. Push-out bond strengths of fiber-reinforced composite posts with various resin cements according to the root level. J. Adv. Prosthod. 2013;5:278–286.

[38] Mumcu E, Erdemir U, Topcu F. Comparison of micro push-out bond strengths of two fiber posts luted using simplified adhesive approaches. Dent. Mater. J. 2010;29:286–296.

[39] Zicari F, Couthino E, De Munck J, et al. Bonding effectiveness and sealing ability of fiber-post bonding. Dent. Mater. 2008;24:967–977.

[40] Wrbas KT, Altenburger MJ, Schirrmeister JF, et al. Effect of adhesive resin cements and post surface silanization on the bond strengths of adhesively inserted fiber posts. J. Endod. 2007;33:840–843.