Original Article

Influence of Er,Cr:YSGG Laser Surface Treatments on Micro Push-Out Bond Strength of Fiber Posts to Composite Resin Core Materials

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Abstract

Statement of problem: The bonding of fiber post to resin core or root dentin is challenged by limited penetration of resin material to the polymeric matrix of fiber posts.

Objectives: The purpose of this study was to investigate the effect of Er,Cr:YSGG on micro push-out bond strength of glass fiber posts to resin core material.

Materials and Methods: We used 2 commercially available fiber posts, Exacto (Angelus) and White Post DC (FGM), which had similar coronal diameters. Specimens of each fiber post (n=36) were randomly divided into three subgroups (n=12 posts per group) according to different surface treatment methods: control (no surface treatment), irradiation by 1W Er,Cr:YSGG, and irradiation by 1.5W Er,Cr:YSGG. A cylindrical plastic tube was placed around the post. Resin core material was filled into the tube and cured. Coronal portions of the posts were sectioned into 1-mm-thick slices. Then, the specimens were subjected to a thermocyling device for 3000 cycles. The micro push-out test was carried out using a Universal Testing Machine. Data were analyzed using one-way ANOVA followed by Tukey's HSD post hoc test to investigate the effect of different surface treatments on each type of fiber post.

Results: The 1.5W Er,Cr:YSGG laser statistically reduced micro push-out bond strength values in the Exacto groups (P<0.05). However, there was no significant difference between the control and 1W Er,Cr:YSGG groups. We observed no significant difference among different surface treatment methods in the White post DC groups (P>0.05). Mode of failure analysis showed that mixed failure was the predominant failure type for all surface treatment groups.

Conclusions: The beneficial effect of Er,Cr:YSGG laser application could not be confirmed based on the results of this in vitro study. Er,Cr:YSGG laser could not significantly enhance the bond strength values. However, the 1.5W laser statistically decreased micro push-out bond strength in the Exacto fiber posts.

Introduction

Endodontically treated teeth may have inadequate crown structures due to severe caries, removal of filings, or excessive wear. Therefore, we should place posts to maintain the core and reconstruct any missing tooth structure. Prefabricated posts are better than cast posts in terms of time and decreased cost [1, 2]. The excellent optical and mechanical properties of fiber posts introduce them as alternatives to casting and ceramic posts [3]. Prefabricated fiber posts are bonded to root canals to reduce microleakage and provide retention for composite resin cores [4]. Strengthening of this bond seems necessary to avoid treatment failure. Fiber posts are usually made of carbon, glass, quartz, silica or polyethylene fibers embedded in a polymer resin matrix based on methacrylate or epoxy resins. The fibers are bonded to matrix by a silane coupling agent [5]. The numbers of fibers depends on the type of post changes (between 25-35) that are parallel to the post axis; each of these fibers ranges in diameter from 6-10 μm/mm2 of cross-section area [6]. Although the fiber posts are easier to use than conventional posts, clinical and laboratory studies suggest that the bond of the fiber post to the dentine of the root canal and resin core can be problematic. The main advantage is that the elastic modulus of the fiber post is similar to dentin. This property provides appropriate stress distribution to minimize the risk of vertical root fracture [4, 7]. However, the polymeric matrix of the fiber post has substantial cross-linking and cannot react with resin composite monomers [1, 4]. Several surface treatment methods (e.g., micro-mechanical and chemical) have been introduced for the fiber posts to improve this bond [8]. Porosity of the surfaces will increase following surface treatment. Thus, resin can penetrate the porosities and micromechanical locking enhances core retention. Numerous chemical and mechanical efforts have been made to improve this bond because it is not satisfactory. For example, a silane coupling agent can modify the chemical surface and enhance wettability by forming a chemical bridge between the composite resin and glass fiber posts [9]. Micromechanical surface treatment of fiber posts with airborne-particle abrasion and hydrofluoric acid also significantly increases bond strength between the fiber posts and resin based materials [10-12]. Micromechanical surface treatments make surfaces rougher, which increases surface area and surface energy. Removal of the superficial layer of the resin matrix will expose the fibers to create a chemical bond [13, 14]. Micromechanical methods for the fiber post surface treatment are harmful. They may reduce the strength of the posts and change its shape, which subsequently affects its ability to fit the canal [2, 13].The use of lasers in dentistry has increased in recent decades. Various lasers have been used as alternatives to previous methods to increase the bond strength of dental materials. This study aimed to evaluate the effect of the Er,Cr:YSGG laser as a surface treatment for fiber posts. The null hypotheses tested in this study were: (1) Er,Cr:YSGG laser does not cause surface changes in fiber posts and (2) prior application of Er,Cr:YSGG laser on the post surface does not affect micro push-out bond strength.

Materials and Methods

In this study, we investigated the effects of the Er,Cr:YSGG laser on micro push-out bond strength of glass fiber posts to resin core material. Table 1 lists the materials used in this study. Two commercially available glass fiber posts with similar coronal diameters and smooth surfaces were used. The first group included 36 glass fiber conical intraradicular posts (Exacto size #3, Angelus, Londrina, PR, Brazil) and the second group included 36 glass fiber double tapered posts (White Post DC n. 2, FGM, Joinville, SC, Brazil). We randomly divided the specimens from each group into three subgroups of 12 posts each for a total of 6 groups, as follows: Group 1: Exacto fiber post that received no surface treatment (control group).Group 2: Exacto fiber post irradiated with an Er,Cr:YSGG laser device (Waterlase MD, Biolase, Irvine) with a MZ8 μm tip, energy level of 1W, repetition rate of 20 Hz, 140 μs pulse duration with 80% water and 60% air for 10 sec, using the non-contact mode. Group 3: Exacto fiber post irradiated with an Er,Cr:YSGG laser device (Waterlase MD, Biolase, Irvine) that had an energy level of 1.5W repetition rate of 20 Hz, 140 μs pulse duration with 80% water and 60% air for 10 sec, using the non-contact mode.

Table 1: Materials used in this study

Trade name	Type	Manufacturer	Lot number
Exacto	Glass fiber conical intraradicular post	Angelus, Londrina, PR, Brazil	S4167256
White Post DC	Glass fiber double tapered posts	FGM, Joinville, SC, Brazil	100615
Dentocore Body	Nanofil composite core build-up material, automix, dual-cure	Itena, France	5194-25QCA3
Silano	Silane	Angelus, Londrina, PR, Brazil	37069
Clearfil SE Bond	Adhesive	Kuraray Noritake Dental, Inc. Okayama, Japan	C30289
Panasil	Vinyl polysiloxane impression material	Kettenbach Gmbh & Co. KG, Germany	22699/2112

Group 4: White Post DC post that received no surface treatment (control group). Group 5: White Post DC post irradiated with an Er,Cr:YSGG laser at energy level of 1W, the same as method 2 (Figure 1A).Group 6: White Post DC post that irradiated with Er,Cr:YSGG laser, at energy level of 1.5W, the same as method 3. After the surface treatments, a single layer of the silane coupling agent was applied with a micro brush to the post surfaces for 1 min, and gently air-dried. Then, a thin layer of unfilled resin (bonding agent) was applied on the surfaces and cured with an LED light curing unit (Bluephase G2, Ivoclar Vivadent). A cylindrical plastic tube (15.0 mm length and 7.0 mm inner diameter) was placed around the post. The apical part of the post was fixed into the putty additional silicon impression material (Panasil, Germany) with the post located at the center of the tube and allowed to set (Figure 1B). Resin core material was filled into the tube and light cured for 20 s each direction of the tube. To ensure optimal polymerization of the core material, an additional light-curing was performed at the end of the specimens for 40 s. Then, the specimens were removed from the tube by sectioning with a scalpel blade and stored in distilled water at 37°C for 24 h. After the storage period, the untapered, coronal portions of the posts were sectioned perpendicular to their long axis by the diamond saw of a cutting machine (Nemopars, Iran) under cooled water with 3 slices (1±0.1 mm thickness) from each specimen. Then, the specimens were subjected to thermocycling (Dorsa, Iran) for 3000 cycles between 5-55°C water baths using a dwell time of 20 s. A compressive push-out load was applied with a Universal Testing Machine at a cross-head speed of 1 mm/min, with a load cell of 20 kgf (BONGSHIN, Model DBBP-20, Korea; Fig 1D). The load was applied in the apical-coronal direction using a 1.5 mm diameter cylindrical plunger, which was placed at the center of the post to avoid contact with the surrounding core material. The maximum load at failure was recorded in Newtons (N) and converted to MPa by dividing the applied load into the bonding area. The bonded area was calculated via the following formula: $A=2\pi rh$ Where r is the post radius, h is the thickness of each disk in mm, and $\pi=3.14$.We analyzed the morphology of the fiber post surfaces from the six groups using a field emission scanning electron microscopy (FE-SEM; TESCAN, Czech Republic). Failure modes were analyzed by a stereomicroscope (Olympus SZ51,
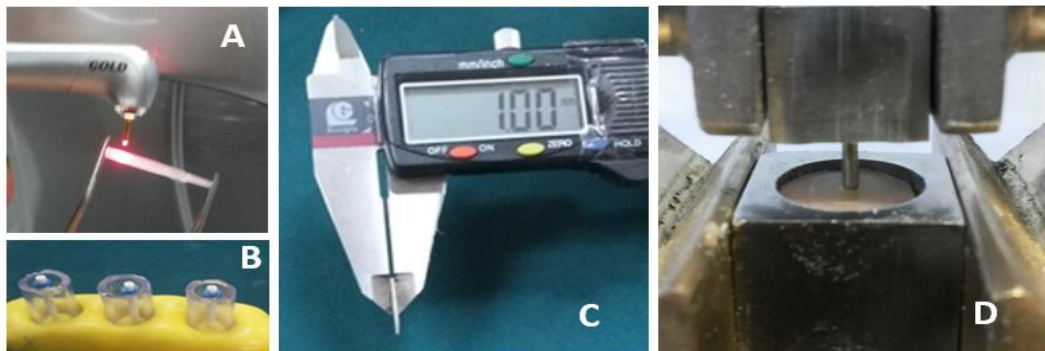
Figure 1: A) Irradiation of glass fiber posts with the Er,Cr:YSGG laser. B) Fixation of posts into the silicon impression material. C) Measuring the thickness of the specimens with a caliper. D) Applying the push-out load by using a Universal Testing Machine

Philippines) at 40x magnification and categorized according to four criteria: 1. cohesive failure within the resin core build-up material; 2. cohesive failure within the fiber post; 3. adhesive failure between the resin core build-up material and fiber post; and 4. mixed failure (a combination of the above failures). Two specimens from each group were analyzed under FE-SEM after fracture to determine the types of failure.

Statistical analysis

Two-way analysis of variance (ANOVA) was performed in order to simultaneously determine the effect of the type of post material and surface treatment on bond strength. We examined these two variables separately considering the significant interaction between surface treatment and type of post material (0.041; $P<0.05$), Therefore, the effect

of different surface treatments on each type of fiber posts was analyzed by one-way ANOVA followed by Tukey's HSD post hoc test. We used the independent t-test to assess the effects of different fiber posts on each surface treatment method.

Results

Table 2 shows the mean±SD of the push-out test. The lowest mean bond strength value was observed in the White post DC irradiated with the 1W Er,Cr:YSGG laser. We observed the highest mean bond strength in the Exacto group irradiated with the 1W Er,Cr:YSGG laser 1W. We compared the effect of different surface treatments on each type of fiber post by one-way ANOVA. Post hoc Tukey's HSD test showed that the 1.5W Er,Cr:YSGG laser statistically reduced the micro push-out bond

Table 2: Mean±standard deviation (SD) of the micro push-out bond strength of the studied groups

|	Control mean±SD (MPa)	1W Er,Cr:YSGG laser mean±SD (MPa)	1.5W Er,Cr:YSGG laser mean±SD (MPa)
Exacto	14.42±2.0 [A,a]	14.52±3.05 [C,a]	12.67±1.75 [E,b]
White post DC	11.98±1.98 [B,c]	11.91±2.04 [D,c]	12.02±1.54 [E,c]

Groups with different lowercase superscript letters are statistically different in the same row. Groups with different capital superscript letters are statistically different in the same column.

strength values in the Exacto groups (P<0.05). However, the difference between the control and 1W Er,Cr:YSGG groups did not statistically differ (P= 0.987). Multiple comparison in the White post DC groups showed no significant difference between the different surface treatment methods (P>0.05). Therefore, surface pretreatment with the laser did not affect bond strength values of White post DC and could not improve bond strength. We performed the independent t-test assessment of the effect of different fiber posts on each surface treatment method. Exacto fiber posts revealed significantly higher bond strength compared to White post DC when using the 1W laser and/or no treatment (P≤0.001). The two commercial fiber posts did not show a significant difference when using the 1.5W laser for surface pretreatment (P=0.172). Figure 2 shows photomicrographs of the six groups after surface pretreatment. FE-SEM micrographs showed that prior application of the surface with the Er,Cr:YSGG laser caused partial dissolution of the epoxy resin matrix. Removal of the epoxy resin matrix might enhance the micromechanical retention of core-build up materials. There were no damaged or cracked fibers observed in White

post DC groups. However, several micro-cracks were found in Exacto posts irradiated with 1.5W Er,Cr:YSGG (Figure 2). Mode of failure after the push-out test revealed that the mixed failure mode had the most failure mode of all groups (Table 3).

Discussion

Based on the results of the present study, we rejected the first null hypothesis. The results of FE-SEM micrographs revealed that the Er,Cr:YSGG laser caused surface changes in the fiber posts because the laser partially removed the cross-linked epoxy resin matrix. Therefore, the surface roughness and porosities of the post surface increased. This might provide better penetration of resin to the porosities and micromechanical locking would improve the retention of core materials. The second null hypothesis was partially rejected. In the White post DC groups as laser irradiation had no significant effect on the micro push-out bond strength. However, the 1.5W Er,Cr:YSGG laser irradiation of the Exacto posts significantly reduced bond strength. The micro push-out bond strength is classified as shear bond strength test.
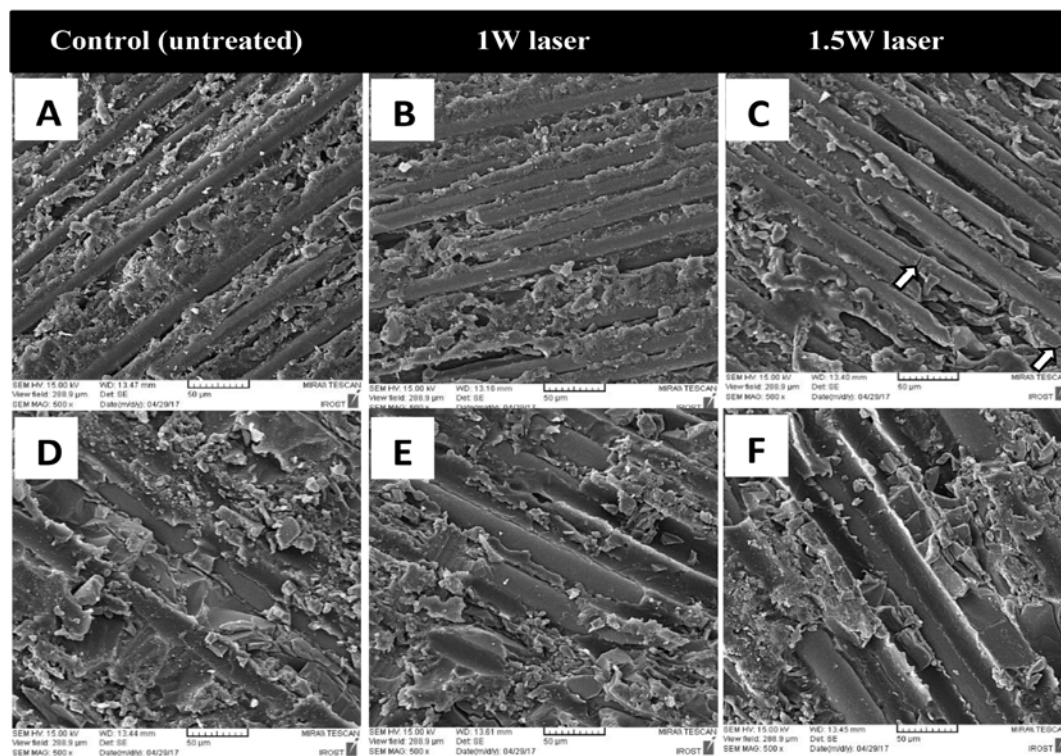
Figure 2: Field emission scanning electron microscopy (FE-SEM) micrographs of glass fiber post surface after different treatments at 500x magnification. (A-C) Exacto post, (D-F) White post DC. The differences in diameter of the fiber posts are clearly shown in the pictures. White post DC fibers are thicker than the Exacto fibers. White arrows show the cracked areas on the surface of the fiber post.

Table 3: Mode of failure distribution in the different groups

Failure mode	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Total
1. Cohesive failure within fiber post	2	-	-	2	-	1	5
2. Cohesive failure within core build-up material	-	-	-	-	-	-	-
3. Adhesive failure between fiber post and core build-up material	2	11	6	4	3	4	30
4. Mixed failure	20	14	19	19	22	20	114
a) 1 and 2	5	2	9	2	8	8	34
b) 1 and 3	-	1	-	4	-	3	8
c) 2 and 3	5	10	8	8	8	3	42
d)1, 2, and 3	10	1	2	5	6	6	30
Specimen could not be investigated	1	-	-	-	-	-	1

Group 1: Exacto (control); Group 2: Exacto irradiated with 1W Er,Cr:YSGG laser; Group 3: Exacto irradiated with 1.5W Er,Cr:YSGG laser; Group 4: White Post DC (control); Group 5: White Post DC irradiated with 1W Er,Cr:YSGG laser; Group 6: White Post DC irradiated with 1.5W Er,Cr:YSGG laser

Using this method, the fracture occurs parallel to the bonding interface [15]. This method provides comparable results with the microtensile test with lower premature failures [16]. This method resembles the clinical condition and provides more reliable results compared to the conventional shear test [15, 17]. Furthermore, the size of specimens was decreased to provide more uniform stress distribution using micro push-out test [15]. We obtained 3-4 samples, each with a thickness of 1 mm from each post.In this study, the surfaces of fiber posts in all six groups were treated by silane. It has been reported that salinization appears to favor its use on the post surface to enhance bond strength [18, 19]. Here, we have used a flowable resin core build-up material. The low viscous materials can easily fill porosities and irregularities formed by various pretreatment methods [20-22]. It has been reported that fibers and matrix properties and the bonding between these components could affect mechanical properties. Orientation, length, and concentration of fibers can also play an important role [23]. Luiz *et al*. evaluated the mechanical properties of the two commercial fiber posts used in the present study. They found no statistically significant differences between the two kinds of posts in terms of fracture resistance and two point bending flexural strength. FE-SEM micrographs showed the larger diameter and lower quantity of White post DC fibers compared to Exacto posts [24]. This could possibly explain the more frequent occurrence of cohesive fractures within the post, at least in some areas in the White post DC (Figure 3). Lower bond strength values of the White post DC in the current study could be explained by the fact that the distance between fibers in the White post DC was more than the Exacto; in addition, the direction of the applied force in mico-push-out was parallel to the fibers [24] than the tests used in the Luiz study. Therefore rupture in the area between fibers was observed in most specimens from the White post DC group.The treatment of fibers of these two posts differs during the manufacturing process. Exacto fibers are pre-stressed under tension during the manufacturing process followed by soaking in resin, after which the resin is polymerized. When the resin is finally cured, the tension in the fibers is released. Thus, the glass fibers
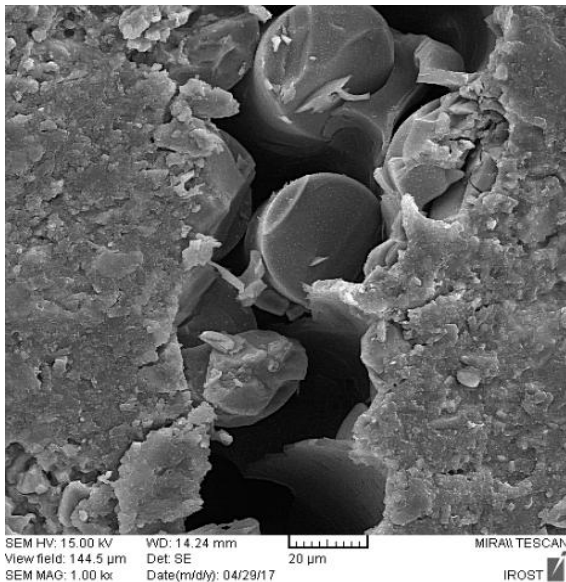
Figure 3: Field emission scanning electron microscopy (FE-SEM) micrographs of White post DC shows a cohesive fracture within the fiber post. The fractures within the fiber posts were observed in more specimens from the White post DC groups, which was probably due to the higher fiber diameters

are placed under compression which enables them to absorb tensile stresses while the post is placed under forces [25]. However, White post DCs are not pre-stressed during the manufacturing process [24]. This factor can be a possible reason for the higher strength of the Exacto fiber posts. Several manufacturers silanize fibers prior to embedding in the resin matrix to ensure adequate fiber/matrix adhesion. If there is adequate interfacial bonding between the fiber and resin matrix, the load can transfer from the resin matrix to the fibers. This would improve both the mechanical properties and integrity of the fiber posts [26]. The commercial fiber posts that have been used in this study were composed of pre-silanized glass fibers. Therefore, this factor did not affect the results. Laser technology has been utilized for different dental procedures in recent years. Surface treatment of dental tissues and dental materials, decreasing of tooth hypersensitivity, and caries removal are some laser applications in the field of dentistry [27-29]. According to the literature, various types of lasers (Nd:YAG, Er:YAG, and Er,Cr:YSGG) have been investigated to increase the bond strength of fiber posts to root dentin, resin cements or resin core materials. Among these, Er:YAG (2.94 nm) and Er,Cr:YSGG (2.78 nm) have similar wavelengths

and may cause similar effects. Arslan *et al.* stated that Er:YAG irradiation (450 mJ at 10Hz) on the fiber post surface increased the bond strength of posts to core materials [29]. However, Kurt *et al.* found that prior application of Er:YAG (500 mJ, 2Hz) on the fiber post surface resulted in decreased bond strength [30]. This might be attributed to different parameters (pulse mode, repetition rate, irradiation time, energy density) and type of devices used in those studies.. Another study by Križnar revealed that methacrylate-based fiber posts significantly decreased bond strength compared to epoxy resin-based fiber posts after Er:YAG pretreatment [22]. The Er,Cr:YSGG laser has been used to improve the bond strength of fiber posts to root dentin. Studies of dentin pretreated with an Er,Cr:YSGG laser showed contradictory results. In a study conducted by Kirmali *et al.*, an Er,Cr:YSGG laser with different power outputs was used as a surface treatment method for root dentin. They reported that push-out bond strength of fiber posts to the treated dentin surface were not enhanced by laser irradiation [31]. However, Mohammadi *et al.* reported a significant increase in bond strength value [32]. Nagase *et al.* found that root dentin irradiation with an Er,Cr:YSGG laser did not cause any statistically significant difference compared to the control group whereas Nd:YAG laser significantly decreased bond strenght value [33]. There is little information about the effects of Er,Cr:YSGG laser irradiation on fiber post surface. Therefore, the current study has evaluated the effects of an Er,Cr:YSGG laser on micro push-out bond strength of two commercial glass fiber posts to resin core build-up material. Only one study conducted by Kurtulmus-Yilmaz *et al.* investigated the Er,Cr:YSGG laser on micro push-out bond strengths between quartz and glass fiber posts and resin core material. They reported that the 1W and 1.5W lasers significantly increased bond strength between the post and resinous core material in both types of posts compared to the control and 2W laser [17]. These results contradicted the current study. We observed no significant difference in the White post DC groups. The Exacto groups showed no significant difference between the 1W laser and control groups. However, we observed significant reduction in bond strength value in the 1.5W laser group. One explanation could be the different

materials (structural characteristics and chemical composition of post and core) used in our study. The second reason was the lack of thermocycling in the study by Kurtulmus-Yilmaz *et al*. However, restorations are exposed to temperature variations in the oral cavity. Hence, the thermocycling procedure was performed as an artificial aging method in the current study. We ignored the 2W laser according to the results reported by Kurtulmus-Yilmaz *et al*. In addition, the authors suggested microscopic evaluations in further research. The influence of the 1 and 1.5W lasers on post surfaces was evaluated under SEM in our study. The reduction in bond strength of the composite resin to the 1.5W Er,Cr:YSGG-treated Exacto posts could be explained by the fact that 1.5W laser irradiation of the post surface partially removed the epoxy resin and resulted in fiber micro-cracking (Figure 2). For the Exacto post, high power output (1.5W) might influence the integrity of the fiber post and have a weakening effect. It could reduce the bonding ability with silane and bonding agent and core material. According to Siqueira *et al*., Er,Cr:YSGG (1.5W) increased the roughness of the fiber post surface and reduced the mechanical properties of fiber posts such as flexural strength and elastic modulus. However, they determined this reduction to be in the acceptable range [34]. The 1.5W laser irradiation of Exacto post in our study compromised the results because of micro-cracking. Hashemikamangar *et al*. reported that 1W Er,Cr:YSGG laser irradiation significantly enhanced the bond strength of fiber posts to core

buildup materials compared to that of the control group [35]. The number of fiber posts in each group (n=3) was not sufficient for adequate assessment. However, the difference in the current study was not statistically significant. Mode of failure analysis showed that mixed failure was the predominant failure type for all surface treatment groups. The highest percentages of adhesive failure between post and core material was observed in the 1W Exacto post group (44%; Table 3). Evaluation of fracture revealed that most specimens in the White post DC groups had areas of fracture within the fiber post (Figures 3,4). This might be due to higher diameters of the fibers. This finding correlated with the lower bond strength values of the White post DC groups. Fractures in the composite core are easily treatable in the clinic. Fractures that occur within the post necessitate the removal of the post for re-treatment of the tooth, which is challenging [35]. Strong adhesion between the post and resin core material is needed. Debonding of posts from the core is the most desirable mode of failure in clinical situations [17, 35]. For future research, it is recommended to study different fiber posts with methacrylate-based resin matrix and other parameters of the Er,Cr:YSGG laser in order to find an optimized power output since SEM micrographs in this in vitro study showed that the laser could partially remove the resin matrix.

Conclusions

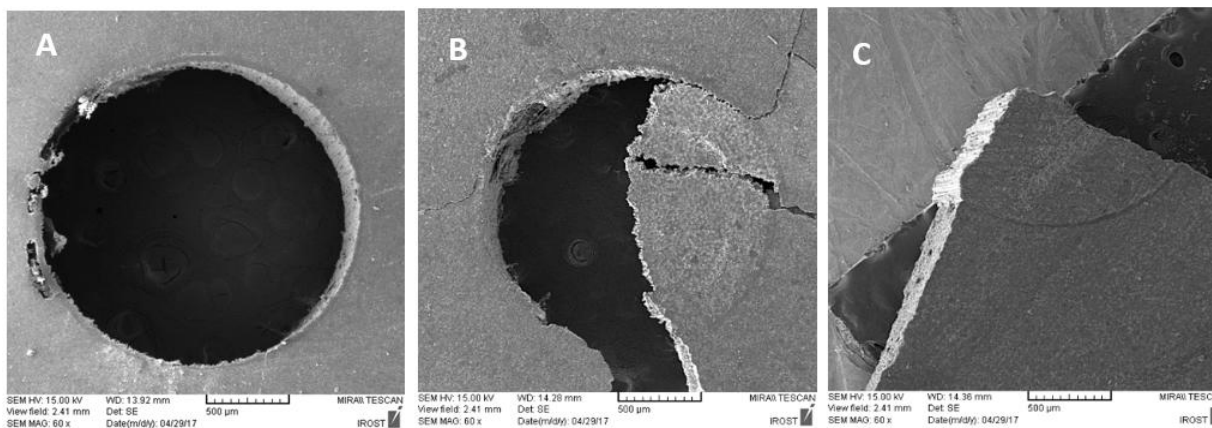Based on the results of this in vitro study, we

Figure 4: Adhesive (A), mixed (B), and cohesive failure (C) within post and core under field emission scanning electron microscopy (FE-SEM)

conclude that there is a difference in micro push-out bond strength of the core build-up material in the White post DC compared to the Exacto post. This might be attributed to structural characteristics, and the diameters and densities of the fibers. The beneficial effect of an Er,Cr:YSGG laser application could not be confirmed according to the results of this in vitro study. The Er,Cr:YSGG laser did not have a significant effect on bond strength values. However, the 1.5W laser statistically decreased micro push-out bond strength in the Exacto fiber posts ($P<0.05$).

Acknowledgments

Conflict of Interest: None declared.

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