Comparison of the Effects of three Different Surface Treatment Methods with Er: YAG Laser Irradiation on the Bond Strength of Fiber Posts to Resin

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ABSTRACT: *This study aimed to compare the effect of different surface treatments on the bond strength of fiber posts to composite core material. Thirty light posts were divided into 5 groups. The control group did not receive surface treatment. The H_2O_2 group was etched with 10% hydrogen peroxide for 20 min, the HF group was etched with 9.5% hydrofluoric acid for 60 sec, the APA group was air abraded with airborne particle abrasion, and the ER group was conditioned with erbium-doped Yttrium Aluminum Garnet (Er: YAG) laser (250 mJ, 20 Hz, pulse duration of 100 µs for 1 min). This study aimed to investigate the post-surface preparation by chemical dissolution with materials such as oxygenated water, hydrofluoric acid, or mechanical stress using sandblasting and laser to determine whether these methods lead to increased bond strength. After composite core buildup, each sample was sectioned horizontally to create 1 mm-thick samples. The micro push-out bond strength was evaluated. Data were analyzed by ANOVA, Tukey's post-hoc, and chi-square tests.*

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The significance=0.05. The control and ER groups indicated the minimum and maximum bond strengths respectively. Interface adhesion was significantly improved in the ER and APA groups compared to the H_2O_2 group. APA and Er: YAG laser (250 mJ, 20 Hz, pulse duration of 100 μs for 1 min) were more efficacious than H_2O_2 in boosting the push-out bond strength of composite resin core material to DT-light fiber post.

KEYWORDS: *Acid etching; Dental Air Abrasion; Erbium YAG Laser; Hydrofluoric Acid.*

INTRODUCTION

The placement of a post for restoration of very damaged endodontically treated teeth is often required to assure sufficient core retention because these teeth have little remaining coronal dentin [1]. Fiber Reinforced Composite (FRC) posts have replaced cast posts to restore endodontically treated teeth since 1990. FRC posts are composite materials that principally consist of a polymer resin matrix, which is an epoxy resin around the quartz or silica fibers [2]. Several factors such as the type of composite and the quality of the post-core interface are involved in the clinical success of a post-core restoration, where there is close contact between the materials of different compositions.[3] As a feasible substitute to cast posts, fiber posts combined with composite core build-up materials are extensively used to restore endodontically treated teeth [4]. Surface treatments boost the chemical and micromechanical retention between different components. They are also typical techniques used to enhance the general adhesion characteristics of substances [5]. Several studies have assessed the efficacy of various post-surface treatment techniques to improve the post-resin composite bond [6-8]. In comparison with metal posts, fiber posts have several advantages such as similar elastic modulus to dentin, [9] high success rates with no root fractures, [10] and taking less time. However, a cast post and core production need extra clinical and laboratory time [11]. These posts also have aesthetic merits owing to elevated light transfer through the root and the surrounding gingival tissues [12] Other merits of fiber posts are lack of corrosive reactions occurring with prefabricated metal alloy posts [13] and easy elimination of endodontic retreatments [14, 15].

The development of reliable bonds at root-post-core interfaces is necessary for post-retained restorations to allow for efficient transfer of stress by interface under functional loading, thereby promoting the long-lastingness of composite resin core restorations [5, 15]. Surface treatment of the posts has drawn some attention from among several factors increasing the bond retention of prefabricated posts to the composite core [6, 14, 16]. One of the methods used to enhance the bonding of fiber posts to composite resin or resin-luting agents is the use of airborne particle abrasion with aluminum oxide: Dental Air Abrasion [17]. Other methods introduced to improve post-composite resin core bonding are hydrofluoric acid etching [15] and hydrogen peroxide use [8]. A new technique proposed for surface treatment is Erbium YAG Laser (Er: YAG laser) irradiation, which has been claimed to have no harmful effects on post-physical properties [17]. laser is used in many clinical fields in dentistry [18,19]. There is limited data on the efficacy of Er: YAG laser irradiation in improving the fiber post-composite core bonding. Hence, the effectiveness of this technique is not clearly known because of contradictory findings [20-22]. Thus, the present in-vitro research was conducted to assess the effect of various surface treatments on the bond strength of Double-tapered Quartz fiber post (DT fiber posts) to a composite resin core material. The null hypothesis formulated in this study was that post-surface treatment would not affect the interfacial strength between fiber posts and composite resin core build-up.

EXPERIMENTAL SECTION

Thirty #3 DT Light Posts (Bisco, Schaumburg, IL, USA), with a maximum diameter of 2.14 mm, were used in this study. DT Light Posts are made of unidirectional pre-tensed quartz fibers (60 vol%) fixed in an epoxy resin matrix (40 vol%). According to the manufacturer's instructions, the surface of the post was cleaned with alcohol. The posts were vertically embedded in an auto polymerizing acrylic resin (Meliodent; Heraeus Kulzer, Armonk, NY) to facilitate their handling, so that the top of the post-surface was put in the center of the acrylic resin block (20 mm in diameter and 10 mm in length) perpendicular to the horizontal plane. The samples were allocated to five groups (six in each group), as follows: Control Group: The posts were rinsed only with distilled water and received no treatment (control group).H_2O_2 Group: The posts were immersed in 10% H_2O_2 (Nova Argentia, Milano, Italy) at room temperature for 20 min. The concentration and treatment time of hydrogen peroxide was determined according to previous studies. [23, 24]. Having been immersed in H_2O_2 solution, the posts were washed with distilled water for two minutes and air-dried for 10 seconds. HF Group: The posts were immersed in 9.5% hydrofluoric acid gel (Bisco, Schaumburg, IL, USA) for 60 s. They were then washed with distilled water for two minutes and air-dried for 10 seconds [25]. Group: The posts were air-borne-particle abraded with 110-μm aluminum oxide (Easyblast, Model No: 26080, Bego, Germany) for 60 seconds at 2.8 bar (0.28 Mpa) from a distance of one cm according to the manufacturer's instructions. Then, they were ultrasonically cleaned i n distilled water for two minutes and air-dried for 10s. ER Group: The posts were irradiated with an Er: YAG laser device (Fidelis plus, Fotona, Ljubljana, Slovenia, 2.94 μm Wavelength) using a Ro7 handpiece and a fiber tip with 16 mm length and one mm diameter, which was followed by water irrigation (250 mJ, 20 Hz, pulse duration of 100 μs) for one min. To ensure standardization, all samples were prepared by one expert during one day.

A two-component silane-coupling agent (BISCO Inc, 1100 W, Irving Park Rd, Schaumburg, IL 60193 USA) was applied (according to manufacturer instruction) on the post surface in a single layer using a brush and was rubbed for five seconds. It took five minutes for the solvent to evaporate. To produce uniform core build-ups, a special device was made to centralize the position of posts relative to the composite build-ups so that three posts could be mounted simultaneously. The posts were then mounted in the prefabricated mold so that only 5 mm of the post length was exposed, while the other parts of the posts were concealed in the mold. A flowable dual-cure composite was utilized for core build-up (CORE-FLO™ DC (BISCO Inc, 1100 W, Irving Park Rd, Schaumburg, IL 60193 USA). Uniform composite core build-ups were obtained after loading the dual-syringe directly into the mold, which resulted in core materials of the same thickness around the posts. According to the manufacturer's recommendations, each increment was placed on the post surface carefully and light-cured separately for 40 s by a halogen light-curing unit with an output of 670 mW/cm^2 (XL2500, 3MESPE, St.Paul, MN, USA). The light source intensity was monitored by a digital radiometer (Jetlite Light Tester, J. Morita USA, Mason Irvine, CA, USA). The cylinder of composite resin core build-ups was confined to the 5-mm end of the posts. The material was directly polymerized from all sides. The samples were then taken out of the mold. Further, 40 s irradiation was performed on the side of the cylinder that was formerly in contact with the mold to ensure complete polymerization of the composite material. Each cylinder of post and core material was mounted on an Isomet cutting machine for sectioning (Buehler, Lake Bluff, IL, USA). Two longitudinal cuts were first made along the two opposite sides of the post at its outermost periphery by a water-cooled diamond blade, which produced a rectangular slab of uniform thickness. Each slab was mounted on the holding device and was serially sectioned by a low-speed diamond saw (Isomer 1000, Beuhler Ltd, lake bluff, IL, USA) under cool water to achieve two 1 mm-thick beams. The thickness of each stick was measured by a digital caliper (Mitutoyo, Tokyo, Japan).

Next, the samples were connected to the flat grips of a micro push-out testing device with cyanoacrylate adhesive (Zapit, Dental Ventures of America, CA, USA). They were then tested in a mechanical testing machine (Nonstop, Bego Germany) at a cross-head speed of 1 mm/min until failure. The micro push-out bond strength was recorded by dividing the load at failure (Newtons) with the bonding surface area (mm^2). Since the bonded interface was curved, its area was measured by a mathematical formula formerly used by *Bouillaguet et al* [26] for similar objectives. The failure modes of each sample were examined with a stereomicroscope (MBC-10, Lomo, Russia) at 40× magnification. The failure modes were classified as adhesive failure (at resin composite/post interface), cohesive within post or core, or mixed (Some parts of resin composite bound on post surface). The data were primarily analyzed by One-way Analysis of Variance (ANOVA).

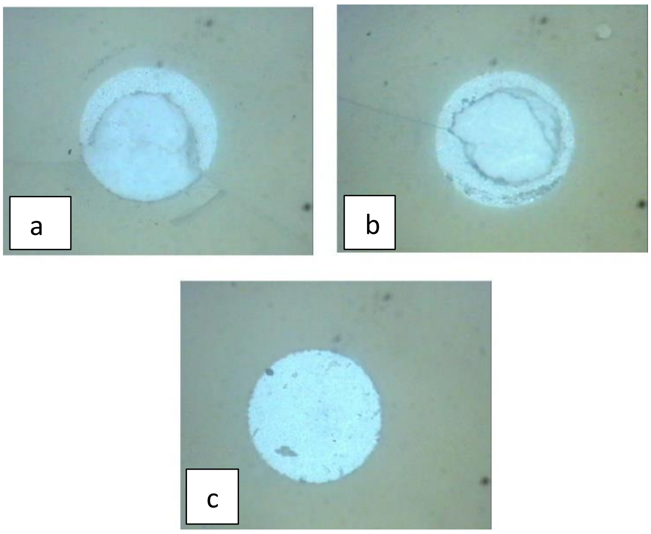

***Fig. 1:** a) Adhesive failure pattern, b) Cohesive failure and c) Mix failure*

The homogeneity of variances was determined by Levene's homogeneity of variance test. $P<0.05$ was considered statistically significant. The statistical analysis was performed by the SPSS 11.5 software (SPSS, Inc., Chicago, IL, USA) using Tukey's test for post-hoc comparisons and chi-square test for the analysis of the modes of failure. All analyses were carried out by an investigator who was blinded to the data.

RESULTS AND DISCUSSION

First, in order to maintain a uniform distance between the posts and the head of the sandblasting machine, a circular wax piece with a diameter of 2 cm was prepared. Each of the posts was placed in the center of the wax circle to be at a distance from the head of the sandblasting machine. Then, in order to perform uniform sand blasting, sand blasting was performed on the 4 sides of the post by pen sandblasting machine for 1 minute with a 2.8 bar and 110-micron aluminum oxide particles. The blasted document posts were then placed in an ultrasonic device containing distilled water for 120 seconds in order to clean and remove the aluminum oxide particles. After that, 5-posts exposed to laser radiation Er: YAG (2940 nm). The posts were irradiated for 250 seconds with a RO7 handpiece of contact type and with a weather spray, from a distance of one millimeter, 250 mJ with a period of 20 Hz and µs 100 pulses of rotation. After applying the mentioned methods, all posts were impregnated with a thin layer of silane and dried in the presence of air at room temperature. Then, in order to perform composite build-up with the same dimensions, the posts were placed in a prefabricated mold. A 5 mm of the parallel part of the post was available for build-up and samples mounted the rest of the post length inside the acrylic which was irradiated. All blinds were immersed in distilled water at room temperature for 48 hours to perform the aging process. Then, the final preparation steps of the samples were performed by adding acrylic around the furnaces. They were cut into plates one millimeter thick. For each group, 12 composite disks containing posts were obtained. In order to obtain the fracture force and check the bond strength, the specimens were loaded in the INSTRON device with a 1.5 mm thick rod that applied force to the center of the post at a speed of 1 mm per minute, until the post was completely removed. The final failure force was recorded by the device monitor. The number recorded in the device was in Newtons, which by dividing this value by the contact area of the post and the composite, the forces were converted to megapascals.

Sample thickness (height): 1mm

Composite contact surface and post = circumference × height $(\pi \times \text{diameter}) \times \text{height}\ (\pi \times 2) \times 1 = \text{mm}^2 28 / 6$

After the fracture, the fractured surfaces were examined by a stereomicroscope to determine the type of fracture. At this stage, three types of failures were observed and recorded: Adhesive failure pattern: In this type, failure occurred only at the contact surface of the post and composite and the post and composite were both healthy. Cohesive failure pattern: In this type of failure, the post structure or composite structure failed (Fig. 1).

A combination of the above two types of failure occurred. Frequency of failure pattern between groups in Fig. 2. First, the data were analyzed for analysis of variance, which was the condition of normalcy and homogeneity of variance. According to the results of one-way analysis of variance, there was a significant difference between the two groups. Two-to-two groups were compared using the Turkey method. Based on the results of this method, there was a significant difference between the fifth group (laser group) and the control group with $P = 0.000$, also the fifth group and the second group (hydrogen peroxide) with $P = 0.001$. Also, the shear strength of the fourth group (sandblast group) was significantly higher than the control group with $P = 0.004$. There was no significant difference between the other

Table 1: Mean bond strength values in MPa for composite resin bonded specimens

Groups	N	Mean	95% Confidence Interval for Mean	
			Lower Bound	Upper Bound
Control	11	18.88±2.05[a]	17.50	20.26
H2O2	12	21.01±1.20[b]	20.24	21.77
HF	12	21.89±2.04[b,c]	20.59	23.19
APA	12	23.17±2.46[c]	21.60	24.73
ER	12	23.64±4.00[c]	21.09	26.18
Total	59	21.76±2.97	20.99	22.54

Means with the same superscript alphabets (a,b,c) are not statistically significant different ($p > 0.05$).

Table 2: Fracture mode analysis of the samples, numbers

Groups	adhesive	Cohesive	Mixed	Total
Control	6	1	4	11
H2O2	7	2	3	12
HF	4	3	5	12
APA	0	9	3	12
ER	5	2	5	12
Total	22	17	20	59

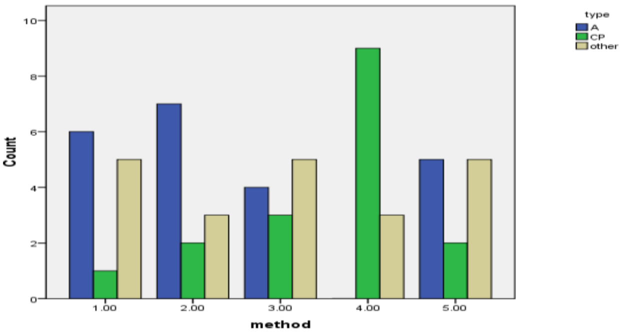

Fig. 2: Frequency of failure pattern between groups

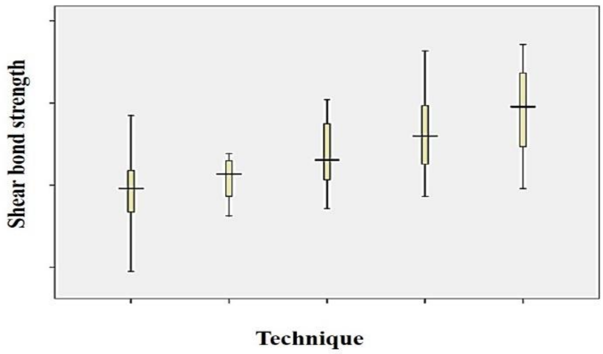

Fig. 3: Amplitude of shear bond strength in each group and the middle of each group

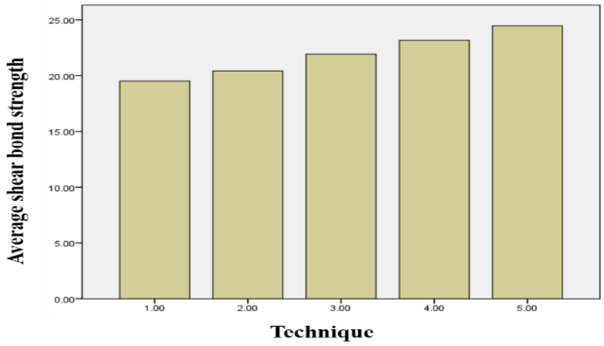

Fig. 4: The average bond strength in each group

groups. The results of comparing the pairs in terms of the P value of the test are presented in Table 2, which can be seen in Fig. 3 and Fig. 4.

The results of the bond strength test for HF, H_2O_2, APA, and Er groups are presented in Table 1. The results of one-way ANOVA showed the significant influence of the type of surface treatment on bond strength at the post-core interface ($P<0.001$). The results of post-hoc comparisons are presented in Table 1.

The minimum bond strength was reported in the control group. The results of Tukey's test indicated a higher bond strength in all experimental groups than in the control group. Further, Er: YAG laser and airborne-particle-abrasion showed a higher bond strength than the 10% H2O2 group. The results of the chi-square test for the failure mode showed a significant difference among the five study groups Table 2 ($P=0.008$). Most failure modes were of adhesive type between the post and core material in the control, ER, and H2O2 groups, while mix type and cohesive type were the most frequent failure modes in the HF and APA groups respectively. Moreover, no significant difference was found among the failure modes in each group. ($P>0.001$). The current study was carried out to determine the impact of various surface treatments of FRC posts on bond strength. onto this end, the bond strength between posts and composite core build-up was evaluated by inserting the posts into the prefabricated mold. The push-out method used in this research was designed as a "micro push-out test" since the size of the samples was decreased to distribute the stress more uniformly [27]. This technique is advantageous over the conventional test owing to a more reliable calculation of bond strength because fracture takes place in parallel with the bonding interface, thereby reproducing clinical conditions.[28] Moreover, two disc-shaped samples were acquired from one post by this method. Further, this method simplifies the bond area computations and inhibits the friction risk, which may contribute to the bond strength overestimation [29]. The DT light post was utilized in the current study since it is a popular FRC post system. The null hypothesis developed in this research stated that post surface treatment would not influence the FRC post-composite resin core bond strength. The null hypothesis was rejected because all surface treatment groups yielded a significantly higher bond strength than the control group. Moreover, the flowable core material was utilized in this study because it has some advantages over hybrid composites, including producing a consistent and tight inter-diffusion zone between the fiber post surface and composite core material and creating superior structural homogeneity and continuity with the post surface, which helps to create a higher bond strength [30-32]. Furthermore, the silane coupling agent was utilized in this study to produce chemical adhesion between the core material resin and the exposed glass fibers of the post or filler particles. Since the development of a multilayer surface could decrease the efficacy of silane coupling due to the decreased number of free methacrylate groups, the silane was applied in a single layer [15]. Acid etching produces a rough fiber post surface, which enhances the fiber post-composite mechanical interlocking. In the present study, surface treatment with 10% H_2O2 and 9.5% hydrofluoric acid significantly affected the post-composite bond strength. The results of the current study are in line with those of other studies [14, 15] that have used DT light posts, indicating the fruitful effects of these pretreatment techniques on fiber post retention. Sandblasting with alumina particles creates a plastic deformation on the surface, which elevates the surface area and loss of the fiber post material [33]. The results of the present study showed a significantly higher FRC post-composite bond strength in the airborne-particle abrasion than in the control group, which is in line with the results of other studies reporting the use of aluminum oxide particles would elevate the FRC post-composite bond strength [9, 15]. Some studies have shown this technique does not enhance the bond strength [17]. The size of particles, the time of sandblasting, and the distance between the posts and the tip of the device is different compared to those of the present study.

Interestingly, a statistically significant difference was found in bond strength between the Er: YAG laser group and the control group, as Er: YAG laser with these special properties (250 mJ and 20 Hz) could efficiently improve the surface treatment of FRC posts. This is in line with the results of another study about the effect of Er: YAG laser on fiber posts [34, 37]. However, there is insufficient information about the bond strength of quartz fiber posts to resin composites. The present study used Er: YAG laser irradiation at 250 mJ and 20 Hz but another study applied lower power laser irradiation (150 mJ, 10 Hz). Moreover, a study [17] showed that Er: YAG laser irradiation reduced the resin-fiber post bond strength. These conflicting findings might be because of the type of fiber post (quartz fiber post versus glass fiber post) and the laser power applied in various studies. The present research indicated most fracture modes were of adhesive type in the control, ER (250 mJ and 20 Hz), and H_2O_2 groups. However, the fracture modes in the HF, APA groups were of mixed type and cohesive type respectively, which is in agreement with the results of former studies indicating that post surface pretreatment with HF and APA produced more irregularities, which increased the post-composite bond strength. However, significant surface alteration and structural attenuation, ranging from microcracks to longitudinal fractures of the fiber layer, were observed [35-37]. Bonding of resin composites to dentine may be improved by interventions. Also, it is difficult to connect composite resin to fiber posts due to the different nature of the underlying material [37-39]. Hydrogels have excellent biocompatibility and are widely used in biomedical applications. However, it is still a challenge to build a hydrogel with outstanding mechanical properties and multiple functions [40-42].

CONCLUSIONS

This study has some limitations like merely one type of composite resin was assessed under in vitro conditions. However, other types of composite resins might produce different results. These surface treatments may elevate the micro push-out strength of quartz fiber posts, but caution should be taken into account in interpreting their effects. In the present study, examinations were not carried out with a field emission scanning electron microscope, so the authors suggest this issue be considered in future studies. Finally, future studies are suggested to evaluate the long-term durability of fiber post-composite bond strength following various post-surface treatments under laboratory and clinical conditions, Within the limitations of the present research in the current study, the following conclusions were drawn:

1- Hydrofluoric acid etching, hydrogen peroxide, air-borne-particle abrasion, and Er:YAG laser (250 mJ and 20 Hz) were effective surface treatment techniques to enhance the bonding of composite resin core material to the DT-light fiber post.
2- Er:YAG laser irradiation using Ro7 handpiece (250 mJ, 20 Hz, pulse duration of 100 μs) for 1 min was an effective technique for the surface treatment of FRC posts.
3- Surface treatment with 9.5% Hydrofluoric acid or sandblasting caused cohesive and mix failures, and Er:YAG laser or 10% Hydrogen peroxide mostly caused adhesive failures. More studies with more samples and simulation of clinical and oral condition are needed.

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