ORIGINAL ARTICLE
Orijinal Araştırma

The Effect of the Water Flow Rate During Laser Irradiation on the Bond Strength of Glass Fiber Posts

Lazer Işınlama Sırasında Su Akış Hızının Cam Fiber Postların Bağlanma Mukavemeti Üzerindeki Etkisi

ABSTRACT

Objectives:

Due to the ablation mechanism, water molecules must be present in the target tissue for effective results with erbium lasers. This study aimed to investigate the effect of the water flow rate during laser irradiation on the bond strength of glass fiber-reinforced composite (GFRC) posts.

Material and Methods:

Sixty glass fiber posts were divided into 6 equal groups: control groups, sandblasting with 30 µm Al_2O_3 particles, 9.5% hydrofluoric acid (HF), and 3 different flow rates (1%, 50%, and 100%) laser groups ($n = 10$). Resin cement was applied to the surfaces of the fiber posts. Then, 1 mm thick sections were taken from each specimen and micro tensile bond strength test was applied. The data obtained were statistically analyzed by a One-way analysis of variance and Tukey's HSD test.

Results:

According to the statistical analysis results, there was a significant difference between the bond strength values of all the groups ($P < 0.001$). The highest bonding value was obtained in the sandblasted group (12.25 ± 0.38) and the lowest in the control group (5.64 ± 0.6). After sandblasting, the highest value was observed in the laser applied group (10.57 ± 0.64) at 100% flow rate.

Conclusion:

As the water flow rate decreases in laser applications, the bond strength between the fiber post and resin cement decreases.

Key Words:

Tensile bond strength, Er,Cr:YSGG laser, Fiber post, Laser etching, Resin cement, SEM

Correspondence address
Yazışma adresi

Ömer KIRMALI
Department of Prosthodontics,
Faculty of Dentistry,
Akdeniz University,
Antalya, Turkiye
omerkrml@ymail.com

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Betül YILMAZ EVMEK
Creative Smiles Dental Clinic,
Antalya, Turkiye

ORCID ID: 0000-0002-6975-5183

Ömer KIRMALI
Department of Prosthodontics,
Faculty of Dentistry,
Akdeniz University,
Antalya, Turkiye

ORCID ID: 0000-0002-4313-344X

Kubilay BARUTCİGİL
Department of Prosthodontics,
Faculty of Dentistry,
Akdeniz University,
Antalya, Turkiye

ORCID ID: 0000-0002-8572-3886

Çağatay BARUTÇUGİL
Department of Restorative Dentistry,
Faculty of Dentistry,
Akdeniz University,
Antalya, Turkiye

ORCID ID: 0000-0002-5321-2299

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ÖZ

Amaç:

Bu çalışmanın amacı, lazer ışınlama sırasında su akış hızının cam fiber ile güçlendirilmiş kompozit (GFRC) postların yapışma mukavemeti üzerindeki etkisini araştırmaktır.

Gereç ve Yöntemler:

Altmış cam fiber post 6 eşit gruba ayrıldı: kontrol grupları, 30 µm Al_2O_3 partikülleri ile kumlama, %9.5 hidroflorik asit (HF) ve 3 farklı akış hızında (%1, %50 ve %100) lazer grupları (n = 10). Fiber postların yüzeylerine rezin siman uygulanmıştır. Daha sonra her bir numuneden 1 mm kalınlığında kesitler alınmış ve mikro çekme bağlanma dayanımı testi uygulanmıştır. Elde edilen veriler tek yönlü varyans analizi ve Tukey HSD testi ile istatistiksel olarak analiz edilmiştir.

Bulgular:

İstatistiksel analiz sonuçlarına göre, tüm grupların bağlanma mukavemeti değerleri arasında anlamlı bir fark vardı ($P < 0.001$). En yüksek bağlanma değeri kumlanmış grupta (12.25 ± 0.38), en düşük değer ise kontrol grubunda (5.64 ± 0.6) elde edilmiştir. Kumlama sonrasında en yüksek değer %100 akış hızında lazer uygulanan grupta (10.57 ± 0.64) gözlenmiştir.

Sonuç:

Lazer uygulamalarında su akış hızı azaldıkça fiber post ile rezin siman arasındaki bağlanma dayanımı azalmaktadır.

Anahtar Sözcükler:

Çekme bağlanma dayanımı, Er,Cr:YSGG lazer, Fiber post, Lazer ışınlama, Resin siman, TEM

INTRODUCTION

Endodontically treated teeth with excessive loss of tooth structure are highly vulnerable to occlusal forces and require post restoration for long-term clinical success (1,2). Glass fiber-reinforced composite (GFRC) posts are generally preferred in the restoration of endodontically treated teeth because of their favorable optical and biomechanical properties (3,4).

GFRC posts are composed of glass fibers, inorganic filler, and polymer matrix, commonly an epoxy resin or other resin polymers with a high degree of conversion and highly cross-linked structures (5). As their elastic modulus is close to that of dentin and resin cements, the stress distribution within the root canal is more homogeneous and thus reduces the risk of root fracture (6). Despite the advantages of GFRC posts, debonding has been frequently reported (7,8). Debonding is associated with many factors, such as remaining coronal structure, post surface treatments, and problems during bonding procedures (9,10).

Studies (11-14) have reported that the surface of dental posts, which can be modified using various treatments, affects the bonding of resin-based luting agents. These treatments, which are intended to roughen the surface and expose inorganic glass fibers, include micromechanical methods (air abrasion or acid etching) and chemical treatments of the composite and post (coating with primer) or a combination of both mechanical and chemical treatments (8,15).

Laser technology is used in different dental applications, such as surface treatments of dental materials or tissues (16-20). Some studies (21-23) reported increased bond strength after laser treatment of the surfaces of GFRC posts due to improved retention of restorative materials. Arslan *et al.* (21) showed that erbium-doped yttrium aluminum garnet (Er:YAG) laser irradiation at 4.5 W power was more effective than sandblasting was in increasing the bond strength of GFRC posts to the composite core. Kurtulmus-Yilmaz *et al.* (24) indicated that erbium, chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser irradiation at 1 W and 1.5 W power improved the bond strength of fiber posts at the post-core interface.

An Er,Cr:YSGG laser is absorbed by water molecules and OH^- groups in the irradiated area and causes a sudden increase in temperature. This heating effect evaporates water molecules, increases internal tissue pressure, and causes microexplosions (25,26). This process, called ablation, leads to morphological changes in hard tissues. Due to this mechanism of action, water molecules must be present in the application area to obtain effective results when using an Er,Cr:YSGG laser. It is well known that an external water source is as important as the water content of the substrates for effective laser ablation on hard surfaces. Without an external water spray, evaporation and dispersion of water molecules will occur rapidly due to the low water content of dental tissues. Drying of the surface causes a significant reduction in the ablation efficiency of the laser, thereby increasing the risk of undesired structural changes, such as cracks, carbonization, or melting in the surrounding tissues (27,28).

Some researchers have reported that the use of Er:YAG laser ablation with an external water source prevents excessive temperature rises and associated thermal damage (26). Although the necessity of an external water source for effective and safe laser ablation is known, the effect of the water flow rate on ablation efficiency has not been clearly demonstrated. The aim of this study was to investigate the effect of the water flow rate during laser irradiation on the bond strength of GFRC posts. The null hypothesis was that different surface treatments would not increase the bond strength and that the water flow rate would not affect the bond strength of GFRC posts and resin cement.

MATERIAL and METHODS

The study protocol was carried out according to the principles of the Helsinki Declaration, including all amendments and revisions. Collected data were only accessible to the researchers. Sixty GFRC posts (Nordin Glassix Glass Fiber Post, Montreux, Switzerland) 1.35 mm in diameter were used in this study. After the posts were cleaned and dried, they were randomly divided into 6 groups according to the surface treatment:

Group C (control): No treatment.

Group S: The specimens were sandblasted by silicate-coated alumina particles (Co-Jet System; 3M ESPE, St. Paul, MN, USA) with a diameter of 30 µm at 2.3 bar pressure for 20 sec at a distance of 10 mm.

Group HF: The specimens were etched with 9.5% hydrofluoric (HF) acid (Ultradent, South Jordan, UT, USA) for 1 min. After the HF application, all the specimens were rinsed with deionized water for 3 min, followed by air drying.

Group E100: The specimens were treated using an Er,Cr:YSGG (Millennium; Biolase Technology, Inc., San Clemente, CA, USA) laser with 2.78 µm wavelength, pulse duration of 140 µs to 200 µs, repetition rate of 10 Hz, and output power of 2 W. Laser optical fiber (600 µm-diameter, 6 mm length) was applied perpendicularly at a 10 mm distance to the specimens surface with 100% water flow and 55% air for 20 sec.

Group E50: The specimens were treated as in Group E100 using the Er,Cr:YSGG laser with 50% water flow and 55% air.

Group E1: The specimens were treated as in Group E100 using the Er,Cr:YSGG laser with 1% water flow and 55% air.

Table 1 shows the laser parameters used in this study. After the surface treatments, all the specimens were cleaned with distilled water in an ultrasonic unit for 5 min and then air-dried for 60 sec.

Table 1. Laser parameters used in the study.

Laser	Er,Cr:YSGG
Manufacturer	Biolase technology; San Clemente, California
Model identifier	Waterlase MD dental laser
Wavelength	2.780 nm
Power	1.5 and 0.50 W
Power density	4.16 and 4.9 W/cm^2
Energy density	53.05 and 62.17 J/cm^2
Frequency	10 Hz
Refrigeration	100% of water 55% of air, 50% of water 55% of air, 1% of water 55% of air
Duration of irradiation	20 sec
Mode of application	Non-contacting mode (Sapphire tip MG6, 0.6mm spot size)

For surface topography analysis, a random specimen was selected from each group, and images of 3 different regions (coronal, middle, and apical) were taken at ×500 magnification using a scanning electron microscope (SEM) device (JSM-6510LV; JEOL Ltd., Tokyo, Japan) after covering the surface with a thin layer of gold. Self-adhesive resin cement (RelyX U200; 3M ESPE, St. Paul., MN, USA) was applied to cover all the surfaces of the fiber posts. Transparent tape and glass were then placed on a silicone mold, respectively. The self-adhesive resin cement was polymerized for 30 sec using an LED light device (VALO Cordless; Ultradent Products, Inc. South Jordan, UT, USA) in line with the manufacturer's recommendations. After the resin cement was polymerized, 8 to 10 sections 1 mm thick were taken from each specimen using a precision cutting device. At least 15 specimens (1 ± 0.02 × 2.2 ± 0.02 mm) were obtained from each group. A digital caliper was used to control the width of the bond area. The ends of each specimen were then glued to a microtensile testing machine (Microtensile Tester; Bisco, Schaumburg, IL, USA) using a cyanoacrylate adhesive, and tension was applied at a speed of 1 mm/min until failure (Fig. 1).

Figure 1. Applying tension to specimens in a microtension testing machine.

The failure modes were classified into three categories: type 1, adhesive failure between the luting resin cement and fiber post; type 2, cohesive fracture in resin luting cement; and type 3, a mix of type 1 and 2 failures.

The data were analyzed using IBM SPSS V23 (SPSS Statistics; IBM, Somers, NY, USA). Normal distribution of the data was tested with the Shapiro−Wilk test, and MPa values were compared using a 1-way analysis of variance. Tukey's HSD was used in multiple comparison tests. The results are presented as mean ± standard deviation. A value of $P < 0.05$ was considered statistically significant.

RESULTS

The values of the microtensile bond strength (µTBS) for each group are presented in Table 2.

Table 2. Mean and Standard Deviation (SD) of microtensile bond strength values (MPa).

Groups	Mean ± SD	p
Group C	5.64 ± 0.6[a]	
Group S	12.25 ± 0.38[d]	
Group HF	8.62 ± 0.66[b]	<0.001
Group E100	10.57 ± 0.64[c]	
Group E50	10.19 ± 0.54[c]	
Group E1	5.83 ± 0.49[a]	

a, b, c, d: There is no statistically significant difference between groups with the same letter
Group C: control; Group S: sandblasted by silicate-coated alumina particles;
Group HF: hydrofluoric acid; Group E100: Er,Cr:YSGG laser with 100% water flow;
Group E50: Er,Cr:YSGG laser with 50% water flow; Group E1: Er,Cr:YSGG laser with 1% water flow

According to the results of the statistical analysis, there was a significant difference between the µTBS values of all the groups ($P < 0.001$). The µTBS values increased in all the experimental groups as compared to those in the control group. The highest bonding strength was obtained in Group S (12.25 ± 0.38), with a significant difference between the other groups. The next highest bonding strength was found in Group E100 (10.57 ± 0.64) and Group E50 (10.19 ± 0.54), with no significant between-group difference. The bond strength in Group HF (8.62 ± 0.66) was closest to that in Groups E100 and E50, but there was no statistically significant difference between the groups. The µTBS value in Group E1 (5.83 ± 0.49) was lower than that in the other laser groups. The lowest value was found in Group C (5.64 ± 0.6), and no significant difference was found between Group E1 (Fig. 2). The failure patterns are presented in Table 3.

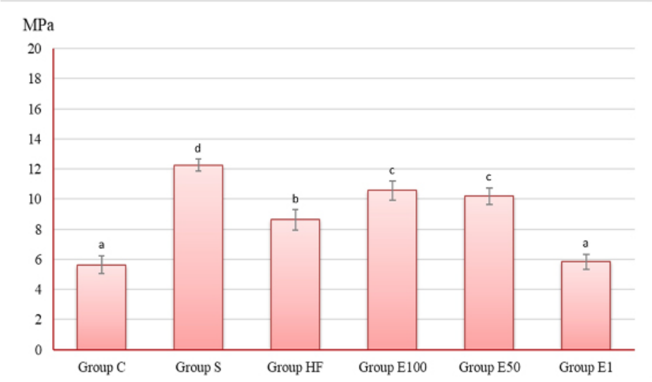

Figure 2. Mean and standard deviation graph of MPa values by groups.

Table 3. Mode of failures of groups for each specimen.

Groups	Adhesive failure	Cohesive failure	Mixed failure
Group C	8	1	1
Group S	1	7	2
Group HF	4	4	2
Group E100	4	5	1
Group E50	3	4	3
Group E1	5	2	3
Total	25	23	12

The most common failure mode was between the resin cement and fiber post (41.66%), followed by cohesive failures (38.33%) and mixed failures (20%).

The SEM images showed that the surface treatments caused changes in the surface topographies of the GFRC posts (Figs. 3 & 4).

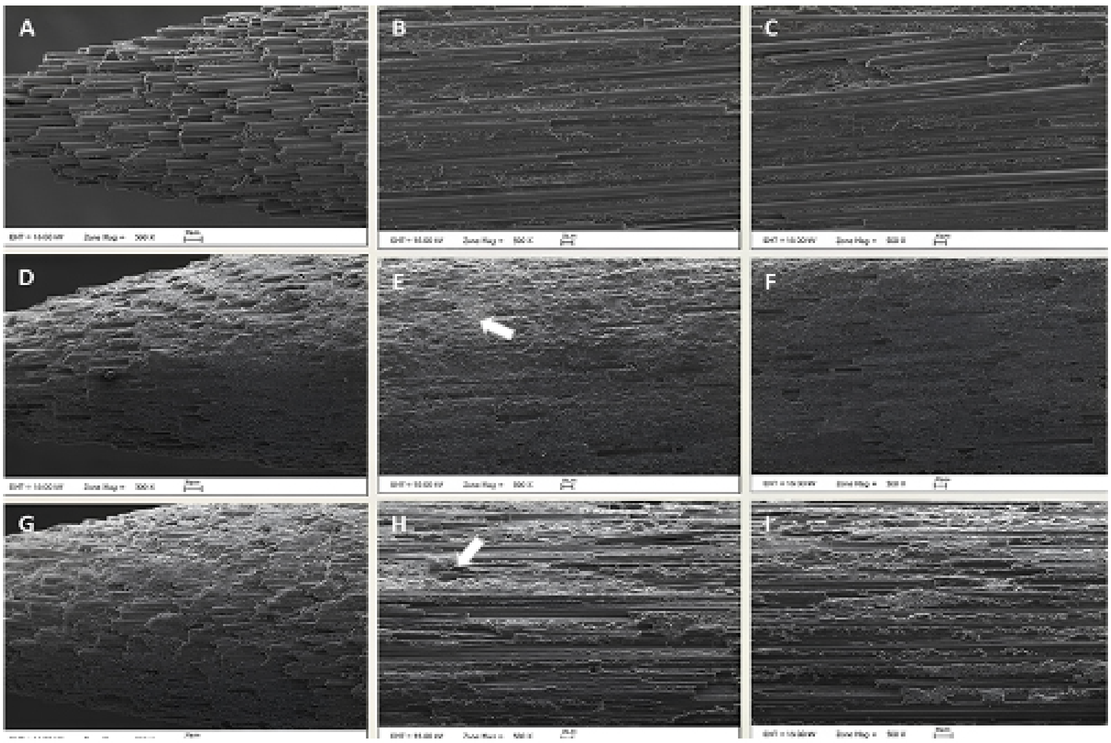

Figure 3. Representative SEM views of treated GFRC post surfaces (X500). (A-C) Untreated post, (D-F) Sandblasted post (arrow indicates the ruptured area), and (G-I) HF acid etched post (arrow indicate the melting area).

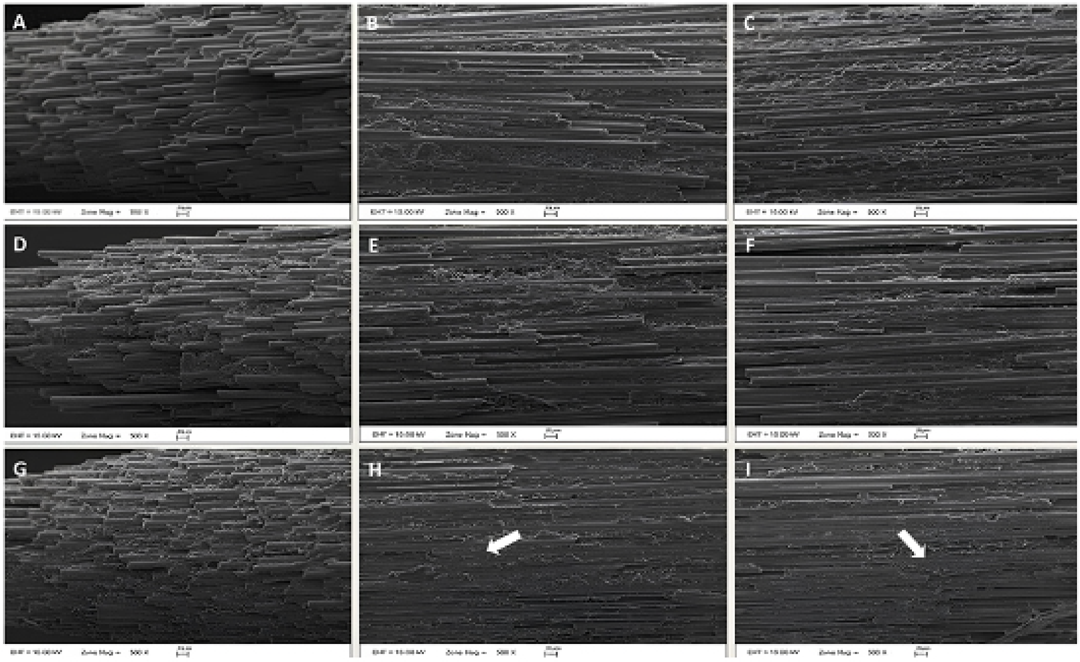

Figure 4.
Representative SEM views of treated GFRC post surfaces (500X). (A-C) 100% water flow laser applied post, (D-F) 50% water flow laser applied post, and (G-I) 1% water flow laser applied post (arrow indicates the carbonized areas).

In the sandblasting group, ruptures were observed in the fibrils (Figs. 3D-F). In the HF etching group, small pits were observed in some areas (Figs. 3G-I). In the E100 and E50 groups, especially in the middle section, fibril continuity was largely preserved, and microretantive areas formed (Figs. 4A-C, D-F). In the E1 group, carbonized areas were observed (Figs. 4G-I).

DISCUSSION

In most clinical cases of endodontically treated teeth with fiber posts, cementation failure of the posts is observed (11). Adhesion of the fiber post is very important for the success and prognosis of the restoration. In this study, the effect of the water flow rate on the bonding strength of GFRC posts during laser irradiation was investigated. According to the results of the study, different surface treatments increased the bond strength, and the water flow rate affected the resin bond strength of the GFRC posts. Therefore, the null hypothesis of the study was rejected.

Various experimental designs have been defined for the evaluation of post and core retention (29,30). In microtensile tests, the stress distribution can be made more homogeneous by using smaller sized test specimens compared to conventional shear tests (19-32). As the microtensile bond strength test is an appropriate test to evaluate the interfacial bond strength of specimens with small cross-sectional areas, this test was preferred in this study.

GFRC posts are composed of glass fibers, inorganic filler, and polymer matrix, commonly an epoxy resin or other resin polymers with a high degree of conversion and highly cross-linked structures (5). Surface treatments change the surface characteristics of GFRC posts, expose the fibers, and increase the surface area available for chemical bonding (11). The spaces between the fibers provide additional space for micromechanical retention of the resin materials. This increases the bond strength values (15).

Air abrasion with alumina particles coated with silica (Co-Jet System) eliminates surface smoothness. When the particles hit the post surface, rough surfaces are obtained, and micromechanical areas are formed for the bonding of the composite. In addition, the impact energy generated during air-abrasion causes the silica to melt and adhere to the substrate surface. Researchers have reported that the application of air abrasion significantly improves the bond strength (20,21,33-35). However, other studies reported that the application of sandblasting significantly reduces the bond strength (14,16). Researchers have attributed this situation to particle size and reported that it causes cracks on the dental material surface. In this study, sandblasting with 30 µm silicate-coated alumina particles significantly increased the bond strength of glass fiber posts to resin cements. Micromechanical gaps in the SEM images support this conclusion.

Although HF acid treatment is an easy technique to roughen the post surface, it can damage the surface due to the corrosive effect of the glass phase. Studies (17,34) have shown that HF acid application increases the bond strength between fiber posts and core materials. Although these studies aimed to improve bond strength values, the effects of surface treatments on the structural strength of the material should also be considered. Some researchers reported that acid and sandblasting did not affect bond strength values due to the degradation effect on the glass phase and that even HF acid (9%, 60 sec) applied to the GFRC post surface caused matrix separation and damaged the post (14,20). In this study, bonding on the HF acid applied surface was better than that in the control group.

An alternative method used to increase the micromechanical bond between GFRC posts and resin cements is laser surface treatment. Laser application on water-free tissues allows the surface to be cleaned with heat or laser energy generated on the surface. In addition, the surface becomes rough with the melting areas formed in the pit formation. This roughness increases micromechanical bonding with the resin cement (16). However, some research reported that laser treatment applied at high power has a destructive effect on the surface, leading to micro-macro fractures and carbonized areas (14).

Kurtulmuş-Yilmaz *et al.* (24) reported that Er,Cr:YSGG laser treatment (80% water, 60% air, 1.5 W, 10 Hz) significantly increased the tensile bond strength of resin cement-post. Similarly, Akin *et al.* (16) reported that an Er:YAG laser (1.5 W, 10 Hz, 20 sec) applied under water cooling significantly increased the bonding values between fiber posts and resin cements.

Kirmali *et al.* (14) evaluated the effect of different Er,Cr:YSGG laser (55% water, 65% air flow) applications (1 W, 2 W, 3 W, 4 W, 5 W, and 6 W) on the mechanical properties of fiber posts. They reported that high-power laser irradiation had destructive effects on fibril bundles, with prominent melting areas and dense carbonized areas observed. In the low power range, with adequate water and air cooling, the breaking resistance of the fiber posts was not statistically significant compared to that of a control group.

Kurt *et al.* (26) investigated the effect of the water flow rate on the morphological properties of dentin and shear bond strength of self-etch resin cement after Er,Cr:YSGG laser applications. They reported that Er,Cr:YSGG laser applications with water flow rates of 100% (19 mL/min) and 50% (6.75 mL/min) increased the bond strengths of resin cements in comparison to those in a 25% water flow rate group (2.75 mL/min) and a control group. They concluded that increasing the water flow rate in the Er,Cr:YSGG laser etching procedure to 50% and higher had a favorable effect on the bond strength of a self-etching adhesive system to dentin. Botta *et al.* (36) reported that dentin had higher bond strength values when an Er,Cr:YSGG laser (0.25 W, 20 Hz) was used with a water flow rate of 20% (11 mL/min) compared to a group without water. In another study (37) the use of an Er,Cr:YSGG laser with maximum water and the following parameters resulted in less carbonized dentin surfaces: 3.5 W, 20 Hz with water spray, air pressure level of 80%, and maximum water pressure level. Meister *et al.* (25) observed no ablation when an Er,Cr:YSGG laser (2 W, 20 Hz) was used on dentin without an external water spray. In the present study, the Er,Cr:YSGG laser with 100% and 50% water flow rates significantly increased the bond strength of the resin cement. The results of the 1% water flow rate group were comparable to those in the control group.

The present study had several limitations. In this study, a robotic application was not used for surface treatments. A single researcher applied the surface treatments and attempted to standardize all the parameters measured. This was an in vitro study and therefore cannot represent in vivo conditions. Thermal cycling was not performed, and pH changes in the oral environment were not simulated. Therefore, further studies that simulate the oral environment are needed.

CONCLUSION

Within the limitations of this in vitro study, in Er,Cr:YSGG laser applications, bonding between a fiber post and resin cement decreases as the water flow rate decreases. The use of an Er,Cr:YSGG laser with a water flow rate of 50% and higher before the application of GFRC post materials seems to be a suitable technique to increase bonding values.

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Author Contribution Statement:
Conceptualization: B.Y.E. and O.K; Investigation: T.A. Methodology: B.Y.E; Data curation: K.B; Formal analysis: C.B; Writing - Original Draft: B.Y.E; Writing - Review and Editing: B.Y.E and O.K; Visualization: C.B. Supervision: O.K. and C.B.

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There is no conflict of interest between the authors

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No need.

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