ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article *Araştırma Makalesi* DOI: 10.17567/currresdentsci.1490761

Effect of Erbium: Yttrium–Aluminum Garnet Laser, XP-Endo Finisher, and Passive Ultrasonic Irrigation in the Cleaning of Post Spaces on Push-Out Bond Strength

Post Boşluklarının Temizlenmesinde Erbium: Yttrium Alüminyum Garnet Lazer, XP-Endo Finisher ve Pasif Ultrasonik İrrigasyonun Bağlanma Dayanımına Etkisi

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ABSTRACT

Objective: This study aimed to evaluate the effects of different cleaning protocols on the push-out bond strength of fiber posts.

Methods: Sixty mandibular premolars were decoronated. The root segments were prepared to size F3 and obturated with F3 gutta-percha and AH Plus sealer. The post-spaces were prepared with post drills and assigned into four groups according to supplementary cleaning protocols: conventional needle irrigation (CNI), passive ultrasonic irrigation (PUI), XP-endo Finisher, and Erbium: yttrium–aluminum–garnet laser (Er: YAG)- photon-induced photoacoustic streaming (PIPS). Fiber posts were luted with dual-curing self-adhesive resin cement. Each group's cervical, middle, and apical regions were measured with the push test.

Results: The data were assessed through one-way analysis of variance (ANOVA) and the Tukey post-hoc test. Push-out strength was statistically different in the XP-endo Finisher, PUI, and Er: YAG laser-PIPS groups compared to the CNI. CNI showed the lowest values.

Conclusion: After preparing the post space, irrigation activation methods increase the bond strength values of fiber posts to root dentin compared to CNI. strength between fiber posts and root dentin.

Keywords: Fiber post, Er: YAG laser, XP-endo Finisher, ultrasonic activation, push-out

ÖZ

Amaç: Bu çalışmanın amacı, farklı temizleme protokollerinin fiber postların bağlanma dayanımı üzerindeki etkilerini değerlendirmektir.

Yöntem: Altmış adet mandibular küçük azı dişinin dekoronasyonu yapıldı. Kök segmentleri F3 boyutuna prepare edildi, F3 gutta-perka ve AH Plus kanal dolgu patı ile dolduruldu. Post boşlukları, post drilleri ile hazırlanarak ve ek temizleme protokollerine göre dört gruba ayrıldı: konvansiyonel şırınga irrigasyonu (KŞİ), pasif ultrasonik irrigasyon (PUI), XP-endo Finisher ve Erbium: itriyum-alüminyum-garnet lazer (Er: YAG)-foton kaynaklı fotoakustik dalgalanma (PIPS). Fiber postlar dual-cure rezin simanla yapıştırıldı. Push-out testi ile her grubun servikal, orta ve apikal bölgeleri ölçüldü.

Bulgular: Veriler tek yönlü varyans analizi (ANOVA) ve Tukey post-hoc testi ile değerlendirildi. İtme kuvveti XP-endo Finisher, PUI ve Er: YAG lazer-PIPS gruplarında KŞİ ile karşılaştırıldığında istatistiksel olarak farklıydı. KŞİ en düşük değerleri gösterdi.

Sonuç: Post boşluğu hazırlandıktan sonra irrigasyon aktivasyon yöntemleri, fiber postların kök dentinine bağlanma dayanımı değerlerini KŞİ'ye göre artırır.

Anahtar Kelimeler: Fiber post, Er: YAG lazer, XP-endo Finisher, ultrasonik aktivasyon, bağlanma dayanımı

Geliş Tarihi/Received 27.05.2024
Revizyon Talebi/Revision Requested 28.11.2024
Son Revizyon/Last Revision 06.01.2025
Kabul Tarihi/Accepted 01.05.2025
Yayın Tarihi/Publication Date 24.02.2026

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Cite this article: Hançerlioğulları D, Karadağ G. Effect of Erbium: Yttrium–Aluminum Garnet Laser, XP-Endo Finisher, and Passive Ultrasonic Irrigation in the Cleaning of Post Spaces on Push-Out Bond Strength. *Curr Res Dent Sci*.2026; 36(2): 121-126 / doi:10.17567/currresdentsci.1490761

INTRODUCTION

Ceramic, metallic, and glass fiber post application is commonly used to strengthen weak coronal structures and obtain long-term restorations.[1,2] The presence of physical properties such as elastic modulus, compressive strength, flexural strength, and thermal expansion coefficient similar to dentin and advantages such as aesthetics and biocompatibility [3,4] make the use of fiberglass posts an applicable alternative in the rehabilitation of endodontically treated teeth with extensive tooth structure loss.[5]

Fiber posts can be cemented to the root canal using multi-step or self-adhesive resin cement.[6,7] Self-adhesive resin cements are often preferred because of the simplified luting procedures compared to conventional multi-step cements.[8,9] It is widely accepted that curing light from the top of post spaces is insufficient for optimal polymerization of light-cured resin cements.[10] It was also stated that chemical activation alone does not provide an ideal polymerization.[11] Although there has yet to be a consensus on the gold standard procedure and various luting protocols, dual-curing cement is widely used globally to cement fiber posts in root canals to restore teeth after endodontic treatment.[12] Failures due to debondingare common in the clinical use of fiber posts. Cementation of fiber posts using resin cement creates two critical interfaces between dentin resin cement and resin cement-fiber posts. Numerous factors that can affect the stability and longevity of this interface have been identified. Including variables such as the condition of the dentin, the presence of a smear layer, bacterial contamination, the orientation of the dentinal tubules, the use of various irrigants and techniques during the root canal treatment, the intra-radicular depth of a post space, the type of adhesive system, and the type of root canal sealer.[13-16]

Drilling during post space preparation forms a smear layer, residual gutta-percha material and root canal sealer remnants, and dentin debris, which directly and critically influence the bond strength of the dentin-resin cement interface. Conventional needle irrigation (CNI) with sodium hypochlorite (NaOCl) is often inadequate for root canal cleaning procedures in removing the smear layer in the root canal system.[17] Various irrigation activation devices have been introduced to provide better disinfection by increasing irrigant flow and removing the smear layer.[18,19] The mid-infrared erbium: yttrium–aluminum garnet (Er: YAG) (2940 nm) laser with minimally ablative laser settings in conjunction with a photoacoustic technique known as the photon-induced photoacoustic streaming (PIPS) has proven to be highly effective in removing the smear layer. This approach offers three-dimensional improvements in smear layer elimination while limiting undesired thermal and ablative damage from laser devices.[20] The XP-endo Finisher (FKG Dentaire, La Chaux-de-Fonds, Switzerland) enhances the efficiency of the final irrigation procedures performed after root canal preparation. A specialized alloy with Martensite-Austenite Electropolish Flex designed by NiTi Max-Wire gains flexibility and enables it to conform to the complex three-dimensional root canal system.[21] Passive ultrasonic irrigation (PUI) has been recognized as a supplementary treatment strategy that involves using a stainless steel file to activate irrigants within the root canal. Ultrasonic-activated irrigation outperforms the CNI method in terms of effectiveness.[17]

This in vitro study aimed to evaluate the effects of various activation techniques (CNI, PUI, XP-endo Finisher, and Er: YAG laser-PIPS) in cleaning the post space on the push-out bond strength of fiber posts. The null hypotheses examined were as follows: 1) there are no significant differences in the bond strength of fıber posts between irrigation activation techniques; and 2) there is no significant association between the irrigation activation techniques and the coronal, middle, and apical regions of the root segments.

METHODS

Ethical Approval

The ethics committee certificate was received by the Local Ethical Committee of Kırıkkale University (Date: September 27, 2023, Protocol number 2023.09.16). The sample size calculation was performed using the G* Power v3.1 (Heinrich Heine, Universitat Dusseldorf, Dusseldorf, Germany) with 0.05 alpha-type error and beta power of 0.95.

In this in vitro study, sixty freshly extracted mandibular premolar teeth were selected and disinfected with 0.5% chloramine-T solution for 1 week and stored in distilled water at +4°C until use.

Inclusion criteria

a. Straight single-rooted teeth
b. Fully formed apex without fracture, defects

Exclusion criteria

a. Teeth with curved root canals
b. Previous endodontic treatments
c. Internal, external, or apical root resorption
d. Calcifications

A flowchart of this study procedure is presented in Figure 1. Crowns of the teeth were decoronated to obtain standard root segments using a water-cooled low-speed diamond disc (IsoMet 1000, Buehler Ltd.) root length of 15 mm. The apical patency was achieved with a #10 K file, and the working length (WL) was determined to be 1 mm short of the apex. The root canals were instrumented up to size F3 (Dentsply, Ballaigues, Switzerland), and 5.25% NaOCl was used as an irrigant between files. The canals were dried with paper points (Meta Dental Co., Ltd., Korea) and obturated with F3 gutta-percha and resin-based sealer AH Plus (Dentsply, Maillefer, Ballaigues, Switzerland), which is the gold standard for in vitro studies and commonly used in clinical applications. The root segments were stored at 37°C in 100% humidity for 1 week. Two endodontists performed all procedures with a dental operating microscope (Carl Zeiss OPMI pico, Munich, Germany).

After 1 week, the gutta-percha was removed using post drills for the post space to the length of 10 mm in each specimen. Samples were randomly divided into four groups according to post space cleaning procedures (n=15). Each post space was activated with 3 ml of 5.25% NaOCl for 40 seconds (s), rinsed with 10 ml distilled water irrigated over 20 s, and then activated for 40 s with 3 ml of 17% EDTA. All samples were activated for 20 s with a resting time of 10 s after activation. All procedures were conducted at a room temperature set at 37°C. The total irrigation activation time was 80 s for each post space. The activation protocols were not applied during irrigation with distilled water.

Group A (CNI): The irrigant was flushed using a conventional syringe (NaviTip; Ultradent, South Jordan, UT, USA).

Group B (PUI): The stainless steel ultrasonic tip (IF43727, K 25/25, Satelek, Acteon, Merignac Celdex-France) was activated (Endosoft EU; EMS, Nyon, Switzerland) 1 mm short of WL and operated by an ultrasonic system (Minipiezo's; EMS, Milan, Italy). Continuous PUI power was set at a power setting of ½.

Group C (Er: YAG laser-PIPS): A 300 µm fiber optic PIPS tip was used with Er: YAG laser with a wavelength of 2940 nm (LightWalker AT, Fotona, Ljubljana, Slovenia). The laser device was set to operating parameters (50 ms pulse, 20 mJ at 15 Hz, 0.3 W), which the manufacturer recommended for irrigation activation. The PIPS tip was placed into the coronal part of the post space to obtain continuous irrigation activation.

Group D (XP-endo Finisher): The root segments were positioned in the water bath with a constant temperature of 37ºC to simulate body temperature. The XP-endo Finisher was placed inside the canal and slowly moved up and down approximately 7-8 mm in length according to the manufacturer's recommendations with a torque-controlled (800 rpm and 1 Ncm) VDW Silver motor.

The cleaning and drying of the fiber posts (Endoart Fiber Post, Inci Dental, Istanbul, Turkey) were done with 70% ethanol and compressed air, respectively. Self-etching, self-adhesive dual-cured resin cement (Rubby SE Cem, Inci Dental, Istanbul, Turkey) with contents of 20-40% methacrylic monomers, 10-30% acidic monomer barium glass, and 50-70% nano-silica placed was into the post space. No etching or adhesive was applied to the post space or post according to the manufacturer's instructions. Then the fiber post was inserted into the canal until fully seated in the prepared length. Excess cement was removed and polymerized in standard mode with an LED light device (Elipar S10; 3M ESPE) at 1200 mW/cm^2 for 40 s. Samples were placed in distilled water at 37°C for seven days before being subjected to thermal cycling.

PRILE 2021 Flowchart

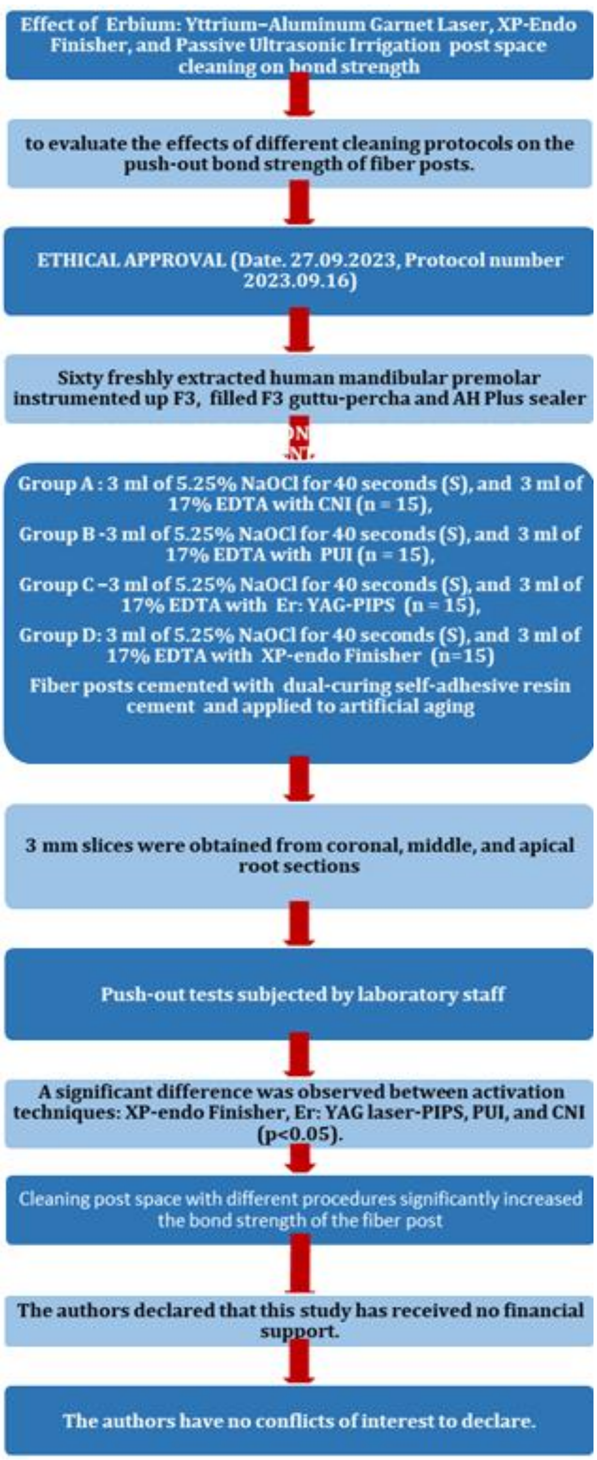

Figure 1. A flowchart of the study

**From: Nagendrababu V, Murray PE, Ordinola-Zapata R, Peters OA, Rôças IN, Siqueira JF Jr, Priya E, Jayaraman J, Pulikkotil SJ, Camilleri J, Boutsioukis C, Rossi-Fedele G, Dummer PMH (2021) PRILE 2021 guidelines for reporting laboratory studies in Endodontology: a consensus-based development. International Endodontic Journal May 3. doi: 10.1111/iej.13542. https://onlinelibrary.wiley.com/doi/abs/10.1111/iej.13542.*

All samples were applied to artificial aging (Esetron, Mod Dental, Ankara, Turkey) between 5°C-55°C for 10,000 cycles with a waiting time of 30 s to simulate the clinical situation. Thermal cycling was applied by placing each sample vertically rooted in epoxy resin using a standard mold. 3 mm slices were obtained from coronal, middle, and apical root sections (total 180 slices) under water cooling using a low-speed diamond saw (Micracut; Metkon, Bursa, Turkey) was used. At a crosshead speed of 0.5 mm/min, the apical aspect of the discs was subjected to loading with a cylindrical plunger featuring a metal rod (0.8 mm and 1.2 mm in diameter for the apical and coronal sections, respectively) until failure occurred. The maximum load force required to separate the post in each sample was recorded in Newton (N). The bond surface areas of the samples were calculated with the formula below.

Bonding surface area: $[\pi (r_1 + r_2)] \times [(r_1 - r_2)^2 + h^2]^{1/2}$

The symbol representation is as follows: $\pi = 3.14$, r_1 is the coronal post radius, r_2 is the apical post radius, and h is the thickness of the slice.

The push-out bond strength was obtained in megapascals (MPa) by dividing the maximum load value by the bond surface area.

Push-out bond strength (MPa) = Maximum load (N)/Bonding surface area (mm^2)

After bond strength testing, all slices (coronal, middle, and apical) were analyzed under a stereomicroscope (Olympus, Optical, Tokyo, Japan) at 40x magnification to examine the detachment surfaces. The mode of failure was categorized as cohesive (fiber post and cement), adhesive (dentin and cement), or mixed.

Statistical Analysis

The data were statistically analyzed using the SPSS software package (Version 24, IBM SPSS Corp., Armonk, NY, USA). The normality of the data obtained was analyzed using the Shapiro-Wilk Test. Descriptive statistics (mean and standard deviation) for push-out bond strength were assessed by one-way analysis of variance (ANOVA) and the Tukey post-hoc test, maintaining the level of significance ($P<.05$).

RESULTS

The means and standard deviations for each group were summarized in Table 1 and graphically drawn in Figure 2. In intra-group comparisons of all experimental groups, significant differences were found in coronal, middle, and apical sections ($P<.05$). Intragroup comparisons showed that the bond strength values decreased in the coronal-to-apical direction ($P<.05$). There was a significant difference between activation techniques: XP-endo Finisher, Er: YAG laser-PIPS, PUI, and CNI ($P<.05$). CNI showed the lowest bond strength values when the experimental groups were compared.

Table 1. The means and standard deviations (MPa) for each group

Activation Methods / **Sections**	Conventional Needle Irrigation	XP-endo Finisher	Er:YAG laser-PIPS	PUI
Coronal	7.18 ± 0.53 ^{A,a}	11.86 ± 1.69 ^{A,b}	8.67 ± 0.50 ^{A,c,d}	9.66 ± 1.30 ^{A,c,d}
Middle	3.98 ± 0.56 ^{B,a}	7.99 ± 1.98 ^{B,b,d}	6.02 ± 0.62 ^{B,c}	6.90 ± 1.00 ^{B,b,d}
Apical	3.44 ± 0.74 ^{C,a}	6.44 ± 0.96 ^{C,b}	4.53 ± 0.73 ^{C,c,d}	4.32 ± 0.86 ^{C,c,d}

Capital letters were used to compare groups in rows (sections of root segments), and lowercase letters were used to compare groups in columns (activation techniques) separately.

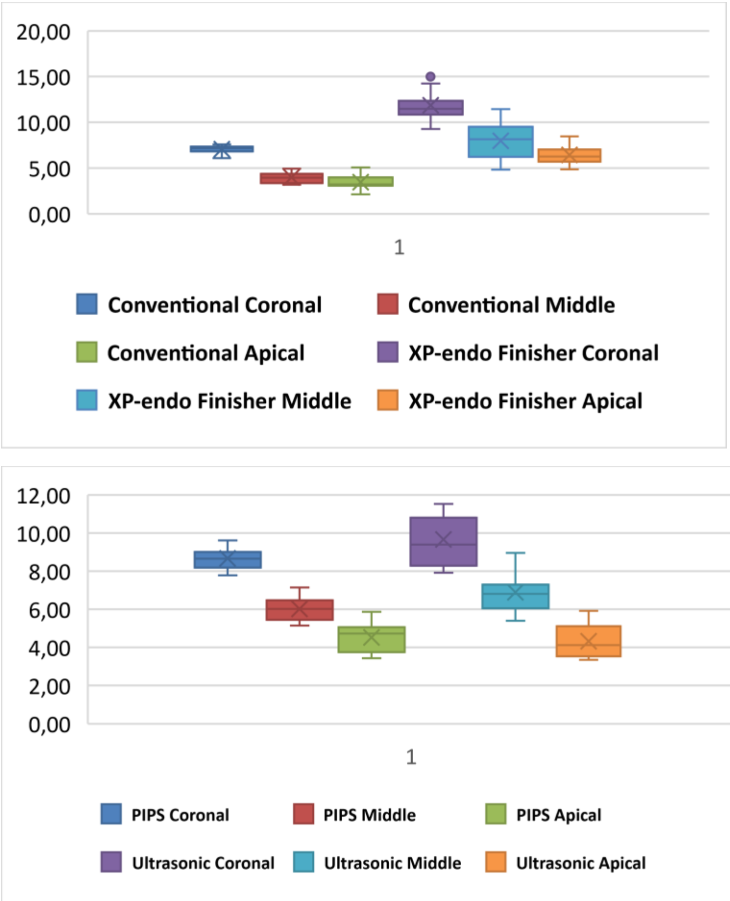

Figure 2. The means and standard deviations for each group

In the intergroup comparisons, the bond strength values of the CNI samples were statistically significantly lower than XP-endo Finisher, Er: YAG laser-PIPS, and PUI (P<.05).

In the coronal section comparison between the intergroup, the lowest bond strength in the coronal section was in CNI; no significant difference was observed between Er: YAG laser-PIPS and PUI (P>.05), XP-endo Finisher was statistically different from Er: YAG laser-PIPS and PUI (P<.05).

Comparisons within middle section groups, CNI is statistically significantly different from activation techniques (P<.05). While there was no significant difference between XP-endo Finisher and PUI (P>.05), Er: YAG laser-PIPS had statistically significantly lower values (P<.05).

Evaluation of the apical section bond strength values, significant differences were observed amongst all experimental groups (P<.05). There was a significant difference in XP-endo Finisher revealed than CNI, Er: YAG laser-PIPS, or PUI (P<.05); however, the difference between Er: YAG laser-PIPS or PUI was not significant (P>.05).

DISCUSSION

This in-vitro study revealed that cleaning post spaces with XP-endo Finisher, Er: YAG laser-PIPS, and PUI bonded to fiber posts improved push-out bond strength. Additionally, it was observed that the push-out bond strength decreased from coronal to apical sections in all groups, leading to the rejection of the hypotheses of the present study. The bases for these results are manifold.

This study used the thin-slice push-off method to test bond strength. The advantages of push bond strength over shear and compressive strength include improved sensitivity, uniform stress distribution, lower failure rate, comparative review of quantitative statistics, and ease of specimen placement.[22] Using NaOCl in endodontic treatments affects the adhesion quality when used with self-etch adhesives.[23,24] NaOCl decomposes into sodium chloride and oxygen (O_2). The O_2 free radicals formed potentially compromise the polymerization of the adhesive system. Therefore, the negative effect of NaOCl in all root segments was compensated by using distilled water as a neutralizing agent.

Self-etch adhesive systems offer a potential solution to issues linked with the moist application technique, thanks to their versatility in effectively applying wet and dry dentin surfaces.[25] These systems create bonds with the superior dentin layer, where the complete removal of smear plugs might not be achieved, and their bonding effectiveness is believed to rely more on the formation of the hybrid layer than on traditional resin tags. The studies also indicated that prior EDTA treatment can enhance self-etch adhesive systems' bond strength.[13,26] EDTA exhibits antioxidative properties and efficiently eliminates oxygen (O_2) and residual chlorine (Cl^-).[27] Due to this nature, it prevents the collapse of dentinal tubules and facilitates enhanced cement penetration, consequently improving push-out bond strength. Therefore, in this study, a self-etch adhesive system was used for luting cement, and irrigation activation techniques were also applied to increase the effectiveness of EDTA.

Establishing the durability of the bond between dentin and resin is crucial when luting a fiber post, and durability is essential for the long-term success of dental restorations. Previous studies have revealed that the effectiveness of post-luting cement depends primarily on two key factors: removing the smear layer and forming the resin-dentin inter-diffusion zone.[28,29] Also, root canal sealer residues, the apical third of the root containing deep, narrow, irregular dentin and fewer dentinal tubules, and the dentin moving away from light activation in the deeper root canal may prevent the polymerization of the resin cement. While artificial aging was not used in push-out bond strength studies of fiber posts,[30,31] and similar to Zaid et al.,[32] in this study, artificial aging was used to resemble the clinical condition.

The results showed that the XP-endo Finisher had significantly higher push-out bond strength values than the PUI and Er: YAG laser-PIPS. These differences may arise due to variances in the operational mechanisms of the XP-endo Finisher. The XP-endo Finisher is primarily engineered for the mechanical removal of tissues, exhibiting a three-dimensional adaptability to root canals and an expansive capacity extending to a 6 mm diameter area. Additionally, applying a vertical movement of 7-8 mm to contact the entire canal length may have enabled the XP-endo Finisher to effectively remove the smear layer, gutta-percha, and sealer remnants [33] required for proper bonding.

Laser, another activation technique of laser energy delivered in pulses to the fluid, initiates photomechanical actions, including cavitation and bubbles forming within the irrigants in the root canals. The resulting shockwave-like effect represents a favorable outcome in laser-activated irrigation and enhances irrigant activity within root canals.[34] Kuhn et al. [35] reported that vapor bubbles formed in distilled water when the exit energy reached or exceeded 0.36 MJ, and there was also a proportional increase in the length of these bubbles as the exit energies increased. The solution exhibited a reciprocating movement primarily directed toward the apical region of the root canal.[36] DiVito et al.[37] revealed that using the Er: YAG laser with a newly designed tip in subablative laser settings significantly enhanced the effectiveness of treatment when combined with EDTA, resulting in more effective root canal debridement. This effect may explain the notably superior bond strength achieved with the PIPS technique. In line with Ekim et al.,[31] using PIPS laser-activated irrigation revealed higher efficiency on push-out bond strength of fiber post than PUI.

In the present study, PUI showed an additional positive effect on the bond strength of fiber posts. The mechanism behind this effect could be attributed to the ability of ultrasonic energy to facilitate the thorough distribution of NaOCl and EDTA throughout the entire root canal length. The acoustic streaming generated by PUI likely amplifies the cleaning action of these solutions, promoting more efficient smear layer and sealer remnants removal and enhancing resin-dentin bond formation, ultimately leading to improved bond strength values.[31,38]

In this study, similar to previous studies,[31,38] the push-out strength of fiber posts exhibited significant dependence on the root section. Notably, push-out bond strength values in the coronal region differed significantly from those in the apical region. When comparing the experimental groups, CNI showed the lowest push-out bond strength. This result could be due to the inability of CNI to perform insufficient cleaning of post space.[31]

In another study investigating the effects of chlorhexidine and NaOCl on smear layer removal, bond strength, and nano leakage of fiber posts using self-adhesive resin cement, chlorhexidine was observed to be effective in reducing nano leakage, additionally activation techniques increased bond strength, similar to the results of this study.[39]

In line with the studies of [30,31,40] failure assessments of debond segments, adhesive failure had the highest percentage among cement-dentin interface, cohesive failure, and mix, respectively. This outcome may related to variations in the density and diameter of dentinal tubules at different canal segments, the complexity of canal configuration, and individual anatomical variations within the dental structure. Although the tests and conditions applied to the samples are standard, the limitation of this study is that they do not reflect precisely the clinical situation.

CLINICAL SIGNIFICANCE

Within the limitations of this study;

1. To increase the bond strength of fiber posts to root canal dentin, activation methods such as XP, laser, or PUI may be recommended instead of conventional irrigation of NaOCl and EDTA after post-space preparation.

2. Additional irrigation activation methods for cleaning post spaces may increase long-term clinical success by influencing the bond strength between fiber posts and root dentin.

Ethics Committee Approval: The ethics committee certificate was received by the Local Ethical Committee of Kirikkale University (Date: 27.09.2023, Protocol number 2023.09.16).
Informed Consent: For the extracted teeth used in this study, patients were given the necessary information and their written informed consent was obtained
Peer-review: Externally peer-reviewed
Author Contributions: Concept –N D.H, G.K; Design-D.H, Supervision-G.K; Resources- D.H; Data Collection and/or Processing- D.H, G.K; Analysis and/or Interpretation- D.H; Literature Search- G.K; Writing Manuscript- D.H.
Conflict of Interest: The authors have no conflicts of interest to declare.
Financial Disclosure: The authors declared that this study has received no financial support.
Use of Artificial Intelligence: During the preparation of this study, no AI-assisted tools, models, or technologies were used to generate scientific content. All analyses, interpretations, and writing processes were carried out by the author(s).

Etik Komite Onayı: Etik kurul onayı Kırıkkale Üniversitesi Yerel Etik Kurulu'ndan, tarih: 27.09.2023, Protokol numarası 2023.09.16 ile alınmıştır.
Hasta Onamı: Bu çalışmada kullanılan çekilmiş dişler için hastalara gerekli bilgi verilip, yazılı aydınlatılmış onamları alınmıştır.
Hakem Değerlendirmesi: Dış bağımsız.
Yazar Katkıları: Konsept – D.H, G.K; Tasarım- D.H, G.K; Denetleme- G.K; Kaynaklar-D.H; Veri Toplanması ve/veya İşlemesi- D.H, G.K; Analiz ve/veya Yorum- D.H; Literatür Taraması- G.K; Yazıyı Yazan- D.H; Eleştirel İnceleme-G.K.
Çıkar Çatışması: Yazarların beyan edecekleri herhangi bir çıkar çatışması bulunmamaktadır.
Finansal Destek: Yazarlar, bu çalışmanın finansal destek almadığını beyan etmişlerdir.
Yapay Zeka Kullanımı: Bu çalışmanın hazırlanması sırasında yapay zekâ destekli herhangi bir araç, model veya teknoloji bilimsel içerik üretmek amacıyla kullanılmamıştır. Tüm analizler, yorumlar ve yazım süreçleri yazar(lar) tarafından gerçekleştirilmiştir.

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