ORIGINAL ARTICLE

Comparison of various irrigation activation procedures after post space preparation on push-out bond strength of fiber posts: an *in vitro* study

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ABSTRACT

Aim: *To compare the effectiveness of various irrigation activation methods applied after post space preparation on the push-out bond strengths of fiber posts to root canal dentin.*

Materials and methods: *Twenty maxillary central incisor teeth were prepared and root-filled. Following the preparation of the post spaces, the teeth were randomly allocated to 5 groups (n=4) based on the irrigation activation method. Post spaces were irrigated with 2.5% NaOCl and 17% EDTA and various irrigation activation techniques were applied in each group as follow. Group 1: conventional syringe irrigation (CSI); Group 2: manual-dynamic activation (MDA); Group 3: negative apical pressure (EndoVac); Group 4: passive ultrasonic irrigation (PUI) and Group 5: Er,Cr:YSGG laser. Subsequent to fiber post placement, the samples were transversally sectioned and push-out tests were applied for measurement of the bond strength of fiber posts.*

Results: *Irrigation activation with Er,Cr:YSGG laser, EndoVac and PUI resulted higher push-out bond strength in comparison to MDA and CSI (P<.05).*

Conclusions: *Irrigation activation with EndoVac, PUI and Er,Cr:YSGG laser provides superior bonding strength for fiber posts.*

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Introduction

Bonding between post, dentin and adhesive material effectively makes contribution to longevity of restorations (1, 2). Nevertheless, owing to the complicated geometry of the root canal and physical properties of adhesive materials, efficient adhesion is still considered as a challenge (3). Post space preparation causes a smear layer consists of debris, sealer and gutta-percha residues that may hinder bonding to root-canal dentin (4, 5). Additionally, it has been shown that bond strength of filling material to root canal dentin may be strengthen with removal of the smear layer (6). To remove the smear layer, irrigation of the root canal is a critical procedure of the root canal treatment. Sodium hypochlorite (NaOCl) and EDTA are two of the contemporary irrigants being used for removal of inorganic and organic contents of the smear layer (7). EDTA is a chelating agent used at various concentrations and durations. It has been shown that, to avoid erosive effects of EDTA on dentin, low concentrations or shorter application times should be used (8, 9). Therefore 17% EDTA irrigation must not be applied for longer than 1 min for avoidance of dentinal erosion (8). Prolonged EDTA application, proportionally to its concentration, was demonstrated to cause collagen rearrangement (10) which is associated with shortened tooth longevity (11). For an effective irrigation procedure, irrigation solutions should come to direct contact with root canal walls (12). Conventional syringe irrigation (CSI) alone is not capable of delivering irrigation solutions three-dimensionally to microstructures of root canal system in effective elimination of the smear layer (13). Moreover "vapor lock effect", the phenomenon of entrapment of air bubbles in the apical third of root canals, might prevent the exchange of irrigation solutions and impair their debridement efficacy (14). Manual dynamic activation (MDA), which is recurring insertion motion of a well-fitted gutta-percha cone to the working length, were used initially for activation of irrigation solutions (15). Eventually, due to the introduction of new dental technologies including ultrasonic devices (Passive Ultrasonic Irrigation, PUI), apical vacuum devices (Negative Apical Pressure, EndoVac), and laser systems (Er:YAG, Er,Cr:YSGG laser), various irrigation activation methods have been claimed to improve the effectiveness of irrigation procedure and smear layer removal (16). Consequently, irrigation activation procedures after post space preparation and its relationship with bond strength of post systems are currently point of interest. However, few studies have been performed on the efficacy of the different irrigation activation procedures on the bond strengths of fiber posts to root canal dentin.

The purpose of this in vitro study was to compare the effectiveness of different irrigant activation techniques on the bonding strengths of fiber posts to root canal dentin.

Materials and Methods

Twenty freshly extracted human maxillary central incisor teeth with straight root canals were stored for this study. Teeth with any defects, curvature, cracks, and previous root canal treatment were excluded. Teeth were decoronated to attain a standard 17 mm root length using diamond burs in a high-speed hand piece. A working length of 1 mm above the radiographic apex was established and the root canals were prepared with ProTaper Universal system (Dentsply Maillefer, Ballaigues, Switzerland) to size F4 with 2.5% NaOCl (Wizard; Rehber Kimya, Istanbul, Turkey) irrigation after each instrument. Root canal irrigations were completed with 2.5% NaOCl and 17% EDTA (Meta Biomed, Cheongju City, Chungbuk, Korea) using conventional syringe irrigation. The root canals were dried with absorbent paper points and root canal treatments were completed with gutta-percha and AH Plus root canal sealer (Dentsply DeTrey GmbH, Germany) using lateral compaction technique. Afterwards, the samples were kept at an incubator at 37 °C 100% humidity for 7 days and subsequently embedded in self-curing acrylic resin (Imicryl SC; Imicryl, Konya, Turkey). Post spaces were prepared by removing the coronal gutta-percha with the help of size 1 post drills (White Post DC System; FGM, Joinville, SC, Brazil) to 12 mm of the filled root canals. The root canals were randomly divided into 5 groups (n=4) based on the irrigation activation procedures.

In group 1 (CSI) the post spaces were irrigated with 3 mL 2.5% NaOCl and 17% EDTA for 40 seconds for each solution. In the course of the root canal irrigation, a 30-gauge needle tip (Ultradent, South Jordan, UT) was located 1 mm short of the post space and manipulated up and down ~4 mm.

In group 2 (MDA), 3 mL 2.5% NaOCl and 3 mL 17% EDTA were used respectively for irrigation of the post spaces and each irrigant was activated with a size F4 (Dentsply Maillefer) gutta-percha cone throughout the post space with manual push-pull strokes. 100 strokes per minute was applied. The gutta-percha cone was renewed per post spaces.

In group 3 (ANP), NaOCl solution was delivered with a syringe at 20 s. The master delivery tip of EndoVac (Discus Dental, Culver City, CA, USA) was placed at the orifice to deliver irrigants into the pulp chamber. The microcannula (#32/0.00), which works with apical negative pressure (ANP), was located 1 mm above the apical end of the post space, and delivery of solution was completed in 20 s. Same irrigation and activation protocol was applied using 3 mL EDTA.

In group 4 (PUI), the post spaces were irrigated with 3 mL 2.5% NaOCl using syringe for 20 s. Irrigation solutions inside the post spaces were activated by placing the ultrasonic tip (Endo Soft Instrument, Electro Medical Systems, Nyon, Switzerland) 1 mm above the apical end of the post space for 20 s. The ultrasonic tip was attached to an ultrasonic device (Minipiezo, EMS, Milan, Italy) at the power setting of "½." 3 mL EDTA was delivered and activated with the same protocol. Irrigation and activation protocols were completed in 40 s per solution.

In group 5 (Er,Cr:YSGG laser) the post spaces were irrigated with 3 mL 2.5% NaOCl solution by using syringe for 20 s. The irrigants were activated by (Waterlase MD, Biolase Technology Inc., CA, USA) via 300 µm radial firing tip (RFT3). Laser settings were 1.5 watt output power, 140 millisecond pulse duration and 20 Hz frequency. Irrigation timing and activation was applied identical to the method with group 4. During the activation, fiber tip was placed 1 mm above the apical end of the post space. The air-water spray was set to "off".

During the irrigation of the post spaces, 3 mL distilled water applied between two irrigation solution and at the end of the irrigation procedure and dried with absorbent paper points. Cementation of the fiber posts (White Post DC, FGM) to the prepared post spaces were applied using Panavia F 2.0 (Kuraray Medical Inc, Tokyo, Japan) in line with the recommended procedure by the manufacturer. During cementation, equal amounts of ED primer II A and B were mixed and applied to the post space for 30 s and gently air dried. Excess primer was removed by paper points. Panavia F 2.0 paste A and paste B were mixed and the posts were coated with the mixture. The posts were seated and light-cured.

All samples were maintained at 37 °C 100% humidity for 24 h prior to the push-out tests.

Three consecutive horizontal sections with 1.00 ± 0.05 mm width from both the apical and coronal region of the post space were acquired from each specimen by the help of a precision saw (Micracut, Metkon, Bursa, Turkey) under water coolant. 24 slices (12 coronal and 12 apical) were collected for each group. Each slice was attached to a tensile test machine (Lloyd LF Plus, Lloyd Instruments, Leicester, UK). Push-out bond strength tests were applied to the apical surface of the sections with a metal rod at a crosshead speed of 0.5 mm/min until the failure.

Digital calipers were used to measure diameters of the coronal and apical post segments and width of the slice and to calculate bonding surface area the formula below was used.

Bonding surface area:

$$\pi (r_1+r_2) \times (\sqrt{(r_1-r_2)^2 + h^2})$$

In this formula r_1 and r_2 stand for the coronal and apical post radius respectively whereas h is the width of the slice.
The push-out bond strength (MPa) of fiber post was calculated by dividing the force needed to dislodge the fiber posts (N) by the bonding area of post segments (mm^2).
Push-out bond strength data were evaluated using Levene's variance homogeneity test. Statistical analyses were performed with SPSS 17.0 for Windows (SPSS Inc., Chicago, IL, USA) using two way analysis of variance and post hoc Tukey test. The level of significance was set at 0.05.
Failure types of 120 post segments were examined under a stereomicroscope (Stemi 2000-C; Carl Zeiss, Göttingen, Germany) at ×40 magnification. Three type of failure mode were categorised, as adhesive failure between cement and dentin, cohesive failure between cement and post, and if both failure types are observed its considered as mixed failure.

Results

The mean and standard deviations of each group in different post space areas are presented in Table 1. In respect of the total bond strength, the highest and lowest values were observed in Er,Cr:YSGG laser and CSI techniques respectively. EndoVac, PUI and Er,Cr:YSGG laser demonstrated significantly higher push-out bond strength values compared to CSI and MDA ($P<.05$). Removing smear layer with special tools considerably improved the bonding strength of the fiber posts. There were no statistically significant differences between MDA and CSI and amongst Er,Cr:YSGG laser, EndoVac and PUI ($P>.05$).
With respect to the total bond strength values, a statistically considerable difference was observed between bond strengths in apical and coronal regions ($P<.05$). The bond strength values predominantly increased in apico-coronal direction. The lowest bond strength values in both coronal and apical regions were obtained in the CSI group. The highest bond strength in the coronal and apical region was observed in the Er,Cr:YSGG laser and EndoVac groups, respectively. When the groups were evaluated within themselves, there was a statistically significant difference between the apical and coronal bond strengths in all groups ($P<.05$), except the Endovac group.
Regarding the failure types, adhesive failure (50.83%) was the commonest, followed by mixed failure (28.33%). Cohesive failure (20.83%) was the least frequent failure type (Table 2).

Discussion

Pulpless teeth are considered more fragile due to reduced dentinal elasticity, deeper cavities and substantial loss of dentin compared to teeth with healthy pulps. Restoration of root-canal treated teeth with fiber posts, that have dentin-matched mechanical characteristics such as elastic modulus close to dentin is favorable due to their capability of distributing homogeneous stress. Thus, fiber posts have lower prevalence of root fracture. As a consequence of post cavity preparation with post drills, smear layer consists of debris, root canal sealer and gutta-percha is formed on root canal walls (17).
Adhesion of the dual-cure cement to dentin necessitates direct contact between cement and dentin through the micromechanical retention and chemical bond. Therefore, smear layer, gutta-percha and sealer debris must be removed by the help of effective irrigation protocol (18). However, some studies have demonstrated that irrigation solutions are not capable of removing root canal filling remnants even if they are activated by sonic or ultrasonic systems (19). Thus, incomplete removal of the remnants might be a reason for the adhesive failures in our study. Prati et al. have showed post-retreatment canal filling material remnants via environmental scanning electron microscopy/energy dispersive X-ray spectroscopy (ESEM/EDX) analysis (20). Micro-computed tomography (micro-CT) has been used in visualizing the remaining root canal filling material (21). A micro-CT study has showed that

Table 1

Mean and Standard Deviations (SD) of push-out bond strength values in groups and two regions of root canal

	Group 1 Mean ± SD	Group 2 Mean ± SD	Group 3 Mean ± SD	Group 4 Mean ± SD	Group 5 Mean ± SD	Total Mean ± SD
Coronal	$3.93 \pm 0.49^{A,a}$	$4.34 \pm 0.39^{A,a}$	$5.34 \pm 0.66^{A,b}$	$5.46 \pm 0.52^{A,b}$	$5.82 \pm 0.39^{A,b}$	4.98 ± 0.87^{A}
Apical	$2.71 \pm 0.54^{B,a}$	$3.15 \pm 0.65^{B,a}$	$4.89 \pm 0.75^{A,b}$	$4.26 \pm 0.78^{B,b}$	$4.67 \pm 0.74^{B,b}$	3.94 ± 1.10^{B}
Total	3.32 ± 0.81^{a}	3.74 ± 0.80^{a}	5.12 ± 0.73^{b}	4.86 ± 0.89^{b}	5.24 ± 0.82^{b}	

Data with different superscript lowercase letters indicate significant differences within each row; data with different superscript uppercase letters indicate significant differences within each column (p<0.05).

Table 2

Type of failure modes in groups

	Group 1	Group 2	Group 3	Group 4	Group 5	Total
Cement-Dentine	15 (62.50%)	14 (58.33%)	11 (45.83%)	11 (45.83%)	10 (41.66%)	61 (50.83%)
Cement-Post	5 (20.83%)	5 (20.83%)	4 (16.66%)	5 (20.83%)	6 (25.00%)	25 (20.83%)
Mixed	4 (16.66%)	5 (20.83%)	9 (37.50%)	8 (33.33%)	8 (33.33%)	34 (28.33%)

despite significantly improving filling remnant removal, irrigation with laser activation fail to removal of epoxy resin-based sealer completely (22). Similarly, another micro-CT study has demonstrated incomplete removal of epoxy resin-based sealer by irrigation with sonic, ultrasonic and laser activation (23).

Several studies demonstrated that smear layer removal is a crucial factor for bond strength between post-luting cement-dentin interface (24, 25). NaOCl and EDTA combination is used in removing of the smear layer (26). Activation of these irrigant solutions could benefit post retention by increasing the efficiency of complete smear layer removal (27-29).

For evaluation of fiber post bond strength, push-out test was performed due to the fact that it provides more homogeneous stress distribution on the adhesive interface and few specimen losses (30). While dentin slices with various thickness were used in previous studies on push-out bond strength (31, 32), in this study, 1 mm-thick sections were prepared due to the lower friction areas and decreased likelihood of overestimated results compared to thicker slices. EndoVac system has been used as an irrigation method for more than a decade. EndoVac system comprises of a delivery tip which delivers irrigation solution in the pulp chamber and aspirates the excessive irrigant to prevent overflow and a tube attaches either a macro- or microcannula (33). In a study, higher mean push-out bonding strength values were achieved with EndoVac than CSI when the same NaOCl and EDTA irrigation regimen applied (29). Another study reported that NaOCl and EDTA delivery with EndoVac system resulted better smear layer removal than NaOCl and EDTA irrigation with CSI (34). Antunes et al. demonstrated that delivering 15% EDTA with EndoVac system results significantly higher push-out bond strength of gutta-percha than 15% EDTA irrigation with conventional irrigation (35). In our study, EndoVac system enhanced bond strength of fiber posts to root canal walls in comparison to conventional syringe irrigation and MDA. Effective smear layer removal in consequence of negative apical pressure could be rational for our results in this regard.

In this study, the use of PUI in irrigant activation had an improving effect on the bond strength. Our finding is accordant with the findings of another study on bond strength of the fiber post to root canal (36). In another study it was found that ultrasonic activation of NaOCl has no positive effect on bond strength of fiber posts in any region of root canals in comparison to NaOCl irrigation alone (37). Contradiction between this study and our study might be attributed to the detrimental effect of NaOCl decreasing bonding ability of dentin by dissolution of collagens which is directly related to bond strength of fiber posts to root canal dentin (38-40). EDTA irrigation following NaOCl has a positive effect on bond strength of fiber posts. Therefore, more effective results were achieved with PUI method with NaOCl and EDTA irrigation.

Laser systems have been introduced to endodontics as a novel technology to improve treatment procedures including irrigation activation. Er,Cr:YSGG laser has been reported to be effective on smear layer removal when it is used for activation of irrigation solutions such as NaOCl and EDTA (28). Although there was no significant difference between Er,Cr:YSGG laser, EndoVac and PUI groups in our study, laser group demonstrated the highest bond strength in overall comparison. It can be asserted this result is correlated with smear layer removal capability of Er;Cr:YSSG laser when used with NaOCl and EDTA. Çökük et al. compared the bond strength of fiber posts after using different irrigation protocols. Results of their study showed that irradiating the post space with Er,Cr:YSGG laser using 1.5 W output power enhances bond strength of fiber post to root canal dentin and leds to higher push-out test values than NaOCI or chlorhexidine (41). In contrast, Kirmali et al. concluded that Er,Cr:YSGG laser application with various power settings did not enhance the bond strength of the fiber posts to the root canal dentin in their study which evaluated the effects of dentin surface treatment with Er,Cr:YSGG laser application. Besides, researchers mentioned that this outcome could be associated with the absence of endodontic irrigation regimes for smear layer elimination in the course of the post space treatment (42). The difference between the results of their study and this study is due to the use of Er,Cr:YSGG laser to activate irrigation solutions in this study, while Er,Cr:YSGG laser was used without irrigation solution in their study.

Araújo et al. compared the impact of Er,Cr:YSGG laser treatment and 5.25% NaOCl irrigation of post-space on push-out bond strength of fiber posts and reported that there were no considerable differences between two groups. While they used the same radial firing tip (RFT3) with this study, different laser settings and the fact that the laser in their study was used with air and water spray instead of irrigation solutions might result in contradicting findings to this study (43).

In this study, the push-out bond strengths were affected by the root region and increased in apico-coronal direction. This result is compatible with the outcomes of the studies investigated the push-out bond strengths of either fiber posts or obturation materials to dentin walls (29, 44, 45). Weaker bond strength of fiber posts in apical region might be associated with less efficient smear layer removal in apical region (28), void formation in resin cement, residues of gutta-percha (46). Smaller root canal diameter and fewer dentinal tubules in the apical part of the root canals can also be reasons for this result. When the groups were evaluated within themselves, there was a statistically significant difference between the apical and coronal regions in terms of bond strength in all groups apart from the EndoVac group. EndoVac was the only group resulted with similar bond strength in apical and coronal regions. This finding is in agreement with the study of Akyuz Ekim and Erdemir (29). The EndoVac system's effectiveness at apical level might be attributed to the apical negative pressure effect which is applied by placing the microcannula to apical portion of the canal. Thus, irrigant is constantly suctioned and replenished at apical region and smear layer might be removed as effectively as at coronal region (34).

EndoVac system showed the most favorable results in apical region. In numerous studies, EndoVac demonstrated better smear removal in apical region than CSI, PUI, MDA and laser assisted activation (34, 47, 48). As mentioned earlier, more efficient removal of smear layer, along with other factors, is correlated with higher push-out bond strength. Apical negative pressure principle and hence disruption of vapour lock effect and increased volume of irrigant delivery in the apical region might be the reason for superior result with EndoVac. In coronal region, Er,Cr:YSGG laser activation resulted highest bond strength mean value. It was reported that Erbium lasers were more efficient than CSI, PUI and EndoVac methods in smear removal from coronal segments of root canals (28, 34, 49). It is known that Erbium lasers, whether it is Er:YAG laser or Er,Cr:YSGG laser, have wavelengths that provide effective absorption in water and sodium hypochlorite (50). The Er,Cr:YSGG laser radiates laser energy in pulses and energy emitted is absorbed in liquid. This results with instant increase in heat of liquid to boiling temperature and vaporization consequently. Primary and secondary bubbles implode and this implosion creates shearing stress through the root canal walls which might be effective for smear layer removal (51). Thus, higher fiber post bond strength in coronal region in this study can be attributed to wavelength and mechanism of Erbium lasers.

None of the 120 specimens failed during specimen preparation before testing. The evaluation of failure types showed that dentine-cement failure was approximately 2 fold cement-post failure. This may be due to the formation of small gaps between dentine and cement due to polymerization shrinkage. In addition, while dual-cured resins have properties suitable for both self-cured and light-cured resins, it was showed that some dual-cured resins may not achieve sufficient degree of conversion in the absence of light (52). Therefore, insufficient light to reach the deep parts of the root canal may cause incomplete polymerization. The present study, however, has some limitations. Firstly, only four teeth per group were included which must be considered when interpreting the results. Although it may be seen as an advantage to use a smaller number of teeth in push-out tests, it can also be considered as a limitation of this study. Moreover, only teeth with straight canals were included in the study and the results might be not applicable to teeth with curved root canals. The use of irrigation activation techniques in curved canals may lead to different results.

Conclusions

Considering the limitations of this study, various irrigation activation protocols can be applied to enhance the bond strength between fiber posts and root canal walls. Removal of the smear layer with special tools such as EndoVac, PUI and Er,Cr:YSGG laser may provide a better push-out bond strength of fiber posts to root canal dentin. Further studies are required to investigate what procedure and settings would affect the smear layer removal from root canal walls by the help of EndoVac, PUI and Er,Cr:YSGG laser to achieve a more preferable bond strength.

Clinical Relevance

Improved smear layer removal with EndoVac, PUI and Er,Cr:YSGG laser before fiber post placement might led to better post retention.

Conflict of Interest

The authors declare no conflict of interests.

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