

Evaluation of Er:YAG and Er,Cr:YSGG lasers on intraradicular bonding using modified glass fiber tips

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The aim of this study was to determine whether erbium laser irradiation emitted by modified glass-fiber tips would improve the intraradicular bonding of fiber posts. Forty human canines were endodontically treated and prepared for fiber-post placement. Roots were divided into five groups ($n=8$); according to the laser-tip combinations (2,940 nm Er:YAG and 2,780 nm Er,Cr:YSGG). Non-irradiated root canals served as control. Posts were cemented with self-adhesive resin cement and subjected to push-out test. Failure modes were characterized, and intraradicular bonded interfaces were analyzed by SEM and submitted to nanoleakage evaluation. Data were analyzed by two-way ANOVA and Tukey test ($\alpha=0.05$). No significant differences were observed in cervical and middle sections ($p>0.05$), while significantly higher bond strengths were observed in apical sections ($p<0.05$). Laser irradiation reduced adhesive failures, cement-dentin gap formation, and nanoleakage apically. Laser-irradiation protocols employing end- or radial-firing tips improved bonding to apical intraradicular dentin contributing to more uniform bonded interfaces.

Keywords: Er:YAG laser, Er,Cr:YSGG laser, Dental bonding, Dental leakage, Resin cement

INTRODUCTION

In dentistry, adhesive procedures have greatly advanced in the past decades and are critical for the durability of restorative treatments. Restoration of endodontically treated teeth may require the placement of endodontic posts in root canals to provide additional retention¹⁻³. Non-metal post-and-core systems, generally composed by translucent glass, quartz, or fiber-reinforced composite, have grown in use due to exceptional biocompatibility and mechanical and optical properties¹. The elastic modulus of fiber-glass posts matching that of dentin with adhesive bonding to root canals provides a more homogeneous dissipation of loading stresses⁴ and can reduce the risk of vertical root fracture^{1,5}. Nevertheless, debonding remains a substantial form of failure^{6,7} due to difficulties in achieving proper bonding to intraradicular dentin⁸.

Less-than-ideal factors for proper intraradicular bonding include, among others, the unfavorable configuration factor (*i.e.*, C-factor), impaired access and visibility, difficulty in moisture control, and low polymerization of resin-based bonding materials with increased radicular depth^{2,8}. Bonding to apical radicular dentin is particularly more challenging due to the presence of sclerotic dentin tubules obliterated by minerals⁹. Smear layer formation during intraradicular preparation also affects dentin bonding^{2,8,10} and may act as a barrier preventing the diffusion of methacrylate-based monomers into dentin¹¹. Traditionally used endodontic instrumentation influences smear layer formation^{12,13}. Carbide burs tend to produce smear layers more resistant to removal¹³. Moreover, plasticized gutta-percha remnants can also be incorporated into

the intraradicular smear layer, further hindering its removal. It is important to note that the quality of the adhesive interface formed between intraradicular dentin and post is critical for the success of this restorative approach. Hence, smear layer removal constitutes an important step for successful intraradicular adhesive bonding^{2,8,10}.

During the past decade, the efficacy of lasers, including Er:YAG¹⁴ and Er,Cr:YSGG¹⁵, in the removal of tooth hard tissues and cavity preparations has been verified¹⁶. More specifically in endodontics, laser irradiation is currently considered a coadjutant treatment for traditional root canal therapy¹⁶⁻¹⁸. Er:YAG laser is a suitable instrument for removal of smear layer in root canals¹⁹⁻²¹. In laser-irradiated dentin surfaces, the orifices of dentinal tubules are large and irregular, and no smear layer or thermal changes such as fusion or carbonization are noticeable²². In contrast, high-power laser irradiation may lead to fusion, carbonization, and the formation of big cracks on the root canal walls¹⁵. Also, laser tips modify the distribution of laser energy, significantly affecting their overall performance. Different fiber tips are currently available, presenting end- and lateral-firing emissions²³. Typically, tips with increased lateral emission present less emission straight forward, especially in the apical radicular area²⁴. Recently, long conical-ended fibers with lateral emissions are increasingly used in endodontics²⁵. Conical-ended fibers should offer superior debriding actions by generating shock waves inside root canals when energy is delivered from a mid-infrared laser (Er:YAG or Er,Cr:YSGG), which has great absorption in water^{25,26}. Since failures of fiber posts appear mainly at the cement-dentin interface^{6,7}, root canal treatment

using lasers applied with different firing tips could benefit intraradicular bonding. Nevertheless, to the best of the authors' knowledge, there is a lack of studies concerning the use of Er:YAG and Er,Cr:YSGG lasers as a surface treatment technique in order to improve intraradicular bonding. Therefore, the aim of this study was to examine whether erbium lasers used with different emission tips may improve the intraradicular bonding of fiber posts. The tested null hypotheses were that irradiation protocols composed by lasers with modified tips would have no effect on (i) the push-out bond strength or (ii) the interfacial interaction of luted fiber posts to intraradicular dentin.

MATERIALS AND METHODS

Sample selection and root canal preparation

Forty extracted sound canines were obtained with informed consent from patients in accordance with local regulations. Extraction indications were not related to this study. Teeth were thoroughly cleaned by removing hard deposits using curettes, stored at 4°C in 0.9% NaCl containing 0.02% NaN₃ to prevent microbial growth, and used within three months after extraction. Teeth with similar sizes and anatomic shapes were selected. Decoronation was performed using a water-cooled slow-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) to obtain root remainders of 18 mm²⁷. Canal patency and working length (17.5 mm) were established by inserting a K file #15 (Hedstroem) into the root canal terminus and subtracting 0.5 mm. Root canals were then instrumented by reciprocating files (WaveOne, Dentsply Sirona, Charlotte, NC, USA) up to size #45 at the working length. Irrigation with 3 mL of 0.9% NaCl solution was performed between files. Root canals were dried with paper points #45 (Dentsply Maillefer, Ballaiguese, Switzerland) and obturated according to the lateral condensation technique with gutta-percha cones and a resin-based root canal sealer (AH Plus, Dentsply DeTrey, Konstanz, Germany). The root canal opening was sealed with resin-modified glass ionomers cement (Vitremmer, 3M Oral Care, St Paul, MN, USA) and placed

in 100% humidity for seven days at 37°C to ensure the setting of the endodontic sealer.

Post-space preparation and laser treatments

A carbide bur, specific to the fiber post system (3M RelyX Fiber Post Drill, 3M Oral Care), size #3 (1.9 mm in diameter), was used at low speed to a depth of 13 mm apical seals, composed by 5 mm-thick endodontic filling, were left at the apex²⁸. Root canal enlargement was performed to standardize the root canal preparations. The post-space was cleaned by copious irrigation with distilled water. Roots were randomly allocated to five groups ($n=8$) according to the laser type and the mode of operation (Table 1). The control group was not lased and only irrigated with 0.9% NaCl solution. Experimental groups consisted of two lasers: (i) an erbium-doped yttrium aluminum garnet (Er:YAG, Lightwalker, Fotona, Ljubljana, Slovenia) and (ii) erbium, chromium-doped yttrium, scandium, gallium garnet (Er,Cr:YSGG, Waterlase, Biolase, San Clemente, CA, USA) applied in NaCl solution-filled root canals following specific manufacturers' protocols for different firing tips (Table 1).

Fiber-post cementation

Fiber posts (RelyX Fiber Post, 3M Oral Care) size #3 were initially cleaned with 70% alcohol and air-dried for 30 s. Silane (RelyX Ceramic Primer S, 3M ESPE, St. Paul, MN, USA) was applied for 60 s on the post surface with the help of disposable applicator brushes waiting 5 min for solvent evaporation as recommended by the manufacturer. Root canals were then dried with paper points (Dentsply Maillefer) to remove excess humidity. A self-adhesive resin cement (U200, 3M ESPE) was carefully inserted into the root canal apically cervically using disposable auto mix endo tips to reduce void formation²⁸. The fiber post was inserted into the root canal preparation, and excess cement was removed. Light curing was performed after 5 min using a LED unit (Elipar Deepcure, 3M ESPE) at 1,400 mW/cm² for 90 s. Subsequently, the specimens were stored in 100% relative humidity for seven days at 37°C.

Table 1 Laser irradiation protocols for intraradicular bonding

Laser	Model	Tip	Firing	Settings	Time	Application mode
Er:YAG 2,940 nm	Lightwalker (Fotona)	PIPS	Radial	20 mJ, 15 Hz, 0.3 W 50 μs (SSP)	120 s	Static tip inside pulp chamber close to the canal orifices
Er:YAG 2,940 nm	Lightwalker (Fotona)	Preciso	End	40 mJ, 12 Hz, 0.45 W 100 μs (MSP)	4×20 s	Helical motion beginning close to apical part
Er,Cr:YSGG 2,780 nm	Waterlase (Biolase)	RFT3	Radial	2.25W, 50 Hz H, Air 35 Water 25	4×20 s	Helical motion beginning close to apical part
Er,Cr:YSGG 2,780 nm	Waterlase (Biolase)	MZ4	End	2.5 W 75 Hz H, Air 20 Water 40	4×20 s	Helical motion beginning close to apical part

Er:YAG: erbium-doped yttrium aluminum garnet laser, Er,Cr:YSGG: erbium,chromium-doped yttrium, scandium, gallium and garnet laser, PIPS: photon induced photoacoustic streaming, SSP: super short pulse, MSP: medium short pulse

Push-out bond strength test

Roots were epoxy embedded inside custom-made molds and sectioned perpendicularly to the fiber post into nine post-dentin root sections measuring approximately 1 mm in thickness using a water-cooled slow-speed diamond saw (Isomet, Buehler). Root sections were coded, and coronal and apical post radiuses were measured at 40× magnification under a stereomicroscope (Leica M60, Leica Microsystems, Wetzlar, Germany) to calculate the coronal and apical post radius using Image J software (National Institutes of Health, Bethesda, MD, USA). Posts were subjected to compressive loads in the apical-coronal direction on a universal testing machine (Autograph AGS-X, Shimadzu, Kyoto, Japan) at 0.5 mm/min using stainless steel cylindrical plungers compatible with post diameters. A blinded operator conducted the push-out test. The plungers were positioned so that they contacted only the post surface. The push-out load was applied until debonding, which was manifested by post extrusion and a sudden drop along the load-displacement graph. The maximum failure load was recorded in N and was used to calculate the push-out bond strengths in MPa for each root section according to the following formula: Push-out bond strength (MPa)=Maximum Load (N)/Adhesion surface area (mm²). The adhesion surface area (SA) was calculated as $SA=(\pi r_1+\pi r_2)\times\sqrt{(r_1-r_2)^2+h^2}$, where π is the constant 3.14, r_1 is the smaller post radius (mm), r_2 is the larger post radius (mm), and h is the thickness of the root section (mm).

Fracture patterns

Fractured samples were analyzed by a blinded-calibrated operator under a stereomicroscope (Leica M60, Leica Microsystems) magnification ranging from 10–40× to determine failure types: (I) adhesive failure between post and resin cement; (II) adhesive failure between resin cement and dentin; (III) mixed failure with resin cement covering part of the post surface; (IV) cohesive failure within the fiber post and (V) cohesive failure of dentin²⁸.

Nanoleakage

For qualitative interfacial nanoleakage analysis, three additional roots ($n=3$) from each group were randomly bonded and sectioned into slices as previously described. Nanoleakage was used to evaluate the integrity of the bonded interface by measuring silver nitrate uptake. Nanoleakage evaluation was performed according to a protocol previously described by Tay *et al.*²⁹. Briefly, slices were initially wet-polished with 2000-grit SiC paper and coated with two layers of nail varnish applied up to 1 mm of bonded interfaces. After rehydration in distilled water for 1 h, slices were immersed for 24 h in 50% (w/v) ammoniacal silver nitrate (pH9.5) and thoroughly rinsed in distilled water for 120 s. Samples were then immersed in a photo-developing solution (Kodak Professional D-76 developer, Kodak, Rochester, NY, USA) for 8 h under fluorescent light to reduce silver ions into metallic silver grains within the water-filled voids along the bonded interface. Slices were embedded in

epoxy resin, wet-polished with 600-, 1000- 2000-grit SiC paper (Carbimet, Buehler) and 1, 0.25 (MetaDi, Buehler) and 0.05 μm (MasterPrep, Buehler) polishing pastes. After each polishing step, samples were ultrasonically cleaned in distilled water, air-dried for 2 h, mounted on stubs, dried in silica overnight, and carbon sputtered. Nanoleakage extension was analyzed using SEM imaging on backscattering mode at 10 kV (Phenom ProX, Phenom-World, Eindhoven, The Netherlands) by an experienced-blinded operator. Silver uptake extensions and nanoleakage patterns were evaluated at higher magnifications (3,000–10,000×).

Intraradicular bonded interface characterization (SEM)

Two additional roots ($n=2$) from each group were randomly bonded and sectioned into slices as previously described for bonded interfacial characterization under SEM. Slices were embedded in epoxy resin and wet-polished with 600-, 1200-, 2000- and 4000-grit SiC paper and 1, 0.25, and 0.05 μm polishing pastes (Buehler). Samples were ultrasonically cleaned in distilled water after each polishing step for 3 min. Bonded interfaces were then treated with 50% H_3PO_4 for 5 s and 3% NaOCl for 10 min, followed by dehydration in ascending ethanol series (50, 70, 80, 90 and 3×100%), fixed in hexamethyldisilane, sputtered with gold/palladium, and analyzed on backscattering electron mode at 10 kV (Phenom ProX, Phenom-World). An experienced-blinded examiner analyzed the entire extension of the bonded interfaces of all slices, and representative micrographs (2,500× magnification) were obtained.

Statistical analyses

Since push-out data were normally distributed (Kolmogorov-Smirnov test $p=0.182$) and homoscedastic (Levene's test $p=0.883$), bond strength values were analyzed by two-way ANOVA followed by Tukey test. A significance level (α) was set at 0.05. Analyses were carried out using IBM SPSS Statistics for Windows, version 26 (IBM, Armonk, NY, USA).

RESULTS

Intraradicular bond strength and fracture patterns

Two-way ANOVA showed that the “root section” ($p<0.0001$; $\eta_p^2=0.211$) and the interaction “laser irradiation protocol* root section” ($p<0.0001$; $\eta_p^2=0.267$) significantly affected push-out bond strengths. Push-out bond strengths are shown in Fig. 1. The control group (unlased) presented no significant differences between cervical and middle root sections ($p>0.05$). The apical section of control samples presented significantly lower bond strengths, roughly –56%, than cervical and middle root sections ($p<0.05$). No significant differences were observed between laser irradiation protocols/tips considering cervical and middle root sections ($p>0.05$). Laser irradiation of cervical and middle root sections was not significantly different than the respective control root sections ($p>0.05$). Laser irradiation produced significantly higher bond strengths on the apical root

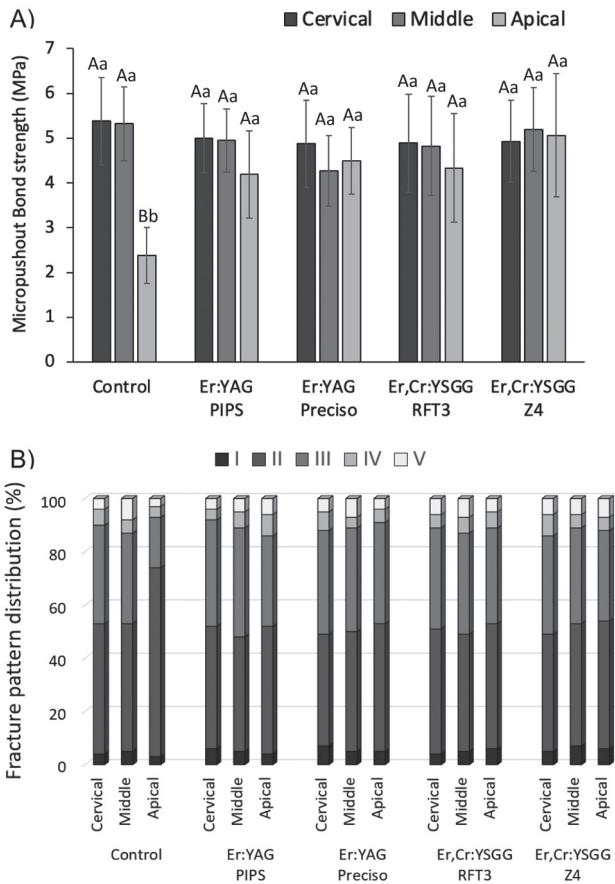


Fig. 1 (A) Push-out bond strength (MPa) means and standard deviations ($n=8$) of fiber posts luted with self-adhesive resin cement (U200, 3M Oral Care). Intraradicular dentin was irradiated by different lasers using different tips. Different uppercase letters indicate significant differences between root sections within the same laser irradiation protocol. Different lowercase letters indicate significant differences between respective root sections within different laser irradiation protocols. (B) Fracture patterns (%) for all groups.

section (from 50% to 2.1-fold) compared to the control apical section ($p<0.05$). Fracture patterns were mostly characterized by adhesive failures between resin cement and intraradicular dentin (type II) followed by mixed failure of resin cement covering part of the post surface (type III). Apical root sections of control samples presented a higher incidence of adhesive failures than the remaining groups.

Nanoleakage

Representative SEM micrographs of silver uptake for all groups are shown in Fig. 2. All samples presented nanoleakage depicting porous-water-filled zones at the bonded interface. The extension of silver deposits varied according to root section and laser irradiation protocol. In general, nanoleakage expression increased with

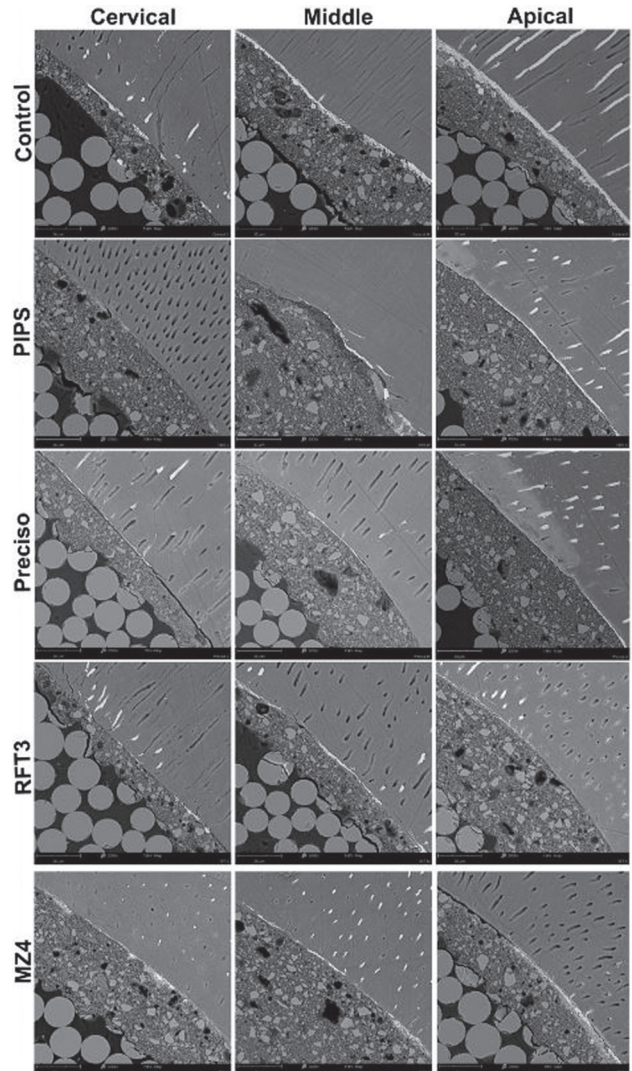


Fig. 2 Representative SEM micrographs of immediate nanoleakage of fiber posts bonded with self-adhesive resin cement to laser-irradiated intraradicular dentin using different fiber-glass tips.

root depth with apical>middle>coronal sections. Laser irradiation using the tested tips reduced nanoleakage levels compared to control (unlased) samples for all root sections. This was more evident in apical root sections, which presented substantially lower silver deposits than control apical samples. The laser tips Preciso, RFT3, and MZ4 presented comparable extensions of silver uptake at the cervical and middle root sections, respectively. Cervical root sections irradiated with PIPS presented the lowest nanoleakage expression. Nonetheless, PIPS produced higher levels of silver deposits at middle root sections compared to Preciso, RFT3 and MZ4. Nanoleakage levels at the apical root sections were characterized as PIPS>MZ4>Preciso>RFT3. Nanoleakage patterns for the control group were mostly reticular silver deposits occupying the cement-

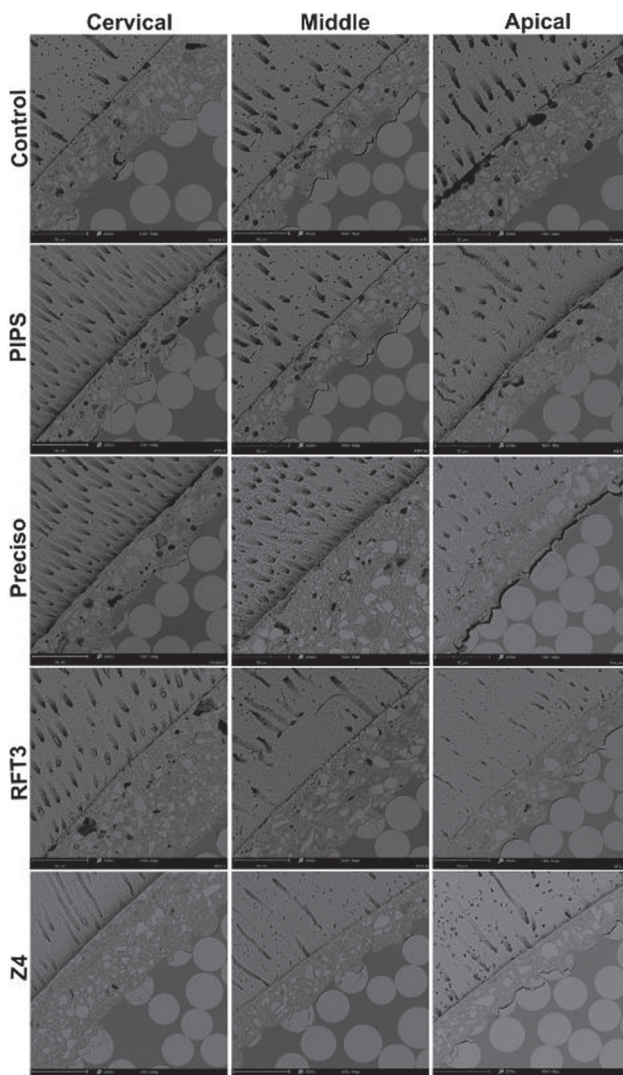


Fig. 3 Representative SEM micrographs of fiber posts bonded with self-adhesive resin cement to laser-irradiated intraradicular dentin using different fiber-glass tips.

dentin interface extending over the cement layer with increasing overall thickness at greater intraradicular depths. Laser-irradiated samples generally presented predominantly thinner reticular silver deposits with a lower extension over the cement layer.

SEM interfacial characterization

Representative SEM micrographs of luted fiber posts to intraradicular dentin for all groups are shown in Fig. 3. The self-adhesive cement interacted superficially with dentin. Flaws and gaps at the cement-dentin interface were commonly identified for all bonding protocols regardless of intraradicular depth. A clear cement-dentin interdiffusion zone was not detected up to 20,000 \times magnification regardless or not of laser irradiation protocols. While the occurrence of interfacial

flaws increased with intraradicular depth in control samples, laser irradiation reduced cement-dentin gap formation in deeper intraradicular areas. Irregular resin-tag formation could be identified in all root sections of RFT3 and at the coronal root sections of MZ4. In the remaining groups, including the control group, tag formation was rarely identified in limited areas without a clear distribution pattern. Middle and apical root sections irradiated with Preciso sparsely presented an acid-resistant 0.8–1.3 μm thick layer, which could be located in some samples without a regular distribution along the cement-dentin interface.

DISCUSSION

Since laser irradiation employing end-firing or radial-firing tips improved push-out bond strengths to apical root sections, the first null hypothesis was rejected. The rationale for selecting a self-adhesive resin cement for this study was the growing popularity of this luting material among clinicians for intraradicular bonding. Apart from improved user-friendliness, self-adhesive resin cements are less sensitive to intraradicular moisture^{30,31}, produce lower polymerization stresses^{32,33}, and thereby may produce superior push-out bond strengths than other classes of self-adhesive resin cements (*i.e.*, etch-and-rinse and self-etch)^{31,34}. Due to differences in bonding mechanisms³⁵⁻³⁷, future studies are necessary to evaluate whether the positive effects of laser irradiation would benefit etch-and-rinse and self-etch resin cements to bond to intraradicular dentin.

Regardless of resin cement type, most studies indicate lower bond strengths at apical root sections^{31,34,38}, which was corroborated by the present study. The morphology of apical root dentin is quite different from cervical and middle root sections, which complicates bonding^{2,8,31}. Other than unfavorable dentin morphology^{2,8-10,31}, several factors contributed to bond strength reductions at deeper radicular sections, such as difficulties in achieving intraradicular cleaning, lower polymerization of resin-based bonding materials^{2,8}, and higher flaw distribution²⁸. The negative effect of the smear layer on intraradicular bonding^{2,8,10} may be minimized by laser irradiation^{39,40}. Historically, several attempts have been proposed to remove such a barrier to allow improved resin cement-dentin interactions^{2,8,31}. EDTA is a chelating agent widely used for smear layer removal in endodontics. Still, EDTA irrigation alone may be irrelevant to improve the push-out bond strength of the tested self-adhesive cement⁴¹. Hence, canal irrigation solutions with the ability to remove the smear layer were not employed in the present study. The aim here was to isolate the effect of laser irradiation on push-out bond strengths, so a 0.9% NaCl solution was the irrigant solution used during laser irradiation.

The use of lasers for nonsurgical endodontic therapy of the root canal system has been testified since the early 1970s⁴². Er:YAG at 2,940 nm and Er,Cr:YSGG at 2,790 nm were explicitly selected due to their high absorption in water-based irrigating solutions resulting in effective

superficial debriding²⁵). Protocols using sub-ablative power levels with very short pulses (<150 μ s) results in high peak power generating the photomechanical phenomenon²⁵). The resultant divergent laser energy interacts with the root canal walls and removes the smear layer⁴³). The debriding action of the tested middle infrared lasers^{39,40,42-44}) certainly contributed to the 2.1-fold higher push-out bond strengths at the apical root sections by improving resin cement-dentin interaction. This effect was observed exclusively at the apical root sections, regardless of the fiber-glass tip used. The apical portion of root canals is generally harder to clean due to the gradual constriction of the root canals towards the apex. The tested dental lasers offered superior accessibility of apical intraradicular sections due to their great penetration into dentinal tissues¹⁸). Therefore, laser irradiation facilitated bonding to such morphologically challenging substrate promoting more uniform intraradicular bonding across root sections.

The integrity of resin cement-dentin interfaces was also improved by all tips, so the second null hypothesis was rejected. Different than the push-out findings, tip configuration affected interfacial bonding quality. The debriding action contributed to lower nanoleakage levels. Previous studies have affirmed that roots without dentin pretreatment (control) had inferior results in bonding³⁸). While Erbium lasers (Er:YAG and Er,Cr:YSGG) assist in successful debriding in endodontics, these could be considered a modern alternative to traditional treatment^{42,45}). This shows the efficacy of laser-assisted endodontic treatments to improve intraradicular resin cement-dentin interaction and produce less-porous interfaces. The tested fiber-glass tips (flat or conical) present different distributions of laser energy. PIPS was designed to be placed only inside the pulp chamber. Invariably, PIPS's photoacoustic shock waves weaken over the distance to the apical region⁴⁶). This distance explains the greater nanoleakage reduction in cervical root sections. Unlike the remaining tips, the inability to enter the root canal limited the irradiation of deeper root sections resulting in higher silver deposits. The form of laser beam emission also affected intraradicular nanoleakage. The lowest nanoleakage levels at the apical section were produced by the radial-firing tip RFT3. Silver uptake reductions were obtained due to more homogeneous irradiation of the root canal walls. Radial-firing tips present a conical outline where laser irradiation is expanded to a broad cone resulting in improved root canal coverage. The spherical irradiation positively influenced debris/smear layer removal, as previously reported¹⁸), lowering nanoleakage levels more effectively than the end-firing tips Preciso and MZ4. Comparatively, the greatest reduction in silver uptake was observed in the apical section. It is possible that the closer proximity of fiber-glass tips to canal walls, at the more constricted apical area, favored the cleaning potential¹⁸), thus reducing nanoleakage to greater extents than other root sections.

Microscopic assessment of cement-intraradicular dentin interfaces indicates that all laser protocols/tips

were effective to increase mechanical interaction. This was evident when observing the unlased and laser-irradiated samples, especially at the apical sections. Flaws at the bonded interface were an expected finding considering the high stress concentration caused by elevated C-factor inside root canals. Difficulties in removing the smear layer at the apical sections¹⁸) contributed to an increased number of flaws. In this study, the SEM preparation protocol consisted of superficially etching bonded interfaces before drying and sputtering. This commonly used SEM preparation step for resin-dentin interfaces dissolves the residual smear layer, which showed up as empty spaces at the interface. Distinguishing whether such gaps originated from polymerization stresses or merely by smear layer removal is beyond the scope of this study. Nonetheless, the lower incidence of flaws/gaps on laser-irradiated samples indicates that the reduced number of interfacial imperfections could be associated with debris removal before bonding produced by lasers¹⁸). The extension in which cement-dentin interactions were improved varied according to tip selection. Using tips with different energy distributions modified the laser's ability to reach canal walls. The most effective cement-dentin interactions were observed by the radial-firing tip RFT3. The broader irradiation area extending laterally from the tip improved laser emission toward canal walls. This does not happen with end-firing tips, where laser emission is predominately apically oriented. While small resin tags were observed at the cervical root for intra-canal end-firing tips (*i.e.*, Preciso, MZ4), tags were frequently identified in all root sections when RFT3 was used. This clearly indicates superior cement-dentin interaction and more uniform resin cement adaption to the canal walls. Therefore, radial-firing tips outperformed traditional tip designs in improving resin cement bonding to intraradicular dentin, especially at the apical section. Additional studies are required to determine the usefulness of these modified fibers in other endodontic applications, such as enlarging and disinfection of root canals.

CONCLUSION

Er:YAG and Er,Cr:YSGG laser irradiation protocols employing different end- or radial-firing tips improved self-adhesive resin cement bonding to intraradicular dentin. Laser irradiation protocols/tips enhanced the integrity of bonded intraradicular interfaces, especially the intra-canal radial-firing tip. Additionally, laser irradiation produced higher bond strengths at the challenging apical root section. Such improvements in intraradicular bonding performance highlight the applicability of lasers to produce more uniform cement-dentin interfaces, which may reduce clinical debonding of fiber posts in restored endodontically treated teeth.

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CONFLICT OF INTEREST

The authors disclose no conflict of interest and certify that they have no proprietary, financial, or other personal interest of any nature in any product, finding and/or company presented in this article.

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