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Adjunctive use of different lasers Er, Cr: YSGG, femtosecond, potassium titanyl phosphate and photodynamic therapy on radicular disinfection bonded to glass fiber post

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Abstract. – OBJECTIVE: The aim of this study was to evaluate and compare the effect of different laser prototypes [Er, Cr: YSGG laser (ECYL), potassium titanyl phosphate laser (KTP), and Femtosecond laser (FSL)]and curcumin photosensitizer (CP) activated by Photodynamic therapy (PDT) on the bond strength of Pre-fabricated fiber reinforced composite (PFRC) post-bonded to radicular dentin.

MATERIALS AND METHODS: A total of fifty mandibular single-rooted closed apex teeth were extracted carefully, assembled, and decoronated up to the cementoenamel junction. The working length of all specimens was determined by using a 10 K patency file and later, were cleaned and shaped with Protaper NiTi system using the crown down approach, dried, and obturated with gutta-percha using an AH Plus sealer. Post space was prepared by guiding peeso-reamer. Based on the method of disinfection, the samples were allocated to five groups (n=10) at random: samples in group 1: curcumin photosensitizer (CP) activated by PDT, samples in group 2 disinfected using 5.25% NaOCl+17% EDTA, samples in group 3 disinfected using 5.25% NaOCl+17% EDTA+FSL, specimens in group 4 sterilized using 5.25% NaOCl+17% EDTA+KTP and samples in group 5 cleaned with 5.25% NaOCl+17% EDTA+ECYL. The fiber post was cemented *via* self-etch resin cement into the post space. All specimens with posts were dissected perpendicularly into apical, middle, and coronal dentin and subjected to the universal testing machine for push-out bond strength (PBS) testing. Statistical analysis was performed using a One-Way analysis of variance and Post-Hoc Tukey multiple comparison tests.

RESULTS: The highest PBS was corroborated when the radicular canal was disinfected with 5.25% NaOCl +17% EDTA+ ECYL at all three root levels (coronal, middle, and apical) and the lowest was adjudicated by decontamination with CP activated by PDT at all inspected root levels. Intergroup comparison presented that specimens in group 2: 5.25% NaOCl+17% EDTA (control) and group 4: 5.25% NaOCl+17% EDTA+KTP revealed comparable PBS outcome to group 5 ($p>0.05$) while samples in group 3 revealed the equivalent PBS values to group 1 ($p<0.05$) at all three root levels.

CONCLUSIONS: Er, Cr: YSGG laser and potassium titanyl phosphate laser when used in combination with the conventional canal disinfection 5.25% NaOCl and 17% EDTA demonstrated the highest push-out bond strength values at coronal, middle, and apical levels of the root.

Key Words:

Push-out bond strength, Curcumin, Femtosecond laser, Ethylene diamine tetraacetic acid, Er, Cr: YSGG laser, Potassium titanyl phosphate laser.

Introduction

Successful endodontic treatment necessitates the comprehensive extermination of bacterial and pulpal tissues stimulating environment modification for the unrivaled pre-emption of progressive microbial colonization and tooth rehabilitation[1]. However, inspection[2] has been given to the use of chemical-mechanical debridement for proficient disinfection and infection recurrence inhibition displaying a nominal microleakage score. Considerably, extensive structural defacement of the endodontic treated tooth may involve consolidation by revolutionary esthetically-qualified 'Pre-fabricated fiber reinforced composite (PFRC) posts' tooth restoring strategy that possesses analogous modulus of elasticity to radicular dentin and restorative cement with no corrosion liability[3,4]. Ex-

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planation from the previous data[5,6] outlined that the persistence of microbial remnants or smear layer within the radicular canal may have a detrimental influence on the rehabilitation process that may affect the deep sealer infiltration process into dentinal tubules for hybridization, in turn, compromising the hermetic seal causing fiber post failure. Therefore efficient antimicrobial disinfectants must be regarded for decontaminating the canals for prolonged clinical durability[7,8].

The administration of sodium hypochlorite (NaOCl) as a traditional endodontic disinfectant and an impressive non-specific proteolytic mediator may illustrate significant antimicrobial properties entailing affinity towards dentinal organic matrix solubilization with facilitation of microbe mutilation[9]. Notwithstanding, explorations on NaOCl posited[10] that using NaOCl alone may not proficiently decimate bacteria from the canal space; thus, ethylene diamine tetra acetic acid (EDTA) has been used for enhanced decontamination results and restoration prognosis. 17% EDTA has been deliberated[11,12] as a potent chelator and demineralizing solution that when introduced into the radicular canal causes dentinal inorganic matrix dissolution, thereby promoting adhesive cement permeation that strengthens the collagenous structure for fiber post placement. In endodontics, the collaborative enactment of NaOCl and EDTA has been considered[13] a domineering aspect for enhanced adhesive binding capacity.

Subsidiary commencement of diverse categories of lasers such as Er, Cr: YSGG laser (ECYL), potassium titanyl phosphate laser (KTP), and Femtosecond laser (FSL) have also been formalized[14-16] for antimicrobial properties that precisely prep the dentin forming submicrometer-sized patterns based on the principle of hydro-photonics generating micro-agitation with simultaneous use of refrigeration system. The laser's trivial collateral and heat destruction effect on the dentinal surface may yield a roughened surface with exposure of dentinal tubules that aids in cement ingression endorsing enhanced post-tooth bond efficacy[17-20]. However, the deployment of these emerging approaches has to be explored further as endodontic disinfectants.

Alternatively, Photodynamic therapy (PDT), a contemporary endodontic canal cleansing method, utilizes varied photosensitizers (PS). When actuated to a certain light wavelength under aerobic conditions liberates reactive oxygen species (ROS) that ensues cell homicide thereby exhibiting an antibacterial effect[21,22]. Among different PS, Curcumin (CP), a natural anionic and polyphenolic PS, has been accredited[23] as a persuasive photo-oxidative dye that due to its superior antioxidant and hydrophobic possessions may augment the mechanical attributes of dentin by validating enhanced bond capacity to fiber post.

Nonetheless, as articulated from the current indexed literature, studies on the decontamination of radicular dentin bonded to PFRC posts utilizing combined use of NaOCl and EDTA with laser activation and PDT are scarce, uncharted, and unparalleled entailing necessary *in vitro* consideration on push-out bond strength (PBS). It is hypothesized that radicular dentin bonded to PFRC post, disinfected with laser types (KTP, ECYL, FSL) and PDT will exhibit comparable bond strength to NaOCl and 17% EDTA disinfectants. Therefore, the present study aimed to evaluate and compare the effect of different laser prototypes (ECYL, KTP, and FSL) and CP activated by PDT on the bond strength of PFRC post-bonded to radicular dentin.

Materials and Methods

Ethical Consideration, CRIS Guidelines, and Sample Mounting

The current study was conducted in harmony with the checklist for reporting *in vitro* study (CRIS) guidelines. Within six months, fifty mandibular single-rooted closed apex teeth were extracted prudently and congregated from a clinical set-up for executing *in vitro* testing and were placed in a 0.5% thymol solution for decontamination purposes for about one month. Samples were evaluated using a stereomicroscope (MAYA, Oem, Guangdong, China) at 20X magnification for any attached tissue fragments and later, using the ultrasonic scaler (Woodpecker DTE D1 Ultrasonic Scaler, Densys India, Uttar Pradesh, India), periodontal ligaments, calculi, and organic debris were debrided off from the samples. Uninterruptedly, for acquiring homogeneity, all teeth were decoronated from the cementoenamel junction by using a slow-speed hand piece (Isomet 1000, Buehler, Lake Bluff, IL, USA) securing a root length of about 14 mm and mounted perpendicularly in heat cure acrylic resin (Pyrax-Polymars, Roorkee, India) *via* a section of polyvinyl pipes of 6 mm diameter for executing an endodontic treatment[24,25].

Endodontic Treatment Execution

Successively, for the affirmation of apical patency and determination of working length, a 10 K patency file (Mani, Tochigi, Japan) was used 1 mm short of the apical foramen. Afterward, the canals were equipped with Protaper NiTi (Dentsply Maillefer, UK) system using the crown down approach. Protaper SX and S1 files were utilized to flare the canals' coronal, middle, and apical thirds. S1 files were maneuvered for shaping coronal and middle root portions, while S2 files were used to contour the complete canal to the apex. F1, F2, and F3 files were employed for canal finishing. During canal shaping, the canals were repetitively irrigated with 2 ml of 2.5% NaOCl solution after every file application for disinfection.

After the cleaning and shaping procedure, the canals were dehydrated with paper points (Hundal Dental Traders, Amritsar, India) and obturated with gutta-percha (Hundal Dental Traders, Amritsar, India) using an AH Plus sealer (Dentsply, Konstanz, Germany) *via* a lateral condensation technique. Later, all prepped samples were stored in a 100% humid environment for 7 days at 37°C. Post spacing was achieved by using peeso-reamers (Dentsply, Beijing, China) in conjunction with special drills suggested by the manufacturer to a length of 12 mm, and the space was disinfected with the designated experimental groups[25,26].

Experimental Groups

Based on diverse modes of disinfection, fifty specimens were distributed into five groups (n=10) at random.

Group 1 (n=10): CP activated by PDT

2.5 mg/ml CP dye solution was injected into the radicular canals of each specimen for about 3 minutes, then, activated for 1 minute with a Light Emitting Diode (Finer, Dental LED curing light, Guangdong, China) radiation unit, at a power intensity of 1,200 mW/cm^2 and wavelength range of 385-515 nm at a distance of 1 mm from the specimen surface[27].

Group 2 (n=10): 5.25% NaOCl+17% EDTA (control)

The specimens were rinsed for 40 seconds with 5.25% sodium hypochlorite (NaOCl)+17% EDTA utilizing a 30-gauge needle tip (Rx Impex, Nagpur, India) with backward and forward motion, 1 mm short of working length (WL). Later, specimens were cleansed and dried without desiccation

Group 3 (n=10): 5.25% NaOCl+17% EDTA+FSL

The canals were disinfected with 5.25% NaOCl+17% EDTA in 10-sec intervals by following four times cycle i.e. performing 10 seconds of irrigation and 10 seconds of activation. Later, the FSL (Femtosecond Laser, Jiangsu, China) was used for the activation of the specimen in an orthogonal position at a wavelength of 400 nm, pulse duration of 140 fs, output mean power of 0.8 Watts, and pulse repetition rate of 5 k Hz for approximately 180 seconds, after which the specimens were rinsed and dried off.

Group 4 (n=10): 5.25% NaOCl+17% EDTA+KTP

The canals were sterilized in 10-second intervals with 5.25% NaOCl+17% EDTA by performing a four-time cycle of 10 seconds irrigation and 10 seconds activation. Later, the KTP laser (Smartlite D, Deka, Calenzano Firenze, Italy) was used four times in a row on the radicular dentin surface at 532 nm, for 10 seconds then 5 seconds interval period, performed the same cycle for a minute, at 1-Watt energy output, 10-ton pulsed mode, and 1 mm focal distance.

Group 5 (n=10): 5.25% NaOCl+17% EDTA+ECYL

The canals were treated with 5.25% NaOCl+17% EDTA in 10-second intervals by performing a four-time cycle of 10 seconds irrigation and 10 seconds activation. Later, the ECYL (Er, Cr: YSGG laser) (Waterlase, Biolase, Foothill Ranch, CA, USA) was used, with a frequency of 30 Hz, a power of 0.5 W, a water/airflow of 25%, and a tip diameter of 275 µm. The laser optical fiber was inserted into the entire root length, and irradiation was executed in a spiral fashion from the apical to the coronal axis at a 2 mm/sec ratio, with constant irrigation. Five cycles of irradiation were completed, with a 20-second interval between each cycle, and the roots were cooled between cycles[20,28].

Following the decontamination procedures, all canals were treated with distilled water and dried with paper points (Hundal Dental Traders, Amritsar, India). Then, fiber posts (GF, Morita, Illinois, USA) were sanitized with 70% ethanol, air dried, and cemented in place with Panavia F 2.0 (Kuraray Dental, Tokyo, Japan) self-etch dual cure cement. Later, all specimens were placed in 100% moisture for 48 hours for PBS analysis.

Push-Out Bond Strength (PBS) Analysis

Roots reinforced with posts were dissected perpendicularly into the apical, middle, and coronal dentin post segments of 0.5 mm thickness, employing a low-speed diamond saw (Isomet 1000, Buehler, Lake Bluff, IL, USA) under copious irrigation. The sections were then positioned in a special jig attached to a universal testing machine (JJ-TEST, OEM, Hebei, China), and a push-out force of 1 mm/min was applied at the apical-cervical direction at the center of the post until fracture. PBS was appraised in 150 sections, 30 from each group. The PBS was determined in Megapascals (MPa) by using the following formula:

$$\text{Debond stress} = N/A$$

Where, N is the force at which post debonded and A is the area of the post.

Failure Mode Analysis

Evaluation of fracture analysis was done utilizing a stereomicroscope at 40X magnification (MAYA, OEM, Guangdong, China). Failure modes were classified as an adhesive (fracture at the cement-dentin interface), cohesive (fracture between cement and post), and admixed (a combination of both).

Statistical Analysis

Levene's test for homogeneity was used to ascertain the normality of PBS data. One-way analysis of variance (ANOVA) was used for the determination of means and standard deviations of PBS and for means comparison Post HocTukey multiple comparison tests were implemented. The statistical package for the social science system SPSS version 19 (SPSS Inc., Chicago, IL, USA) was employed for statistical analysis at a *p*-value lower than 0.05.

Results

PBS Analysis

The means and standard deviations (SD) of PBS values among experimental groups at coronal, middle, and apical levels of the root are displayed In Table I, Figure 1. As per the exploration, the highest PBS was corroborated when the radicular canal was disinfected with 5.25% NaOCl+17% EDTA+ ECYL at all three root levels [coronal (9.01 ± 0.54 MPa), middle (6.95 ± 0.74 MPa) and apical (4.00 ± 0.18 MPa)] ($p>0.05$) whereas the lowest PBS was adjudicated by the decontamination of samples in group 1: CP activated by PDT coronal (6.12 ± 0.64 MPa), middle (4.99 ± 0.13 MPa) and apical (3.17 ± 0.81 MPa) PBS values at inspected root levels.

Intergroup comparison presented that group 2: 5.25% NaOCl+17% EDTA (control); coronal (8.01 ± 0.44 MPa), middle (6.65 ± 0.65 MPa) and apical (4.25 ± 0.55 MPa) and group 4: 5.25% NaOCl+17% EDTA+KTP; coronal (7.99 ± 0.38 MPa), middle (6.11 ± 0.75 MPa) and apical (4.15 ± 0.69 MPa) divulged comparable PBS outcomes to group 5 at all three root levels ($p>0.05$). Similarly, group 3 revealed equivalent PBS values at coronal (6.31 ± 0.74 MPa), middle (6.11 ± 0.75 MPa) and apical (4.15 ± 0.69 MPa) radicular levels to group 1 ($p>0.05$). Moreover, the apical portion of all groups substantiated analogous PBS outcomes to each other ($p>0.05$).

Intragroup comparison designated that all analyzed groups manifested a decline in bond strength from the coronal to apical direction. However, no significant difference in PBS values was discerned in coronal and middle root segments of all groups ($p>0.05$), except for the apical section ($p<0.05$), respectively.

Table I. Means and standard deviations (SD) of push-out bond strength values among experimental groups at coronal, middle, and apical levels of the root.

Groups	Coronal (MPa ± SD)	Middle (MPa ± SD)	Apical (MPa ± SD)
Group 1: Curcumin activated by PDT	$6.12{\pm}0.64^{a,B}$	$4.99{\pm}0.13^{a,B}$	$3.17{\pm}0.81^{a,C}$
Group 2: 5.25% NaOCl+17% EDTA (control)	$8.01{\pm}0.44^{b,B}$	$6.65{\pm}0.65^{b,B}$	$4.25{\pm}0.55^{a,C}$
Group 3: 5.25% NaOCl+17% EDTA+FSL	$6.31{\pm}0.74^{a,B}$	$4.85{\pm}0.41^{a,B}$	$3.26{\pm}0.64^{a,C}$
Group 4: 5.25% NaOCl+17% EDTA+KTP	$7.99{\pm}0.38^{b,B}$	$6.11{\pm}0.75^{b,B}$	$4.15{\pm}0.69^{a,C}$
Group 5: 5.25% NaOCl+17% EDTA+ECYL	$9.01{\pm}0.54^{b,B}$	$6.95{\pm}0.74^{b,B}$	$4.00{\pm}0.18^{a,C}$

Er, Cr: YSGG laser (ECYL), potassium titanyl phosphate laser (KTP), Femtosecond laser (FSL). Different superscript lowercase alphabets denote statistically significant differences within the same column ($p<0.05$). Data with different upper-case alphabets (a, b, c) denote significant differences within each row ($p<0.05$).

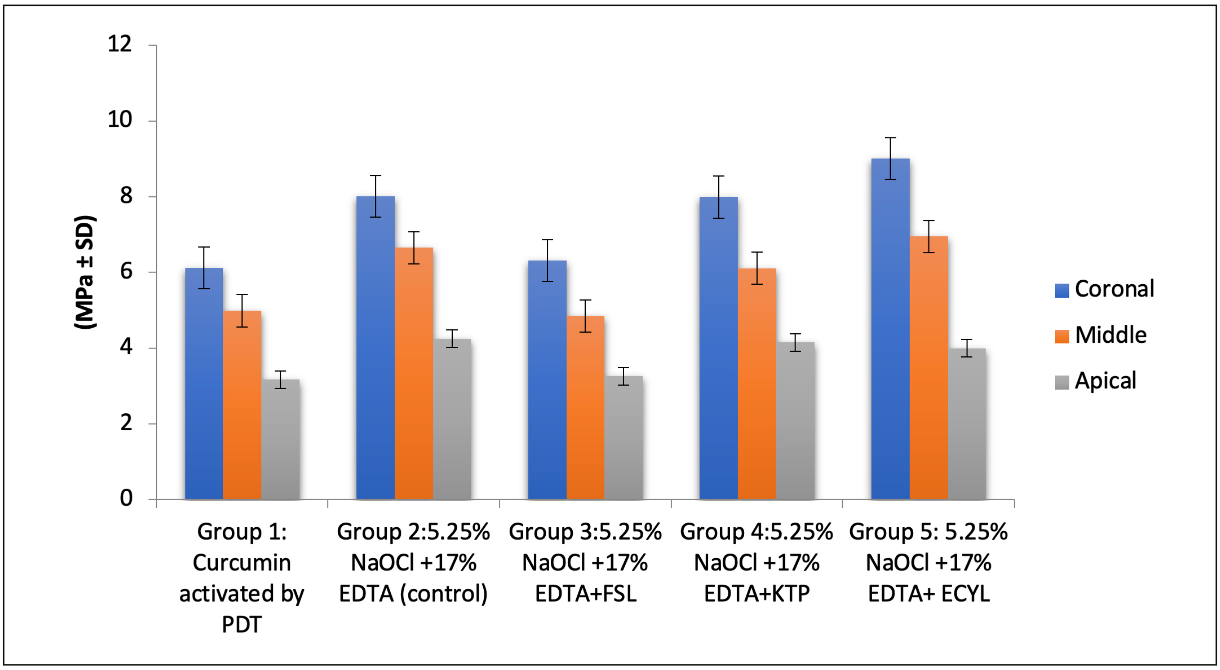

Figure 1. Means and standard deviations (SD) of push-out bond strength values among experimental groups at coronal, middle, and apical levels of the root.

Failure Mode Analysis

Percentages of modes of failure of post-bonded to radicular dentin in each group are demonstrated in Figure 2. As per the findings, groups 2, 4, and 5 suffered a cohesive failure while groups 1 and 3 perceived adhesive failure in the majority. However, admixed failure was the least acquired failure mode in all scrutinized groups.

Discussion

The present *in vitro* study was designed to evaluate and compare the antimicrobial effect of different laser prototypes (ECYL, KTP, and FSL) and CP activated by PDT on bond strength of PFRC post-bonded to radicular dentin at coronal, middle, and apical root levels. Presumptively, the

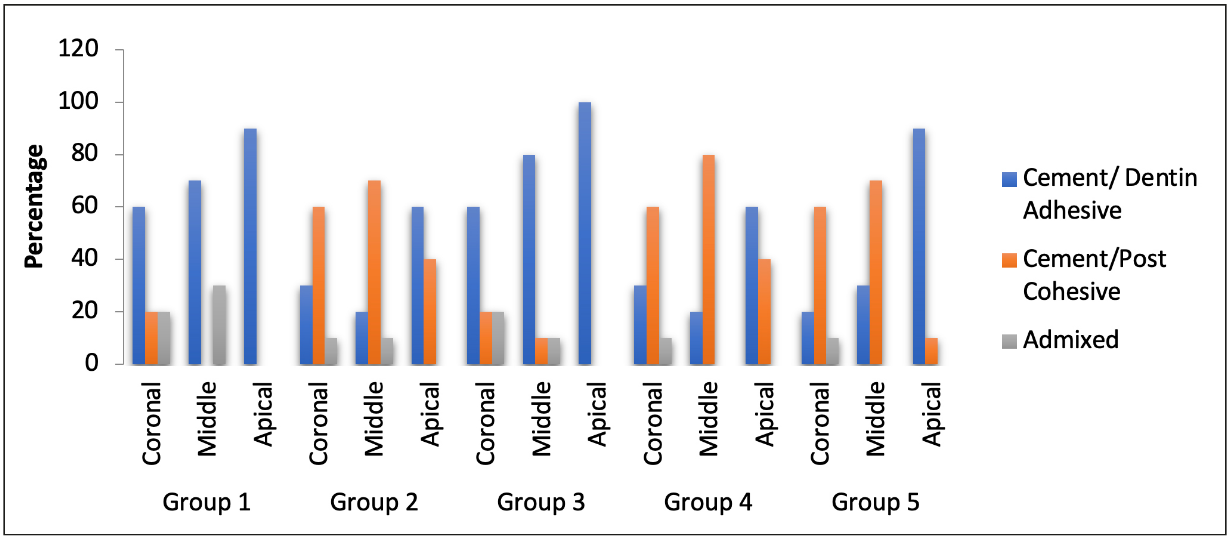

Figure 2. Percentage of modes of failure in each group.

existing data were articulated on the assumption that radicular dentin bonded to laser disinfected (KTP, ECYL, FSL) PFRC post and PDT will exhibit comparable PBS to NaOCl and 17% EDTA disinfectant. Distinctly, enlightening the results, the judgment was partially accepted as ECYL and KTP corroborated analogous PBS results to the control group except for FSL treated group.

Persuasively, rehabilitation of coronally destructed teeth *via* post and core has been advocated[29] as an imperative task in endodontics as utilization of PFRC post divulges biomechanical protection and occlusal stress dissemination thereby preventing radicular fracture. Concurrently, conveyance of adhesion has also been deliberated as a prerequisite for sustaining cement-dentin bond integrity. Therefore, self-etch resin (SERC) was used in the study to provide adhesive bond competence due to various resin monomers and fillers. These monomers and fillers allow a resistant bond with low polymerization shrinkage and deep penetration of dentinal tubules[30,31]Likewise, the fiber push-out bond strength test was entailed in the study for bond proficiency as it alleviates interfacial stress for proper cement ingression into tubular dentin yielding reproducibility and reliability[32]. However, smear layer manifestation, cement properties, dentinal tubular structure, occlusion, and dehydration may influence PFRC post-bond to dentin, consequently entailing decontamination strategies for amended bond efficacy[33,34].

Samples in group 5 (5.25% NaOCl+17% EDTA+ECYL) demonstrated the highest PBS value for PFRC post-dentin bond at all root levels in distinction with other examined groups. Likewise, specimens in group 2 (5.25% NaOCl+17% EDTA) and group 4 (5.25% NaOCl+17% EDTA+KTP) corroborated parallel bond integrity outcome to ECYL disinfected group. Explaining the anti-oxidative mechanism of NaOCl, it dissociates into Na^+ and hypochlorous acid (OCL^-) in water, in turn forming O_2 enriched layer over the dentinal exterior that causes organic dentinal collagen degradation with partial smear layer eradication when smearing 17% EDTA. The comprehensive smear layer removal occurs as decalcification of the inorganic dentinal portion leading to sealer permeation resin tags formation and post-dentin bond[35,36]. Hence, the combination use of 5.25% NaOCl and 17% EDTA has been considered effective for canal sanitization[37,38]. This is in congruence with the work steered by Goldman et al[39].

Significantly, a conceivable reason for the enhanced PBS in utilizing ECYL and KTP lasers, adjunct to the conventional regime on the radicular canal surface, is that ECYL and KTP can cause NaOCl and EDTA modification, in turn, resulting in the elimination of the smear layer from the radicular dentin and de-occluding of the tubular orifice that benefits in the enhancement of surface roughness and surface wettability leading to heightened sealer impregnation for effective post-dentin mechanical dovetailing[18,40,41]. Unswervingly, our result is in line with the study conducted by Jaramillo et al[42] and Mohammadi et al[43].

CP activated by PDT substantiated the lowest PBS. CP when activated by PDT releases reactive oxygen species (ROS) and free radicals that may impart a detrimental effect on the bond efficacy. Moreover, CP's hydrophobicity, ionicity, photo-liability, and binding affinity to dentin structure may also accredit the adhesion deterioration and restoration failure[44]. However, PDT's oxidative potential effect and PS nature may oblige further inspection for an absolute judgment. Similarly, samples in group 3 (5.25% NaOCl+ 17% EDTA+FSL) presented a similar PBS to the PDT disinfected group. Radicular disinfection of FSL may roughen the radicular dentin surface due to the formation of a circular ablation pattern and fusion of dentinal tubules. It is assumed, at this frequency and power setting, that FSL interferes with resin-impregnated hybrid layer formation leading to the bond weakening, therefore exhibiting low PBS[45]. A study performed by Tuncdemir et al[46] deduced similar results. However, additional research in the future examining various FS laser settings for the posts-dentin bond should be executed.

Determining the PBS analysis, all scrutinized groups unveiled[47,48] a declining tendency of PBS values, from coronal to the apical direction, that might be due to the altered laser ablation efficacies and effect, the high oxidative potential of PDT, dentin tubular density or obstruction, the presence of sclerotic dentin or smear layer, damaged collagenous network, adhesive and disinfectants properties, high c-factor, deviated curing light path and distance, and inadequate endodontic debridement as described in the investigation done by Mosharraf et al[49]. The apical region possessed the lower PBS value among all groups as a low degree of conversion of methacrylate monomer to polymer and inadequate resin hybridization of dentin may account for this effect[50,51].

Foreseeing the fallouts of failure mode analysis, NaOCl, ECYL, and KTP treatment groups suffered a cohesive failure in prevalence while specimens treated with PDT and FSL displayed adhesive failure in dominance, and admixed was the least acquired failure. This outcome is in harmony with the study done by Zicari et al[52]. The discrepancy in dentinal tubule density at different root regions and the type of cement attributes could be explainable for this bond failure tendency[53].

Undoubtedly, within the precincts of the current *in vitro* study, combined use of NaOCl and EDTA with laser activation and PDT for disinfection of radicular dentin bonded to PFRC post should be patrolled, further utilizing *in vivo* setup. Implementation of thermocycling, scanning electron microscopy (SEM) and atomic force microscopy (AFM) should also be performed for assessing the effects of lasers and PS on different radicular dentin sections bonded to adhesive resin with microleakage and micromorphological analysis of the bonding interface.

Conclusions

Er, Cr: YSGG laser and potassium titanyl phosphate laser when used in combination with the conventional canal disinfection 5.25% NaOCl+17% EDTA demonstrated the highest push-out bond strength values at coronal, middle, and apical levels of the root.

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No funding was received for the study.

Conflict of Interest
The authors of the present study have no conflict of interest.

Ethics Approval
The study did not include clinical patients and only involved laboratory and *in vitro* experiments; therefore, it did not require a full ethical approval.

Authors' Contribution
Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, data curation, writing-original, draft preparation, writing-review and editing, supervision, project administration, funding acquisition: K.A and M.A. Visualization: K.A. All authors have read and agreed to the published the version of the manuscript.

Informed Consent
Not applicable.

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