Journal of
Lasers
in Medical Sciences

J Lasers Med Sci 2022;13:e12

Original Article

http://journals.sbmu.ac.ir/jlms

doi 10.34172/jlms.2022.12

Efficacy of Photoinduced Photoacoustic Streaming and Diode Laser Irrigation Techniques on Smear Layer Removal, Sealer Penetration and Push-out Bond Strength

Latifa Mohamed Abdelgawad[1*], Nancy Attia Ahmed ElShafei[2], Somaia Abdlatif Eissa[3], Dalia Yahia Ibrahim[2]

[1]Dental Laser Applications Department, National Institute of Laser Enhanced Sciences (NILES), Cairo University, Egypt.
[2]Restorative and Dental Materials department, Oral and Dental Research Division, National Research Centre, Cairo, Egypt.
[3]Meical Microbiology and Immunology Department, Faculty of Medicine, Cairo University, Cairo, Egypt

***Correspondence to**
Latifa Mohamed Abdelgawad,
Tel: 00201005215402,
Fax: 0235708480,
E-mail address: latifa@niles.edu.eg

Received: March 6, 2021
Accepted: November 3, 2021
Published online March 18, 2022

Abstract

Introduction: The present study aimed to test the efficiency of photoinduced photoacoustic streaming using 2940 nm Er: YAG laser and 980 nm diode laser agitation on smear layer removal, sealer penetration and push-out bond strength.

Methods: Sixty single canaled human permanent teeth were collected for this study. Specimens were grouped into three experimental groups (20 teeth in each group), depending on the activation protocol used for final irrigation: Group I (needle agitation), group II (980nm diode laser agitation) and group III (photon induced photoacoustic streaming (PIPS) using 2940 nm Er: YAG laser. The quantity of irrigant was standardized in all groups to 4 ml. The irrigant was activated for 40 seconds in different groups under continuous flow. Two teeth from each group were used to check the smear layer removal, and then the remaining teeth in each group were randomly divided into three equal experimental subgroups according to methods of evaluation used: subgroup A: Sealing ability evaluated by dye penetration method; subgroup B: SEM for sealer penetration; and subgroup C: Push-out bond strength assessed by the universal test machine.

Results: As regards smear layer removal, results showed that the PIPS group had opened dentinal tubules, followed by the diode laser group, while the least cleaning effect was found in the Side-vented needle group. As for Sealing ability and dye penetration, a statistically significant difference was found between all of the three groups, with the Er:YAG laser (PIPS) having the best sealing ability and sealer penetration. Push-out bond strength results showed no statistically significant difference between diode and Er:YAG groups, with a significant difference between each of them and the Side-vented needle group.

Conclusion: Using the diode or Er:YAG laser (PIPS) for irrigant activation led to better irrigant penetration and smear layer removal which subsequently led to obvious sealer penetration, better sealing, and strength properties of endodontic treated teeth.

Keywords: Diode laser, Er:YAG laser, PIPS, laser agitation, smear layer removal, Sealer penetration, Push-out bond strength.

Introduction

Conventional endodontics utilizes distinctive types of activation of the irrigants to achieve better cleaning and sealer penetration, which hence will lead to a successful treatment.[1]

Previous studies have revealed the agitation of the irrigant allows faster dissolution of the tissues, as well as enhancing the efficiency of solutions of irrigation[1] different techniques which are generally classified as manual (syringe irrigation with needles or cannulae, Endobrush agitation and manual–dynamic agitation) and machine-assisted (rotary brush agitation, continuous irrigation during rotary instrumentation, sonic and ultrasonic agitation) techniques are used for irrigant agitation.[1-2]

Many investigations tested the ability of the laser to activate the irrigants inside the root canals. This technique, called laser-activated irrigation (LAI), which has been proven to be more beneficial in eliminating all canal debris as well as the smear layer compared to traditional techniques.[1-3]

A laser plays an important role over conventional and other irrigant agitation methods. It is a highly beneficial tool for eliminating debris, the smear layer as

Please cite this article as follows: Abdelgawad LM, ElShafei NAA, Eissa SA, Yahia DI. Efficacy of photoinduced photoacoustic streaming and diode laser irrigation techniques on smear layer removal, sealer penetration and push-out bond strength. *J Lasers Med Sci*. 2022;13:e12. doi:10.34172/jlms.2022.12.

well as materials after obturation. In addition, it is an effective tool for a disinfection purpose. Distinctive laser wavelengths interact with diverse targets (dentin, bacteria and irrigants), generating biological effects which are responsible for diverse therapeutic actions which can be summarized as photothermal effects, photochemical effects, photomechanical and photoacoustic effects.[4-6]

The smear layer is defined as an amorphous layer containing organic pulp tissue, inorganic debris, odontoblastic processes, and microorganisms with metabolic products. The smear layer improves both sealer and intracanal disinfectants penetration along dentinal tubules with compromising a root canal filling seal. The smear layer can remain in the dentin tubules up to a depth of 40 µm. Researchers have shown that after removing the smear layer, sealers have stronger adhesion to the canal wall. Thus, using a unique method to remove the smear layer; increases the chances of successful treatment.[7]

According to many previous considerations, the success of endodontic treatment depends on mechanical preparation and chemical irrigation of the root canal. During the preparation process, endodontic instruments may not be able to enter the entire frame of the root canal, especially irregular and continuous channels. After the mechanical is preparation, a smear layer containing microorganisms, their derivatives, and necrotic tissue is formed, which interferes with the connection between the irrigation fluid and the medicine in the dentinal tubules.[8-11]

Recently, scientific researchers have focused on new equipment triggering irrigation activation. Dental lasers have potential biological effects, including photochemical, photothermal and photoacoustic effects. The introduction of LAI was in the purpose of irrigant activation. Photon-induced photoacoustic streaming (PIPS) is used as a novel irrigant activation method which utilizes an Er: YAG laser.[12-15]

PIPS activation method for irrigation may be beneficial in obtaining sufficient root canal cleaning with superior adhesion between resin sealer and root canal dentin in endodontic treatment. This suggests that irrigant activation and streaming creation positively affect the bond strength of resin-based sealer. Also, laser irradiation improved the sealing ability of the AH Plus sealer.[16]

After sufficient chemomechanical preparation, insulation sealing with a biocompatible material is another important requirement for endodontic treatment. Root sealants should seal the canal completely and also must be highly adaptive to the canal.[17] Sealant penetration along dentinal tubules is essential as it enhances the bond between the sealant and the dentin, leading to mechanical locking which enhances sealing ability and sealer retention.[17,18] During the obturation stage, sealer penetration along dentinal tubules is a must, as it emphasizes adhesion between obturation material and dentin, and subsequently the optimization of both adaptability and sealing capability of root canal filling occurs.[15,18,19]

Several studies within the literature have evaluated the bond quality of distinctive irrigation solutions. However, few studies to date, have examined the effect of diverse laser types on the bond quality of root canal sealers. Therefore, it is important to think about the effect of distinctive irrigation protocols on physical properties of root canal dentin and hence their effect on the root canal obturation framework.[19-22] The present study highlights the effect of side-vented needle irrigant agitation, 980nm diode laser irrigant agitation and a 2940nm Er: YAG laser (Photon induced photoacoustic streaming) on Smear layer removal, sealing ability and adaptability as well as pushout bond quality of the obturation system.

Materials and Methods

Selection and Preparation

Forty-eight extracted single rooted premolar teeth were collected, and the crowns were sectioned in such a way that the roots were standardized to 12 + 2 mm and stored in labeled vials at 100% humidity. Preparation was performed by utilizing the ProTaper system (Dentsply-Maillefer, Ballaigues, Switzerland), following the sequence of S1, S2, F1, F2, F3 and F4 and utilizing X–smart motor at 300 rpm/ Ncm (Dentsply, Switzerland). At each instrument change, the canals were irrigated with 2 mL of 2.5% sodium hypochlorite “NaOCl” solution (Clorox, Nobel Wax Factories for chemicals, Egypt), utilizing a syringe with 30–G side-vented needle (Canal Clean, Biodent, Co, Ltd, Paju city, Korea) inserted in the root canal, 2 mm short of the working length ProTaper universal rotary nickel-titanium disobedient (Dentsply Maillefer, Ballaigues, Switzerland) was utilized for canal preparations for all specimens and final apical preparations.

Technique of Activated Agitation

After instrumentation, activated irrigation was done in all groups, utilizing a total of 4 mL of 17% ethylenediaminetetraacetic acid (CERKAMED medical company, Poland with pH 7.7) for 40 seconds followed by 5 mL of 5.25% NaOCl, and finally a solution of 5 mL of refined water was utilized as a final flush. All canals were dried with paper points.[13]

Grouping of Specimens

Forty-eight specimens were divided into three equal groups (n = 16) according to the final agitation protocol as a follows:

- Group I (Side-vented needle agitation): specimens were subjected to an irrigant placed passively with a side-vented needle (Monoject, Sherwood Medical, Switzerland) up to 2 mm from working length with up and down movement of the needle.

- Group II (980nm diode laser agitation): EDTA irrigant in the specimens were agitated with a 980 nm diode laser (Wiser doctor smile, Italy), using a 400 µm tip, and a plain fiber was inserted shorter than the working length by 2 mm and was stimulated for 10 seconds under nonstop flow at 2 W power of 1 mL of the irrigant. This procedure was repeated four times. The total amount of the irrigant used was 4ml and it was totally activated for 40 seconds (10-second activation for each 1 mL).
- Group III (PIPS using 2940nm Er: YAG laser): the irrigant was agitated utilizing 2940 nm Er: YAG laser (Fotona, Ljubljana, Slovenia) at 15 Hz, 20 mJ and 0.3 W, using a 400 µm quartz PIPS tip (Fotona, Ljubljana, Slovenia) (with the last 3 mm stripped from its polyamide sheath). It was placed coronally and kept stationary, not advanced into the root canal system during irrigation. The coaxial air–water spray was powered off.

The total quantity of the irrigant (EDTA 17%) was standardized to 4ml in all three groups, and for each group, 1ml of irrigant was activated for 10 seconds by the same person for standardization. This procedure was repeated four times until reaching 4 mL irrigant. The irrigant was totally activated for 40 seconds (10-second activation for each 1 mL) under continuous flow.[9]

Obturation of Specimens for Sealing and Push-out Bond Strength

Specimens for fixing and push-out bond strength assessment were at that point obturated by an adjusted single-cone technique, in which 2 auxiliary cones were passively embedded in addition to the master cone (ProTaper F4) (F4, Dentsply, Maillefer, Ballaigues, Switzerland) in case of oval canals. AH plus sealer (AH Plus Jet, Dentsply De Trey, Kontanz, Germany) was used as root canal sealer for obturation of the samples. After finishing canal obturation, a temporary filling material (Cavit; 3M ESPE, Seefeld, Germany) was used to fill the coronal cavity, and then specimens were stored at 100 % humidity, 37°C in an incubator for 24 hours to fully set.[2]

Evaluation of the Treatment

Evaluation of Smear Layer Removal

After applying diverse final irrigation protocols, smear layer removal was assessed in two specimens from each group as a representative purpose, utilizing the scanning electron microscope (SEM) (JEOL, JXA-840A). At the time of evaluation, the samples were sectioned in a bucco-lingual direction and one half of each specimen was examined; prior to examination, specimens were smoothed and polished beneath running water, utilizing discs made specifically for finishing and polishing (Sof-lex, 3M ESPE, ST. Paul, MN, USA). Then specimens were gold sputter-coated before scanning electron microscope examination by the Sputter coater.[4]

Sealing Evaluation

Sealing Ability Evaluation Using Dye Penetration Method and Stereomicroscope

After obturation, the specimens were dried, and on the surface of each specimen, two coats of transparent nail cover were used to cover the outer root surface except the apical 2 mm. The specimens were then kept for 72 hours in recently prepared methylene blue with a concentration of 2% (School of Chemistry, UNESP, Araraquara, SP, Brazil). Then, the specimens were washed for 15 minutes beneath the continuous flow of water. The varnish layers were scrapped off, and the specimens were divided in a longitudinal manner parallel to the long axis, utilizing a diamond disc in the presence of water coolant. The depth of color penetration was examined using the stereomicroscope (Carl Zeiss, Jena, Germany.

Evaluation of Sealer Penetration Using Scanning Electron Microscope (SEM)

For a representative purpose, sealer penetration was examined within the samples from each group, utilizing the SEM at the time of evaluation after sectioning the samples in a buccolingual direction. The half which retained the obturation material was chosen for the examination of sealer penetration, and prior to examination, the specimens were smoothed and polished beneath running water, utilizing a disc made specifically for finishing and polishing (Sof-lex, 3M ESPE, ST. Paul, MN, USA). Then the specimens were gold sputter-coated before scanning electron microscope examination by the Sputter coater.[19]

Evaluation of Push-out Bond Strength

When obturation procedure was done, the specimens were invested in acrylic at that point and sectioned horizontally at approximately 7 mm depth (center third of the root) and 1mm thick slices, utilizing the IsoMet machine. A stainless-steel support was utilized to hold each specimen in place to guarantee stability and proper placement according to the previous study.[12] The filling material was loaded with a stainless-steel plunger, utilizing a universal testing machine (Instron, Norwood, Massachusetts, USA). The tip of the plunger was measured and positioned only touching the filling material. The load was always formed in an apical-coronal direction avoiding constriction interferences of root at a speed of 0.5 mm/min. The force that dislodged the filling material was at that point recorded in Newtons (N).[12]

The area under the load was calculated by using the following equation:

Area = 1/2 x (circumference of coronal aspect + circumference of apical aspect) x thickness

The pushout strength was then calculated in megapascals (MPa) by dividing the force (N) by area in mm^2.

Statistical Analysis

A total sample estimate of 48 was sufficient where $\alpha = 0.40$ and a power (1-β) of 80% at a significant level of 5% ($P < 0.05$); each group was represented by 16 teeth. The sample estimate was calculated according to G*Power software version 3.1.9.4, Where $\alpha = 0.05$, $\beta = 0.2$, and Power = 1-β = 0.8. For each group, the mean and standard deviation values were calculated. On measuring normality, both Kolmogorov-Smirnov and Shapiro-Wilk tests were used. The collected data were parametric with normal distribution. To compare between more than two groups in non-related samples. One-way ANOVA followed by Tukey post hoc test was utilized. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM® SPSS® Statistics version 20 for Windows.

Results

The results of this study were presented as follows:

Smear Layer Removal Results

SEM results showed that the PIPS group removed debris and the smear layer, followed by the diode laser group (Table 1), while the side-vented needle group showed less smear layer removal than both laser groups (Figure 1).

Sealing Results

Dye Penetration Method Using Stereomicroscope

Table 1. Laser Parameters Used in This Study

Parameters	Laser Type	
	Diode	Er: YAG
Wavelength	980 nm	2940 nm
Mode	Continuous	Pulsed (SSP) with 50 micro-seconds duration
Energy	-	20 mJ
Frequency	-	15 Hz
Power	2W	0.3 W
Tip	400 µm tip	400 µm tip
Position	2 mm short of working length	In the coronal reservoir
Activation time	Total time of diode laser agitation was 40 seconds	Total time of PIPS by Er:YAG laser was 40 seconds

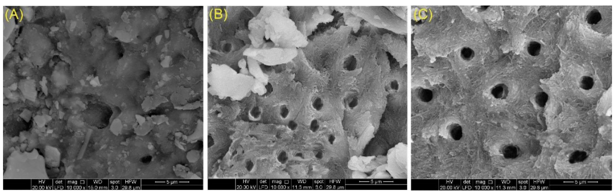

Figure 1. Smear Layer Removal (a) SEM image of the Side-vented needle group, less cleaning of dentinal tubules than other groups, (b) SEM image of the diode laser group, good cleaning of dentinal tubules and (c) SEM image of the Er:YAG laser (PIPS) group, exceptionally good cleaning of dentinal tubules.

The stereomicroscope showed that there was a statistically significant difference between group I (5.70 ± 0.36 mm), group II (4.20 ± 0.13 mm) and group III (2.95 ± 0.14 mm) ($P < 0.001$).

There was a statistically significant difference between group I and each of groups II ($P < 0.01$) and III ($P < 0.001$). Also, a statistically significant difference between group II and group III ($P = 0.001$) was identified. The maximum mean value was found in group I followed by group II, while the minimum mean value was found in group III (Table 2; Figures 2 and 3).

Sealer Penetration Evaluation Using SEM

The SEM image of the side-vented needle group specimen obturated by using AH Plus showed less smear layer removal than both laser groups with subsequently less sealer penetration into the dentinal tubules (Figure 4A). However, the representative SEM image of the Er: YAG laser (Table 1) showed effective cleaning and smear layer removal and good sealer penetration (Figure 4C) followed by the diode laser (Figure 4B).

Push-out Bond Strength Results

There was a statistically significant difference between group I (3.40 ± 0.15 MPa), group II (5.12 ± 0.54 Mpa) and group III (6.23 ± 0.70 MPa) ($P < 0.001$).

Also, a statistically significant difference was found

Table 2. The Mean, Standard Deviation Values of Dye Penetration and Push-out Bond Strength for Different Groups

Variables	Dye penetration (mm)		Push-out bond strength (MPa)	
	Mean	SD	Mean	SD
Group I (Side-vented needle)	5.70 ^{a}	0.36	3.40 ^{b}	0.15
Group II (Diode laser)	4.20 ^{b}	0.13	5.12 ^{a}	0.54
Group III (Er:YAG laser)	2.95 ^{c}	0.14	6.23 ^{a}	0.70
P value	**< 0.001***		**< 0.001***	

Means with different small letters in the same column indicates a significant difference. * Significant ($P < 0.05$).
The relation between different groups was tested using One-way ANOVA followed by Tukey post hoc test to compare between more than two groups in non-related samples with a significance level of $P \leq 0.05$.

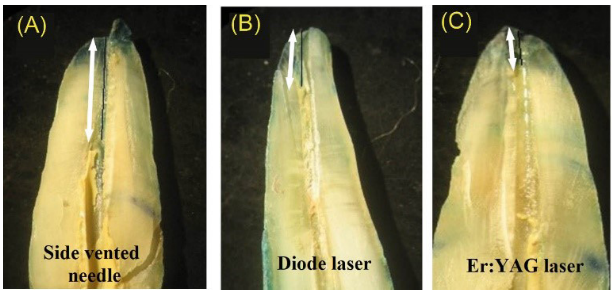

Figure 2. Stereomicroscopic Images for Sealing Ability Evaluation (Dye Penetration Test) (A) Side-Vented Needle Group (B) Diode Laser Group (c) Er-YAG Laser (PIPS) Group.

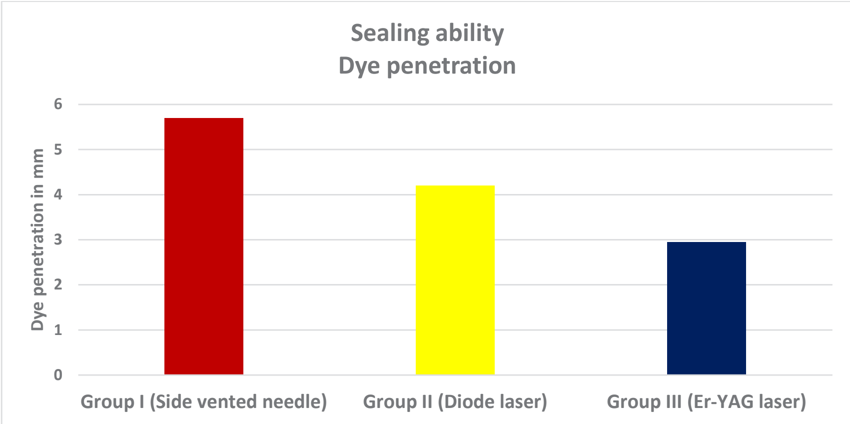

Figure 3. Bar Chart Representing Sealing Ability Evaluation Showing Maximum Dye Penetration in Group I (Side Vented Needle), Followed by Group II (Diode Laser), and the Least Dye Penetration in Group III (Er:YAG).

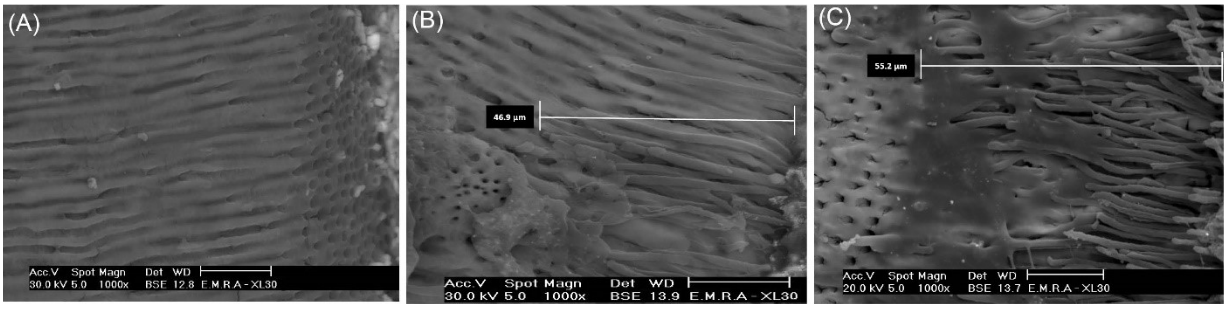

Figure 4. Sealer Penetration Evaluation (A) SEM image of the side-vented needle group, no penetration of the sealer into the dentinal tubules (B) SEM image of the diode laser group, good penetration of the sealer into the dentinal tubules and (C) SEM image of the Er:YAG laser (PIPS) group, very good penetration of the sealer into the dentinal tubules.

between group I and each of groups II ($P=0.002$) and III ($P<0.001$). However, no statistically significant difference was found between Group II and Group III ($P=0.067$). The maximum mean value was found in Group III followed by group II, while the minimum mean value was found in group I (Table 2; Figures 5 and 6).

Discussion

Endodontics preserves pathologic teeth and restores their functions. A successful endodontic treatment should accomplish the triad of endodontics: shaping, cleaning, and filling of the root canal frameworks in three dimensions. Although a combination of those three factors needs to be achieved, it is broadly accepted that root canal disinfection is central to the outcome of root canal treatment. This procedure involves removing pulp tissue, bacteria, and related irritants from the root canal frameworks as well as the smear layer produced amid the shaping step.[1,4,23]

Tissue solvents and antimicrobial agents which act as canal irrigants play a huge role in this regard, and they are usually conveyed by utilizing a syringe and a needle. The requirement for potentiating irrigants action inside the root canal framework must not be overemphasized, especially after the enlargement of knowledge of the tenacity of microbial biofilms and complexity of root canal anatomy.[10,24]

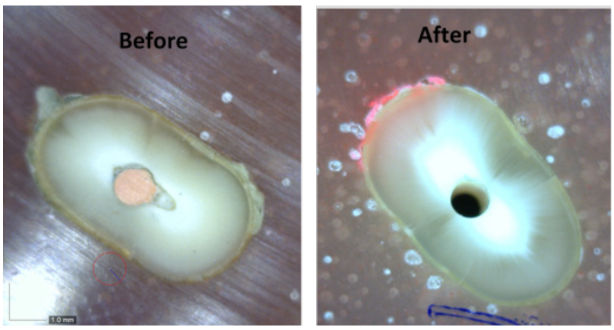

Figure 5. Specimen Transverse section Before and After the Push-out Test.

Nowadays endodontics utilizes distinctive methods of irrigation activation for longtime success. Recently, researches have revealed that irrigant agitation affects tissue dissolution greater than temperature. Accordingly, diverse techniques for agitation were proposed, aiming to enhance the efficiency of irrigants, including sonic, ultrasonic devices, hand agitation and recently laser devices.[10,11]

Different laser types were utilized for a long period for reaching optimum results mainly with endodontic irrigation. A laser, as an effective method for the treatment of endodontics, has shown broad application prospects within the treatment of dental hard tissue diseases, viable

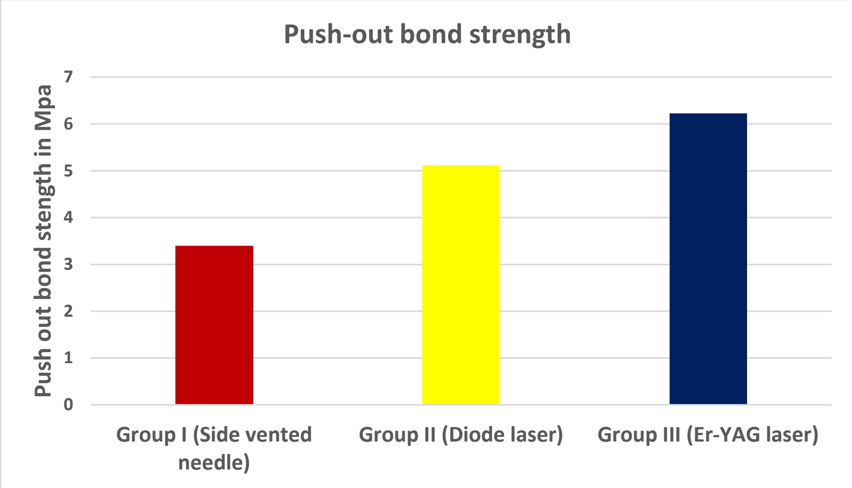

Figure 6. Bar Chart Representing Push-out Bond Strength Evaluation Showing Maximum Bond Strength in Group III (Er:YAG laser), Followed by Group II (Diode Laser), and the Least Bond Strength in Group I (Side-Vented Needle).

pulp preservation therapy, root canal therapy and apical surgery.[23]

Diode 980 nm, Er: YAG, Nd: YAG and CO2 are lasers with a wide range of characteristics which are highly efficient in smear layer elimination, antimicrobial activity and sealing ability.[10,11]

So far, there have been few relevant research reports, and more clinical research is still required to provide a scientific basis for the application of distinctive types of laser in endodontics.[1-3,25]

One of the techniques which depends on the photomechanical effects of the lasers at low settings is LAI. It aims at the creation of certain phenomena of cavitation and acoustic streaming in intracanal liquids. Recently, a more enlightened technique with an Er: YAG laser was utilized with sub-ablative vitality (20 mJ, 15 Hz) and super-short pulses (50 µs), which forms shockwaves and intracanal cavitation as a result of the effect of photoacoustic and photomechanical properties. This phenomenon is called PIPS which can be considered as an extraordinary method for irrigant activation.[23-32]

The aim of the present study was to assess the effect of PIPS and diode laser agitation on smear layer removal, sealer penetration and bond strength.

For irrigant activation by utilizing a diode laser, the optical fiber was placed in the interior of the root canal 2mm shorter than the working length and removed in slow, helical movements and in an apicocoronal direction to overcome the problem of parallel laser release vitality from the optical fiber tip and to guarantee that each part of the canal was irradiated, obtaining uniform coverage of the canal surface. For irrigant activation by utilizing an Er:YAG laser, the PIPS tip was utilized and it was only held within the pulp chamber, in contrast to other tips which require to be embedded in the interior of the root canal. Such requirement was replaced by the photoacoustic shockwaves induced with the pulsed laser within the irrigant travelling throughout the root canal framework, allowing its 3-D movement without the requirement for intracanal tip insertion.[26,32-37]

PIPS is a laser agitation technique, which employs the Er: YAG laser at 2940 nm. This technology relies on the high wavelength absorption of the Er: YAG laser in the pulp chamber filled with water-based irritants. When the Er: YAG laser is launched in an aqueous medium, the irrigant solution will immediately heat up, beyond its boiling state, and bubbles will begin to form at the end of the fiber. This vapour bubble will collapse after reaching its maximum volume.[2,28-32]

The characteristic of cavitation is the production of a cavity containing air bubbles in the liquid. This option allows the flushing fluid to enter the apical third of the canal more easily. In the same time, produced bubbles will grow and become unbalanced, and then they will go bust, which is called implosion. explosion will have an impact on the root canal surfaces, generating lateral and shear forces, deformation of the surface and surface materials removal. It was observed that PIPS utilizing the Er: YAG laser with this cavitation phenomena (photoacoustic agitation) appears to enhance the action of endodontic irrigants, causing the three-dimensionally streaming of root canal irrigant throughout the root canal framework in terms of the removal of the smear layer.[13]

On discussing the effect of laser activation on root canal cleaning and smear layer removal, the present research in agreement with Dhawan et al.[13] showed that the use of an Er: YAG laser for the activation of irrigants causes the elimination of the smear layer, the alteration of the dentin tissue and an increase in dentin irregularities.[13] These irregularities on the surface of the dentin structure, formed after surface treatment, may affect mechanical adhesion. On utilizing PIPS, dentinal tubules were melted and sealed, the organic matrix was eliminated, leading to a decrease in liquid permeability, the root apex was sterilized, and resistance to root resorption was improved. All were produced because of the cavitation creation which was done by the PIPS technique.[12,13]

In agreement with the outcomes of the present study, Ekim and Erdemir[26] evaluated the effect of distinctive irrigant activation protocols by utilizing a laser and stated the positive efficiency of the laser for irrigant activation.[26]

Regarding the results of the smear layer, the present study was in accordance with the results reported by previous studies; for example, Jhingan et al, demonstrated superior elimination of both dentinal debris and the smear layer from the surfaces of the canal after treatment with a diode laser, which increased the success rate of the root canal treatment and reduced the chances for reinfection of the root canal.[15]

Although laser treatment along with the irrigating solution is effective in cleaning the root canal framework, a variety of factors affect the cleaning ability of root canal walls. such as the type of laser wavelength, pulse duration, exposure time, laser power, type of instrumentation, amount of water and air steam created, type of irrigants, and the distance from the tooth surface to the laser tip.[13-15]

In the present study, in agreement with previous studies 980 nm diode laser with output power of 2 W and continuous mode for agitation of the root canal irrigant with 10 seconds activation for each 1 ml irrigant was used as these parameters safe for the tooth without side effects.[13]

Colors, radioisotopes, bacteria, and their products such as endotoxins all act as tracers for sealing ability evaluation, also, different techniques like dye extraction method and liquid filtration were utilized. Among all, linear measurement of color penetration can be considered one of the simplest and commonly utilized methods for sealing ability evaluation which we utilized within the present study.[6]

Methylene blue dye was utilized in this study as it has pH manipulation and high availability, low molecular weight and less irritation.[6]

On discussing sealing ability and sealer penetration into dentinal tubules, utilizing both stereomicroscope and SEM, studies done by various authors on microleakage and sealing ability on root canals irradiated by diode lasers show less microleakage and a good seal.[15- 17]

In agreement with the present research, Faria et al investigated the efficacy of a diode laser (980 nm) on the morphology of root canal dentin and apical microleakage after obturation of canals and found that the change in dentin morphology aids in obtaining tall sealer penetration which increases the sealer penetration and adaptation of the filling material in the root canal.[18]

According to Dhawan et al, pressure waves which were generated after laser application move fast and aid endodontic irrigants role in removing the smear layer and allowing for optimal sealer penetration, adaptation of the sealer to dentinal walls and sealing ability.[13]

To assess the sealers' retention, the push-out test was employed as it measures the material's dislodgement resistance as a function of its retention. On testing pushout strength, the universal testing machine was attached to two distinctive parts: a plate with three holes and a cylindrical plunger. The size of the cylindrical plungers was performed in relation to the dentine disks' apical diameter (middle third were utilized), while the holes performance was in relation with dentin disks' coronal diameter. The side which has the narrower diameter of the disk was placed to face upward in alignment with the plunger, which will cause bond failure. A constant speed of 1 mm/min was used. Once material used for obturation was pushed and dislodged from the canal wall, both the load and the force required to dislodge the obturation material were recorded.[11]

The push-out test was utilized for measuring dentin bond quality of root canal filling materials in this study as this method achieves standardization of the specimens and evaluation of exceptionally low bond quality values. Testing of bond quality is the adhesion leading. Adhesion of root canal filling to the dentinal walls is essential for getting rid of spaces between the filling material and the root canal wall, and it stands up to dislodgement of the filling obturation materials. Different previous studies have discussed the influence of final irrigation regimen on root canal sealers penetration depth and the quality of obturation material push-out bond.[22,24,36]

Mohammadian et al studied how the removal of the smear layer affects push-out bond quality and proved that removing the smear layer highly emphasizes bond quality, which was in agreement with our results. 980-nm diode laser groups showed increased push-out bond quality which can be attributed to smear layer elimination and debris from the dentin surface.[12]

Utilizing both the diode laser and PIPS by Er:YAG were highly efficient in obtaining great bond quality. A previous investigation done by Moura-Netto et al. agreed with this finding which stated that diode laser irradiation improved the penetration of the endodontic sealer into dentinal tubules.[8]

Laser application in endodontic therapy sufficiently removes the smear layer inside the root canal, causing firm integration of the filling material and the root canal. It causes dissolving and remineralization of hard tissue which improves closure of the root canal and produces closed dentinal tubules. However, some noticeable discrepancies were stated among distinctive studies because of various laser parameters and experimental conditions utilized in each study. Clinical application of lasers is fairly being explored. Thus, more standardized experiments are required for optimizing the application of lasers in clinic. All things considered, the present study declares the great promise of clinical application of lasers in RCT. Apical sealing was highly improved on utilizing lasers for irrigant activation before obturation.[20-36]

Further studies should be carried out to improve the effects of lasers and its combination with different irrigating solutions in eliminating the smear layer from the root canal walls. Further research on the diode laser for the practical use in endodontics is needed before it is clinically applied.

Conclusion

Within the limitation of the present in vitro study, the results suggest that:

1. Both PIPS using 2940 nm Er: YAG laser and 980 nm diode laser agitation have a better effect on cleaning and smear layer removal than the conventional agitation method (Side - vented needle).
2. PIPS using 2940 nm Er: YAG laser leads to better sealer penetration and bond strength of the AH Plus sealer as compared with 980 nm diode laser agitation or Side - vented needle agitation.
3. Both PIPS using 2940 nm Er: YAG laser and 980 nm diode laser agitation have a positive effect on the push-out bond strength of endodontic treated teeth.

Conflict of Interests

No conflict of interest.

Ethical Considerations

The present study was done with the approval of the Ethics Committee of National institute of Laser enhanced Science (NILES), Cairo University (Ethical Code: 019/029).

References

1. Abdelgawad LM, Asmail N, Latif SA, Safaan AM. Efficacy of diode laser and sonic agitation of Chlorhexidine and Silver-nanoparticles in infected root canals. *Braz Dent Sci*. 2020; 23(3):1-7. doi: 10.14295/bds.2020.v23i3.1989
2. Akcay M, Arslan H, Mese M, Sahin NN. The effect of photon-initiated photoacoustic streaming, ultrasonically and sonically irrigation techniques on the push-out bond strength of a resin sealer to the root dentin. *Clin Oral Investig*. 2015;19(5):1055-61. doi: 10.1007/s00784-014-1332-0.
3. Ghorbanzadeh A, Aminsobhani M, Sohrabi K, Chiniforush N, Ghafari S, Shamshiri AR, Noroozi N. Penetration Depth of Sodium Hypochlorite in Dentinal Tubules after Conventional Irrigation, Passive Ultrasonic Agitation and Nd:YAG Laser Activated Irrigation. *J Lasers Med Sci*. 2016;7(2):105-11. doi: 10.15171/jlms.2016.18.
4. Turkel E, Onay EO, Ungor M. Comparison of Three Final Irrigation Activation Techniques: Effects on Canal Cleanness, Smear Layer Removal, and Dentinal Tubule Penetration of Two Root Canal Sealers. *Photomed Laser Surg*. 2017;35(12):672-681. doi: 10.1089/pho.2016.4234.
5. Carrilho E, Marto CM, Botelho MF, Girão H, Marques-Ferreira M. Effect of Different Irrigation Solutions on the Diffusion of MTA Cement into the Root Canal Dentin. *Materials (Basel)*. 2020;13(23):5472. doi: 10.3390/ma13235472.
6. Pawar SS, Pujar MA, Makandar SD. Evaluation of the apical sealing ability of bioceramic sealer, AH plus & epiphany: An in vitro study. *J Conserv Dent*. 2014;17(6):579-82. doi: 10.4103/0972-0707.144609.
7. Bodrumlu E, Parlak E, Bodrumlu EH. The effect of irrigation solutions on the apical sealing ability in different root canal sealers. *Braz Oral Res*. 2010;24(2):165-169. doi: 10.1590/s1806-83242010000200007.
8. Moura-Netto C, Palo RM, Camargo SEA, Jent C, Leonardo RT, Marques MM. Influence of prior 810-nm-diode intracanal laser irradiation on hydrophilic resin-based sealer obturation. *Braz Oral Res*. 2012;26(4):323-329. doi:10.1590/s1806-83242012005000010.
9. Kamaci, A, Aydin B, Erdilek N. The effect of ultrasonically activated irrigation and laser based root canal irrigation methods on debris removal. *Int J Artif Organs*. 2018;41(2):71–75. doi: 10.5301/ijao.5000646.
10. Natansabapathy V, Durvasulu A, Krithikadatta J, Namasivayam A, Deivanayagam K, Manali S. Current Trends in the Use of Irrigant Activation Techniques Among Endodontists & Post-Graduate Dental Students in India - A Knowledge, Attitude and Practice Based Survey. *Eur Endod*. 2020;5(2):73–80. doi: 10.14744/eej.2020.98698.
11. Ayrancı LB, Köseoğlu M. The evalution of the effects of different irrigating solutions and laser systems on adhesion of resin-based root canal sealers. *Photomed Laser Surg*. 2014;32(3):152-9. doi: 10.1089/pho.2013.3606.
12. Mohammadian F, Soufi S, Dibaji F, Sarraf P, Chiniforush N, Kharrazifard MJ. Push-out bond strength of calcium-silicate cements following Er:YAG and diode laser irradiation of root dentin. *Lasers Med Sci*. 2019;34(1):201-207. doi: 10.1007/s10103-018-02705-0.
13. Dhawan S, Jasuja P, Khurana H, Gakhar E and Singh H. A comparative evaluation of the efficacy of erbium: yttrium–aluminum–garnet and diode lasers in smear layer removal and dentin permeability of root canal after biomechanical preparation – A scanning electron microscopy study. *J Indian Soc Pedod Prev Dent*. 2020;38(1):64-70. doi: 10.4103/JISPPD.JISPPD_174_19.
14. Wang J, Yang K, Zhang B, Zhou Z, Wang Z, Ge X. Effects of Er:YAG laser pre-treatment on dentin structure and bonding strength of primary teeth: an in vitro study. *BMC Oral health*. 2020;20:316-326. doi:10.21203/rs.3.rs-35761/v1
15. Jhingan P, Sandhu M, Jindal G, Goel D, Sachdev V. An in-vitro evaluation of the effect of 980 nm diode laser irradiation on intra-canal dentin surface and dentinal tubule openings after biomechanical preparation: Scanning electron microscopic study. *Indian J Dent*. 2015;6(2):85-90. doi: 10.4103/0975-962X.155889.
16. Das M, Kumar GA, Ramesh S, Garapati S, Sharma D. An in vitro evaluation of microtensile bond strength of resin-based sealer with dentin treated with diode and Nd: YAG laser. *J Contemp Dent Pract*. 2013;14(2):183-187. doi: 10.5005/jp-journals-10024-1297.
17. Faria MI, Souza-Gabriel AE, Alfredo E, Messias DC, Silva-Sousa YT. Apical microleakage and SEM analysis of dentin surface after 980 nm diode laser irradiation. *Braz Dent J*. 2011;22(5):382-387. doi: 10.1590/S0103-64402011000500006.
18. Khoshbin E, Donyavi Z, Atibeh EA, Kasraei S, Yousefimashouf R, Roshanaei G. Effect of Nd:YAG and Diode Lasers on Apical Seal of Root Canals Filled with AH Plus and Mineral Trioxide Aggregate-Based Sealers. *J Dent (Tehran)*. 2018;15(1):30-40.
19. Todea C, Balabuc C, Sinescu C, Filip L, Kerezsi C, Calniceanu M. En face optical coherence tomography investigation of apical microleakage after laser-assisted endodontic treatment. *Lasers Med Sci*. 2010;25(5):629-39. doi: 10.1007/s10103-009-0680-5.
20. Onay EO, Orucoglu H, Kiremitci A, Korkmaz Y, Berk G. Effect of Er,Cr:YSGG laser irradiation on the apical sealing ability of AH Plus/gutta-percha and Hybrid Root Seal/Resilon Combinations. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2010;110(5):657-64. doi: 10.1016/j.

tripleo.2010.05.062.

21. Elmessirya AE, Darragb AM, Ghoneim WM. Effect of different irrigation solutions and techniques on push-out bond strength of resin-based sealer. *Tanta den J*. 2019;16(1):46-54. doi: 10.4103/tdj.tdj_45_18.
22. Lukac N, Muc BT, Jezersek M, Lukac M. Photoacoustic Endodontics Using the Novel SWEEPS Er:YAG Laser Modality. *J Laser Health Acad*. 2017; 1:1-7.
23. Ballal NV, Ulusoy Öİ, Chhaparwal S, Ginjupalli K. Effect of novel chelating agents on the push-out bond strength of calcium silicate cements to the simulated root-end cavities. *Microsc Res Tech*. 2018;81(2):214-219. doi: 10.1002/jemt.22969.
24. do Carmo SS, Néspoli FFP, Bachmann L, Miranda CES, Castro-Raucci LMS, Oliveira IR, et al. Influence of early mineral deposits of silicate-and aluminate-based cements on push-out bond strength to root dentine. *Int Endod J*. 2018; 51(1):92–101. doi: 10.1111/iej.12791.
25. Ekim SNA and Erdemir A. Effect of different irrigant activation protocols on push-out bond strength. *Lasers Med Sci*. 2015;30(8):2143-2149. doi: 10.1007/s10103-015-1772-z.
26. DiVito E, Peters OA, Olivi G. Effectiveness of the erbium: YAG laser and new design radial and stripped tips in removing the smear layer after root canal instrumentation. *Lasers Med Sci*. 2012;27(2):273-280. doi: 10.1007/s10103-010-0858-x.
27. George R, Meyers IA, Walsh LJ. Laser activation of endodontic irrigants with improved conical laser fiber tips for removing smear layer in the apical third of the root canal. *J Endod*. 2008;34(12):1524-1527. doi: 10.1016/j.joen.2008.08.029.
28. Lukac N, Gregorcic P, Jezersek M. Optodynamic Phenomena During Laser-Activated Irrigation Within Root Canals. *Int J Thermophys*. 2016;37(7):65-72. doi:10.1007/s10765-016-2071-z
29. Do QL, Gaudin A. The Efficiency of the Er: YAG Laser and Photon Induced Photoacoustic Streaming (PIPS) as an Activation Method in Endodontic Irrigation: A Literature Review. *J Lasers Med Sci*. 2020;11(3):316-331. doi: 10.34172/jlms.2020.53.
30. Cheung AWT, Lee AHC, Cheung GCP. Clinical efficacy of activated irrigation in endodontics: a focused review. *Restor Dent Endod*. 2021;46(1):1-16. doi: 10.5395/rde.2021.46.e10.
31. Hong L, Wang J, Liu L, Jiao S, Wang Y. Application of Er:YAG laser in the treatment of endodontics. *World J Pharm Res*. 2020;9(7):2719-2730. doi: 10.1089/104454702760090218.
32. Otaify RR, Roshdy NN, Sabet NE. Evaluation of competency of diode laser and Er:YAG laser activation on sodium hypochlorite capability for biofilm eradication and smear layer removal: A comparative In vitro study. *Acta sci dent sci*. 2020;4(2):28-36. doi:10.31080/ASDS.2020.04
33. Mancini M, Cerroni L, Palopoli P, Olivi G, Olivi M, Buoni C, et al. FESEM evaluation of smear layer removal from conservatively shaped canals: laser activated irrigation (PIPS and SWEEPS) compared to sonic and passive ultrasonic activation—an ex vivo study. *BMC Oral Health*. 2021;21(1):81-91. doi: 10.1186/s12903-021-01427-0.
34. Sreedev CP, Raju I, Kumaravadivel K, Mathew S, Thangavel B, Thangaraj DN. Influence of Different Types of Root Canal Irrigation Regimen on Resin-based Sealer Penetration and Pushout Bond Strength. *Cureus*. 2020;12(4): 7807-7814. doi: 10.7759/cureus.7807.
35. Kırmal O, Sekmen T, Karaarslan A. Push-out bond strength of various surface treatments on fiber post to root canal dentine using different irrigation techniques. *Microsc Res Tech*. 2021:1-10. doi: 10.1002/jemt.23758.
36. Dash S, Ismail PMS, Singh J, Agwan MAS, Ravikumar K, Annadurai T. Assessment of Effectiveness of Erbium:Yttrium-Aluminum-Garnet Laser, GentleWave Irradiation, Photodynamic Therapy, and Sodium Hypochlorite in Smear Layer Removal. *J Contemp Dent Pract*. 2020;21(11):1266-1269. doi:10.5005/jp-journals-10024-2976.